Best Available Techniques (BAT) Reference Document in the Food, Drink and Milk Industries

Colour code:
Black: Text from the original FDM BREF (August 2006)
Red: Updated and new text proposed for the first draft of the revised FDM BREF.
The text highlighted in yellow will not appear in the revised BREF; it is used to:
  - remind the TWG of the conclusions reached at the kick-off meeting;
  - indicate information missing that TWG members are invited to collect and submit;
  - make clarifications to the TWG.

Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)

JOINT RESEARCH CENTRE
Directorate B – Growth and Innovation
Circular Economy and Industrial Leadership Unit

European IPPC Bureau

First Draft (January 2017)
This document is one of a series of foreseen documents as below (at the time of writing, not all documents have been drafted):

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**Reference Document (REF)**

| Economics and Cross-media Effects                      | ECM   |
| General Principles of Monitoring                       | MON   |

Electronic versions of draft and finalised documents are publicly available and can be downloaded from [http://eippcb.jrc.ec.europa.eu](http://eippcb.jrc.ec.europa.eu)
1. Status of this document


This document is a working draft of the European IPPC Bureau (of the Commission's Joint Research Centre). It is not an official publication of the European Union and does not necessarily reflect the position of the European Commission.

2. Participants in the information exchange

As required in Article 13(3) of the Directive, the Commission has established a forum to promote the exchange of information, which is composed of representatives from Member States, the industries concerned and non-governmental organisations promoting environmental protection (Commission Decision of 16 May 2011 establishing a forum for the exchange of information pursuant to Article 13 of the Directive 2010/75/EU on industrial emissions (2011/C 146/03), OJ C 146, 17.05.2011, p. 3).

Forum members have nominated technical experts constituting the technical working group (TWG) that was the main source of information for drafting this document. The work of the TWG was led by the European IPPC Bureau (of the Commission's Joint Research Centre).

3. Structure and contents of this document

Chapter 1 provides general information on the food, drink and milk (FDM) sector and on the industrial processes and techniques used within this sector.

Chapter 2 provides information on the common industrial processes, abatement systems and general techniques that are used across the sector. General techniques to consider in the determination of BAT (i.e. those techniques to consider that are widely applied in this sector) are reported in Chapter 2. Chapters 3 to 15 give the applied processes, current emission and consumption levels, techniques to consider in the determination of BAT and emerging techniques for the FDM sectors that are covered by these chapters. Chapter 16 provides thumbnail descriptions of additional FDM sectors, for which a data collection via questionnaires has not been carried out. Chapter 17 presents the BAT conclusions as defined in Article 3(12) of the Directive, both general and sector-specific.

Chapters 3 to 15 provide the information given below on specific FDM sectors (i.e. animal feed, brewing, dairies, ethanol production, fish and shellfish processing, fruit and vegetables, grain milling, meat processing, oilseed processing and vegetable oil refining, olive oil processing and refining, soft drinks and nectar/ juice, starch production, sugar manufacturing). For each FDM sector, the chapter is structured as follows (X is the chapter number):

- Section X.1 provides general information on the FDM sector.
- Section X.2 provides information on applied processes and techniques.
- Section X.3 provides data and information concerning the environmental performance of installations within the sector, and in operation at the time of writing, in terms of current emissions, consumption and nature of raw materials, and use of energy.
- Section X.4 describes in more detail the techniques to prevent or, where this is not practicable, to reduce the environmental impact of operating installations in this sector that were considered in determining the BAT. This information includes, where relevant, the environmental performance levels (e.g. emission and consumption levels)
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which can be achieved by using the techniques, the associated monitoring, the costs and the cross-media issues associated with the techniques.

- Section X.5 presents information on emerging techniques as defined in Article 3(14) of the Directive.

Concluding remarks and recommendations for future work are presented in Chapter 18.

4. Information sources and the derivation of BAT

This document is based on information collected from a number of sources, in particular through the TWG that was established specifically for the exchange of information under Article 13 of the Directive. The information has been collated and assessed by the European IPPC Bureau (of the Commission’s Joint Research Centre) who led the work on determining BAT, guided by the principles of technical expertise, transparency and neutrality. The work of the TWG and all other contributors is gratefully acknowledged.

The BAT conclusions have been established through an iterative process involving the following steps:

- identification of the key environmental issues for the Food, Drink and Milk Industries;
- examination of the techniques most relevant to address these key issues;
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide;
- examination of the conditions under which these environmental performance levels were achieved, such as costs, cross-media effects, and the main driving forces involved in the implementation of the techniques;
- selection of the best available techniques (BAT), their associated emission levels (and other environmental performance levels) and the associated monitoring for this sector according to Article 3(10) of, and Annex III to, the Directive.

Expert judgement by the European IPPC Bureau and the TWG has played a key role in each of these steps and the way in which the information is presented here.

Where available, economic data have been given together with the descriptions of the techniques presented in sections of Techniques to consider in the determination of BAT. These data give a rough indication of the magnitude of the costs and benefits. However, the actual costs and benefits of applying a technique may depend strongly on the specific situation of the installation concerned, which cannot be evaluated fully in this document. In the absence of data concerning costs, conclusions on the economic viability of techniques are drawn from observations on existing installations.

5. Review of BAT reference documents (BREFs)

BAT is a dynamic concept and so the review of BREFs is a continuing process. For example, new measures and techniques may emerge, science and technologies are continuously developing and new or emerging processes are being successfully introduced into the industries. In order to reflect such changes and their consequences for BAT, this document will be periodically reviewed and, if necessary, updated accordingly.
6. **Contact information**

All comments and suggestions should be made to the European IPPC Bureau at the Institute for Prospective Technological Studies at the following address:

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SCOPE

This BAT reference document (BREF) concerns the following activities specified in Sections 6.4 (b) and (c) of Annex I to Directive 2010/75/EU, namely:

6.4 (b) Treatment and processing, other than exclusively packaging, of the following raw materials, whether previously processed or unprocessed, intended for the production of food or feed from:

   (i) only animal raw materials (other than exclusively milk) with a finished product production capacity greater than 75 tonnes per day;

   (ii) only vegetable raw materials with a finished product production capacity greater than 300 tonnes per day or 600 tonnes per day where the installation operates for a period of no more than 90 consecutive days in any year;

   (iii) animal and vegetable raw materials, both in combined and separate products, with a finished product production capacity in tonnes per day greater than:

   — 75 if A is equal to 10 or more; or,
   — [300 - (22.5 × A)] in any other case,

   where ‘A’ is the portion of animal material (in percent of weight) of the finished product production capacity.

Packaging shall not be included in the final weight of the product.

This subsection shall not apply where the raw material is milk only.

(c) Treatment and processing of milk only, the quantity of milk received being greater than 200 tonnes per day (average value on an annual basis).

In particular, this BREF covers the following issues:

- environmental management systems;
- energy efficiency;
- water saving;
Scope

- waste water management, collection and treatment;
- by-products, residues and waste management;
- waste gas treatment;
- noise and vibration emissions;
- odour emissions.

This BREF does not address the following activities or processes:

- on-site combustion plants generating waste gases that are not used for direct contact heating, drying or any other treatment of objects or materials; this may be covered by the BAT conclusions for Large Combustion Plants (LCP);
- production of primary products from animal by-products, such as rendering and fat melting; fish-meal and fish oil production; blood processing and gelatine manufacturing; this may be covered by the BAT conclusions for Slaughterhouses and Animals By-products Industries (SA);
- the making of standard cuts for large animals and cuts for poultry; this is covered by the BAT conclusions for Slaughterhouses and Animals By-products Industries (SA);
- ethanol production taking place on an installation not covered by the activity description in 6.4 (b) (ii) of Annex I to the IED or as a directly associated activity; this is covered by the BAT conclusions for the Large Volume Organic Chemical Industry (LVOC).

Other reference documents which could be relevant for the activities covered by this BREF are the following:

- Large Combustion Plants (LCP);
- Slaughterhouses and Animals By-products Industries (SA);
- Large Volume Organic Chemical Industry (LVOC);
- Waste Treatment (WT);
- Production of Cement, Lime and Magnesium Oxide (CLM);
- Monitoring of emissions to air and water from IED-installations (ROM);
- Economics and Cross-Media Effects (ECM);
- Emissions from Storage (EFS);
- Energy Efficiency (ENE);
- Industrial Cooling Systems (ICS).

The scope of this document does not include matters that only concern safety in the workplace or the safety of products because these matters are not covered by the Directive. They are discussed only where they affect matters within the scope of the Directive.

This document reflects an exchange of information about the activities listed in Annex 1 parts 6.4. (b) and (c) of Council Directive 96/61/EC of 24 September 1996 on integrated pollution prevention and control (IPPC Directive), i.e.

6.4. (b) Treatment and processing intended for the production of food products from:

- animal raw materials (other than milk) with a finished product production capacity greater than 75 tonnes per day
- vegetable raw materials with a finished product production capacity greater than 300 tonnes per day (average value on a quarterly basis)

6.4. (c) Treatment and processing of milk, the quantity of milk received being greater than 200 tonnes per day (average value on an annual basis)

The scope includes the whole range of activities that may be found in European installations with capacities exceeding the above threshold values.
The document does not cover small scale activities, such as catering or activities in restaurants. Also, food industrial activities that do not use animal or vegetable raw materials are not covered, except as associated activities, e.g. mineral water processing and production of salt.

Agriculture, hunting and the slaughtering of animals are excluded. The manufacture of products other than food, e.g. soap, candles, cosmetics, pharmaceuticals; manufacture of gelatine and glue from hides, skin and bones are also excluded.

Another BREF in the series, i.e. the Slaughterhouses and animal by-products BREF [93, COM 2005 ] covers the slaughtering of animals. The “slaughter” activity is considered to end with the making of standard cuts for large animals and the production of a clean whole saleable carcase for poultry. The scope of that BREF also includes some animal by-products processes which may produce food products, i.e. fat melting; fish meal and fish oil production; blood processing and gelatine manufacturing.

Generally, packaging is not included but the packing of FDM products on the premises is included.

Animal feed of animal and vegetable origin are also within the scope of this document.

Information submitted about national legislation and standards is not included in this document. It is available in a separate document, which can be downloaded from the Activities page on the EIPPCB website, under Additional Information. (see http://eippcb.jrc.es).
1 GENERAL INFORMATION ABOUT THE FDM SECTOR

1.1 Description, turnover, growth, employment

The FDM sector produces both finished products destined for consumption and intermediate products destined for further processing. A sectoral breakdown in EU-15 shows that for most FDM product categories production exceeds consumption. The FDM sector in EU-15 had a reported total production value amounting to EUR 593000 million in 2000.

Average real annual growth rates of consumption and production are slow, which is a typical trend for mature markets. For example, growth during 1997 was less than 2 %. In employment terms, the EU-15 FDM sector employs a workforce of 2.7 million. This represents 11 % of the industrial workforce.

Europe’s food and drink industry had an annual turnover of EUR 1 039 billion and generated 4.42 million jobs, making it the largest manufacturing industry in the EU-28 during 2013. This represented 14.6 % of the total manufacturing sector turnover and 14.5 % of the total manufacturing sector employment in the EU-28. The industry is highly fragmented with over 287 000 companies, approximately 285 000 of which are small and medium-sized enterprises (SMEs), accounts for almost half of the total industry turnover and two thirds of overall industry employment. Europe’s food manufacturing industry is also a local industry, using 70 % of agricultural raw materials produced in the EU, which helps generate jobs both up and downstream in communities throughout the European Union. Data from Member States in the EU-28 are presented in Table 1.1 and in Table 1.2.

Table 1.1: Structure and production of the food and drink industry by Member State in the EU-28 (2013)

<table>
<thead>
<tr>
<th>Member State</th>
<th>Turnover (million EUR)</th>
<th>Number of persons employed</th>
<th>Number of enterprises</th>
<th>Exports (million EUR)</th>
<th>Imports (million EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>21 614</td>
<td>80 536</td>
<td>3 818</td>
<td>2 154</td>
<td>1 385</td>
</tr>
<tr>
<td>Belgium</td>
<td>45 872</td>
<td>95 843</td>
<td>6 984</td>
<td>4 473</td>
<td>5 928</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>4 921</td>
<td>94 342</td>
<td>5 834</td>
<td>1 142</td>
<td>404</td>
</tr>
<tr>
<td>Croatia</td>
<td>5 217</td>
<td>62 909</td>
<td>3 240</td>
<td>606</td>
<td>444</td>
</tr>
<tr>
<td>Cyprus</td>
<td>4 094</td>
<td>11 677</td>
<td>866</td>
<td>120</td>
<td>151</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>13 835</td>
<td>113 062</td>
<td>8 432</td>
<td>472</td>
<td>410</td>
</tr>
<tr>
<td>Denmark</td>
<td>15 746</td>
<td>62 504</td>
<td>1 575</td>
<td>4 607</td>
<td>3 173</td>
</tr>
<tr>
<td>Estonia</td>
<td>1 778</td>
<td>14 369</td>
<td>490</td>
<td>376</td>
<td>88</td>
</tr>
<tr>
<td>Finland</td>
<td>11 283</td>
<td>39 374</td>
<td>1 737</td>
<td>712</td>
<td>703</td>
</tr>
<tr>
<td>France</td>
<td>182 821</td>
<td>624 357</td>
<td>60 603</td>
<td>19 516</td>
<td>8 875</td>
</tr>
<tr>
<td>Germany</td>
<td>193 159</td>
<td>867 495</td>
<td>29 635</td>
<td>12 981</td>
<td>13 631</td>
</tr>
<tr>
<td>Greece</td>
<td>13 423</td>
<td>86 979</td>
<td>15 429</td>
<td>1 178</td>
<td>946</td>
</tr>
<tr>
<td>Hungary</td>
<td>11 396</td>
<td>102 261</td>
<td>6 625</td>
<td>973</td>
<td>269</td>
</tr>
<tr>
<td>Ireland</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2 499</td>
<td>914</td>
</tr>
<tr>
<td>Italy</td>
<td>128 342</td>
<td>428 601</td>
<td>57 640</td>
<td>9 615</td>
<td>8 035</td>
</tr>
<tr>
<td>Latvia</td>
<td>1 894</td>
<td>25 653</td>
<td>968</td>
<td>1 001</td>
<td>225</td>
</tr>
<tr>
<td>Lithuania</td>
<td>4 144</td>
<td>42 128</td>
<td>1 489</td>
<td>2 165</td>
<td>447</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>884</td>
<td>5 457</td>
<td>162</td>
<td>39</td>
<td>80</td>
</tr>
<tr>
<td>Malta</td>
<td>NA</td>
<td>3 696</td>
<td>397</td>
<td>187</td>
<td>59</td>
</tr>
<tr>
<td>Poland</td>
<td>69 301</td>
<td>126 996</td>
<td>5 587</td>
<td>135 84</td>
<td>15 769</td>
</tr>
<tr>
<td>Portugal</td>
<td>55 191</td>
<td>404 963</td>
<td>12 631</td>
<td>4 120</td>
<td>2 150</td>
</tr>
<tr>
<td>Romania</td>
<td>14 960</td>
<td>102 670</td>
<td>10 649</td>
<td>1 480</td>
<td>1 581</td>
</tr>
<tr>
<td>Slovakia</td>
<td>11 216</td>
<td>184 476</td>
<td>8 566</td>
<td>1 889</td>
<td>755</td>
</tr>
<tr>
<td>Slovenia</td>
<td>4 462</td>
<td>37 242</td>
<td>2 766</td>
<td>109</td>
<td>95</td>
</tr>
<tr>
<td>Spain</td>
<td>2 137</td>
<td>16 007</td>
<td>1 940</td>
<td>318</td>
<td>636</td>
</tr>
<tr>
<td>Sweden</td>
<td>103 249</td>
<td>355 262</td>
<td>27 119</td>
<td>7 395</td>
<td>8 961</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>19 584</td>
<td>63 242</td>
<td>3 820</td>
<td>1 970</td>
<td>4 357</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>91 331</td>
<td>368 140</td>
<td>8 230</td>
<td>8 732</td>
<td>13 170</td>
</tr>
<tr>
<td>EU-28</td>
<td>1 039 159</td>
<td>4 419 341</td>
<td>287 252</td>
<td>104 421</td>
<td>93 612</td>
</tr>
</tbody>
</table>

NB: NA = not available.

Source: [176, Eurostat 2016]
Table 1.2: Structure and production of some food and drink sectors in the EU-28 (2013)

<table>
<thead>
<tr>
<th></th>
<th>Production</th>
<th>Added value</th>
<th>Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Million EUR</td>
<td>%</td>
<td>Million EUR</td>
</tr>
<tr>
<td>Processing and preserving of meat and production of meat products</td>
<td>207 683</td>
<td>24.7</td>
<td>30 577</td>
</tr>
<tr>
<td>Processing and preserving of fish, crustaceans and molluscs</td>
<td>23 630</td>
<td>2.8</td>
<td>4 208</td>
</tr>
<tr>
<td>Processing and preserving of fruit and vegetables</td>
<td>60 425</td>
<td>7.2</td>
<td>13 177</td>
</tr>
<tr>
<td>Manufacture of vegetable and animal oils and fats</td>
<td>45 243</td>
<td>5.4</td>
<td>4 258</td>
</tr>
<tr>
<td>Manufacture of dairy products</td>
<td>140 000</td>
<td>16.7</td>
<td>20 000</td>
</tr>
<tr>
<td>Manufacture of grain mill products, starches and starch products</td>
<td>43 379</td>
<td>5.2</td>
<td>7 273</td>
</tr>
<tr>
<td>Manufacture of bakery and farinaceous products</td>
<td>107 411</td>
<td>12.8</td>
<td>40 281</td>
</tr>
<tr>
<td>Manufacture of other food products</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Manufacture of prepared animal feeds</td>
<td>70 000</td>
<td>8.3</td>
<td>10 100</td>
</tr>
<tr>
<td>Manufacture of beverages</td>
<td>142 801</td>
<td>17.0</td>
<td>37 636</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>840 572</td>
<td>100</td>
<td>167 513</td>
</tr>
</tbody>
</table>

NB: NA = not available.
Source: [176, Eurostat 2016]

More detailed figures for the total quantities and values of production in the major sectors of the EU-15 FDM sector, according to Eurostat (1999), are summarised in Table XX.
| 15.87 | Condiments and seasonings | 2917 | 5024 |
| 15.88 | Homogenised food preparations and dietetic food | 624 | 2646 |
| 15.89 | Other food products n.e.c. | 3784 | 8416 |
| 15.91 | Distilled potable alcoholic drinks | 1082 | 581 |
| 15.92 | Ethyl alcohol from fermented materials | 1362 | 973 |
| 15.93 | Wines | 13184 | 20169 |
| 15.94 | Other fermented drinks, e.g. cider, perry and mead, and mixed drinks containing alcohol | 279 | 408 |
| 15.95 | Vermouth and other flavoured wine of fresh grapes | 330 | 449 |
| 15.96 | Beer made from malt | 28030 | 17256 |
| 15.97 | Malt | 4516 | 1154 |
| 15.98 | Mineral waters and soft drinks | 61408 | 26664 |
| **Total value** | | 615260 | 449464 |

*The NACE code is a statistical classification of economic activities in the European Community Union based on an interpretation of the International Standard Industrial Classification (ISIC) [229, EC, 1990].

*These figures include both the production by the feed industry (125 million tonnes) and the production by home-mixers. This explains why the turnover mentioned for the feed industry in is EUR 37000 million and not EUR 50000 million.

Table XX: EU-15 production in the major sectors (1999) [1, CIAA, 2002]
1.2 Sector structure

Available statistics show that the EU-28 FDM sector comprises close to 287,000 companies, most of which have over 20 employees, around 90% of which have 20 or less employees. The food and drink industry is the top employment sector in the EU (14.5%) and leading employer in the manufacturing sector in more than half of the EU Member States.

The EU-28 FDM sector is exceptionally diverse compared to many other industrial sectors. This diversity can be seen in terms of the size and nature of companies; the wide range of raw materials, products and processes and the numerous combinations of each, and the production of homogenised global products as well as numerous specialist or traditional products on national and even regional scales. The sector is also subject to very diverse local economic, social and environmental conditions, and varying national legislation.

The EU-28 FDM industry is quite fragmented. Approximately 92% of the sector is made up of SMEs, although there are some sectors, such as sugar manufacturing, which have very large companies. Approximately 70% of the agricultural raw materials used by the industry are produced in the EU, which helps generate jobs both up and downstream in rural and urban communities throughout the European Union. This fragmentation and diversity, as well as divergent data collection systems in individual MSs, makes it difficult to ascertain exact figures for the sector as a whole. Based on data submitted by Member State during 2009–2011, information on the number of installations specified in Sections 6.4 (b) and (c) of Annex I to the IED Directive is given in Table 1.3.

Table 1.3: Summary of existing FDM installations requiring a permit by activity category in Annex I to Directive 2010/75/EU (reference period 2012–2013)

<table>
<thead>
<tr>
<th>Member State</th>
<th>6.4 (b)</th>
<th>6.4 (c)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>12</td>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td>Belgium</td>
<td>58</td>
<td>16</td>
<td>74</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>8</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Croatia</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Cyprus</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>74</td>
<td>18</td>
<td>92</td>
</tr>
<tr>
<td>Denmark</td>
<td>38</td>
<td>20</td>
<td>58</td>
</tr>
<tr>
<td>Estonia</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Finland</td>
<td>16</td>
<td>13</td>
<td>29</td>
</tr>
<tr>
<td>France</td>
<td>384</td>
<td>199</td>
<td>583</td>
</tr>
<tr>
<td>Germany</td>
<td>285</td>
<td>121</td>
<td>406</td>
</tr>
<tr>
<td>Greece</td>
<td>36</td>
<td>7</td>
<td>43</td>
</tr>
<tr>
<td>Hungary</td>
<td>21</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>Ireland</td>
<td>14</td>
<td>24</td>
<td>38</td>
</tr>
<tr>
<td>Italy</td>
<td>259</td>
<td>32</td>
<td>291</td>
</tr>
<tr>
<td>Latvia</td>
<td>NA</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Lithuania</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>NA</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Malta</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Poland</td>
<td>136</td>
<td>45</td>
<td>181</td>
</tr>
<tr>
<td>Portugal</td>
<td>60</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td>Romania</td>
<td>22</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>Slovakia</td>
<td>13</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>Slovenia</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Spain</td>
<td>292</td>
<td>40</td>
<td>332</td>
</tr>
<tr>
<td>Sweden</td>
<td>20</td>
<td>17</td>
<td>37</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>94</td>
<td>31</td>
<td>125</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>287</td>
<td>56</td>
<td>343</td>
</tr>
<tr>
<td><strong>EU-28</strong></td>
<td><strong>2134</strong></td>
<td><strong>678</strong></td>
<td><strong>2812</strong></td>
</tr>
</tbody>
</table>

NB: NA = not available.

Source: [177, COM 2016]
The sector is spread all over Europe, in very industrialised regions as well as in rural areas. Traditionally, industrial production has been closely related to primary production, climate, and natural resources, e.g. land and water, along with the actual requirements of the particular production technique. These heavily influence the structure and geographical location of specific industrial production. Although this kind of dependence is being reduced, it still holds true in many sectors. For example, some sectors are still concentrated in special regions, e.g. fish processing is usually found in countries, or regions which have direct access to the sea and traditions of fishing, and olive oil is mainly manufactured in Mediterranean countries, especially in Andalusia in Spain. Other activities such as sugar production/refining, grain milling and dairy industries are found in all countries. Some FDM production activities have special requirements with regards to natural resources, such as the need for a receiving water body for the discharge of large volumes of treated waste water. Sugar- and starch-producing installations, oilseeds installations and oil refineries and fruit and vegetable preservation installations are normally situated near water for this reason. Sugar installations, refineries and fruit and vegetable preservation installations are normally situated near to water, for this reason.
1.3 Trade

For many companies, exporting their product out of Europe is an important part of their business. In the first semester of 2013, the EU-28 FDM sector exports amounted to EUR 42 400 million. This is a 4% increase over 2012 figures, which represented 79% of European global exports of agricultural and FDM products. This is a slight decrease over 1998 figures.

The main export market for European FDM products is the US. The Chinese, Japanese, Swiss and Russian markets are also significant. The top export destinations of EU-28 FDM products in 2014, in financial terms, are shown in Table 1.4. The origins of the top imports to the EU-28 are shown in Table 1.5.

Table 1.4: Top export destinations of EU-28 FDM products in 2014

<table>
<thead>
<tr>
<th>Export destination</th>
<th>Million EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>14 566</td>
</tr>
<tr>
<td>Russia</td>
<td>6 335</td>
</tr>
<tr>
<td>China</td>
<td>5 583</td>
</tr>
<tr>
<td>Switzerland</td>
<td>5 304</td>
</tr>
<tr>
<td>Japan</td>
<td>4 607</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>3 662</td>
</tr>
<tr>
<td>Norway</td>
<td>3 146</td>
</tr>
<tr>
<td>Canada</td>
<td>2 592</td>
</tr>
<tr>
<td>Australia</td>
<td>2 348</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>2 219</td>
</tr>
</tbody>
</table>

Source: [176, Eurostat 2016]

Table 1.5: Origins of top imports of non-EU FDM products in 2014

<table>
<thead>
<tr>
<th>Import origin</th>
<th>Million EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>6 706</td>
</tr>
<tr>
<td>USA</td>
<td>4 853</td>
</tr>
<tr>
<td>Argentina</td>
<td>4 341</td>
</tr>
<tr>
<td>Switzerland</td>
<td>4 137</td>
</tr>
<tr>
<td>China</td>
<td>3 655</td>
</tr>
<tr>
<td>India</td>
<td>3 647</td>
</tr>
<tr>
<td>Thailand</td>
<td>2 549</td>
</tr>
<tr>
<td>Turkey</td>
<td>2 505</td>
</tr>
<tr>
<td>Norway</td>
<td>1 989</td>
</tr>
<tr>
<td>Malaysia</td>
<td>1 765</td>
</tr>
</tbody>
</table>

Source: [176, Eurostat 2016]

The top individual export sectors in the FDM sector in 2014 are shown in Table 1.6
Table 1.6: Exports by sector in the EU-28 in 2014

<table>
<thead>
<tr>
<th>Sector</th>
<th>Million EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drinks, of which:</td>
<td></td>
</tr>
<tr>
<td>spirits</td>
<td>25 706</td>
</tr>
<tr>
<td>wine</td>
<td>10 176</td>
</tr>
<tr>
<td>mineral water and soft drinks</td>
<td>8 867</td>
</tr>
<tr>
<td></td>
<td>2 761</td>
</tr>
<tr>
<td>Chocolate and confectionary</td>
<td>5 235</td>
</tr>
<tr>
<td>Processed tea and coffee</td>
<td>2 111</td>
</tr>
<tr>
<td>Meat products</td>
<td>11 249</td>
</tr>
<tr>
<td>Dairy products</td>
<td>9 488</td>
</tr>
<tr>
<td>Fruit and vegetable products</td>
<td>4 981</td>
</tr>
<tr>
<td>Oils and fats</td>
<td>4 538</td>
</tr>
<tr>
<td>Prepared animal feeds</td>
<td>2 883</td>
</tr>
<tr>
<td>Bakery and farinaceous products</td>
<td>2 498</td>
</tr>
<tr>
<td>Fish and sea food products</td>
<td>3 419</td>
</tr>
<tr>
<td>Grain mill products and starch products</td>
<td>2 828</td>
</tr>
</tbody>
</table>

Source: [176, Eurostat 2016]

The UN predicts that the world population will reach 9 billion in 2050 and will require 70% more food production. This will necessarily lead to an increased demand for food, drink and milk products and production. The European food and drink industry is faced with the twin challenges of ensuring access to raw materials at competitive prices and the sustainable supply of nutritious food against the backdrop of global food security.


1.4 Market forces: demand, distribution and competition

1.4.1 Demand

An ever increasing number of social and economic factors affect FDM consumption patterns throughout the EU-28 leading to some diversification in traditional consumption and purchasing models. In recent years, European consumers have developed Greater homogeneity in lifestyles is reflected in the consumption and purchasing patterns for a growing variety of goods. The European food and drink industry is constantly responding to changing consumer demands by providing a wide range of food products. Even so, FDM products still retain elements of cultural specificity linked to national or regional traditions. So although consumers want to be able to purchase the same items and quality of products throughout the whole of the EU-28, they also demand the option/choice of different products linked to their own tradition or culture. This can be reflected at a national, regional or even more local level and can also vary throughout the year. For instance, for the feed industry, this impacts feed formulation through diverse feed specifications to allow livestock farmers to meet the requirements related to the quality of animal products, while ensuring their profitability and resource efficiency. Food and feed products may have different quality specifications (e.g. on taste, colour, texture) that require specific technologies.

1.4.2 Distribution

Cost control activities, e.g. labour-saving technologies, improvements in logistics and distribution channels and resource saving practices, have been introduced. In general, most FDM products tend to be distributed to the major retail chains, although substantial differences persist between countries.

1.4.3 Competition

As is the case with most mature markets, the FDM sector is facing sharp competitive pressure and progressive market concentration. In fact, even if great fragmentation still persists in most countries, the size and corresponding economic strength of companies is becoming crucial for balancing the increasing bargaining power of retailers and achieving the minimum critical mass in terms of production volumes.
1.5 The importance of food safety in FDM processing

As well as environmental considerations, there are other legal requirements and prohibitions which must be considered when identifying best available techniques in the FDM industry. There are specific requirements relating to, e.g. food safety, and these are updated from time to time. All FDM production installations, regardless of their size, geographical location or point in the production process, must comply with the required food safety standards.

The achievement of the required standards can be made easier if all of the operators with responsibilities collaborate closely. The FDM industry has identified five key areas that can ensure day-to-day food safety, i.e. improved food safety systems, robust traceability systems, crisis management, risk identification and communication. The application of such principles, in particular in relation to crisis management, risk identification and communication, should also be considered with respect to environmental protection. Where quality management systems developed from, e.g. ISO 9001 Quality System–Model for quality assurance in design/development, production, installation and servicing, and ISO 9002 Quality System–Model for quality assurance in production, installation and servicing, exist, the familiarity with such systems may facilitate the use of equivalent environmental standards-related systems.

The food safety laws may have an influence on environmental considerations. For example, food safety and hygiene requirements may affect the requirement for water use to clean the equipment and the installation, making it necessary to use hot water, so there are also energy considerations. Likewise, waste water is contaminated by substances used for hygiene purposes, for cleaning and sterilisation, e.g. during the production and packaging of long-life FDM products. Heat treatment is a key tool to manage microbiological contamination of feed and is even mandatory under many countries' national legislation. These issues have to be considered to ensure that hygiene standards are maintained, but taking into account the control of water, energy, and detergent and sterilant use. Cooling is another parameter relevant to maintenance of hygiene requirements and food safety that will also have a significant impact on energy consumption.

Care has been taken to ensure that nothing in this document conflicts with relevant food safety legislation.
1.6 Legislative framework for food, drink and milk products

Protection of the consumer and of the environment, and the elimination of obstacles to the free movement of goods are among the main concerns of EU FDM legislation. The EU legislative framework is based on horizontal measures across product categories as well as on commodity-specific so-called vertical measures, derived from the agricultural policy or the agri-monetary system.

As well as the general legislation, e.g. financial, environmental, health and safety, the FDM sector is also controlled by specific very detailed and comprehensive legislation starting at the farm gate and ending on the dinner plate. This legislation covers the following main areas:

- food and feed safety (contaminants, pesticide residues, quality of water intended for food consumption, official control of foodstuffs, materials in contact with foodstuffs);
- food and feed hygiene (general rules, health rules concerning foodstuffs of animal origin);
- food and feed composition (additives, flavourings, processing aids, GMOs);
- consumer information (general labelling rules, quantitative ingredient declaration, lot identification, unit pricing);
- food and feed nutrition, food and feed labelling;
- animal by-products;
- ionisation;
- organic production.

Section 1.7 refers to some selected legislation on the environment. Other pieces of environmental legislation are also valid for the industry, e.g. 98/83/EC Directive on the quality of water for human consumption.
1.7 The FDM sector and the environment

The FDM sector often depends on the quality of natural resources, especially that of land and water, so preserving the environment in which the raw materials are grown is very important. The level of pollution in waste water and the amount of waste produced by the industry can represent a significant load in some countries or regions. While most emissions from the industry are biodegradable, some sectors use materials such as salt or brine which are resistant to conventional treatment methods and can introduce, e.g. pesticide residues used on the source crop.

Traditionally, in many European countries, the sector has not been heavily regulated by environmental legislation. The trigger for the sector to improve its environmental performance has therefore been based on efficiency improvements, e.g. maximising the utilisation of materials, which subsequently leads to a minimisation of waste. Food wastage represents a missed opportunity to feed the growing world population, a major waste of resources and a needless source of greenhouse gas emissions that impacts climate change. It also has negative economic consequences for everyone along the food chain when food goes to waste. For this reason, significant efforts have been made in recent years to reduce the amount of food wasted in the food and drink sector through different industry initiatives. In 2013, some food chain partners launched a joint effort to tackle the problem of food wastage via the publication of their ‘Every Crumb Counts’ Joint Declaration, aiming at maximising the food and feed use of inedible crop residues, inedible animal parts and by-products [178, Every Crumb Counts 2015].

The FDM industry focuses on proactive environmental management systems, natural resource conservation and the performance of waste minimisation techniques. To ensure sustainability, the effects of the raw material supply, food processing, transport, distribution, preparation, packaging and disposal must be considered and controlled. Both primary production and processing are critically dependent upon a reliable water supply and adequate water quality, in conformity with legal requirements.

The FDM sector complies with the requirements of the Packaging Directive 94/62/EC by preventing the production of packaging waste, and by reuse and recycling, as well as by recovering packaging waste. Packaging is essential for complying with the food and drink products’ strict hygienic standards and preserving their quality from production to consumption, which also helps to prevent and reduce food waste. It is also a marketing and sales tool and it conveys information like ingredients, nutrient content, cooking instructions and storage information.

Annex I to the Packaging and Packaging Waste Directive lays out the essential requirements on the composition and the reusable and recoverable (including recyclable) nature of packaging. The essential requirements, along with their associated CEN standards, are the leading set of legally binding EU design requirements for packaging. A list of CEN standards developed on packaging design can be found below:

- EN 13427: requirements for the use of European Standards in the field of packaging and packaging waste.
- EN 13428: requirements specific to manufacturing and composition–Prevention by source reduction.
- EN 13429: reuse.
- EN 13430: requirements for packaging recoverable by material recycling.
- EN 13431: requirements for packaging recoverable in the form of energy recovery, including specification of minimum inferior calorific value.
- EN 13432: requirements for packaging recoverable through composting and biodegradation.
Chapter 1

The efficient management of packaging and the minimisation of packaging waste is the responsibility of the FDM sector as well as farmers, retailers and consumers. In this context, the CEN standards on packaging, e.g. EN 13427:2000 [195, CEN, 2000], EN 13428:2000 [196, CEN, 2000] and EN 13431:2000 [197, CEN, 2000], are very useful.

These standards provide guidelines to operators to enable them to comply with the essential requirements laid down by the Packaging Directive 94/62/EC. They offer the required flexibility to encourage innovation and enable packaging to be adapted to consumer needs. They can also be incorporated into the environmental and quality management systems within companies.

EMSs involve developing policies and guidelines, establishing objectives and programmes, allocating environmental responsibilities within an organisational structure, training and communication activities, operational control and conducting surveys and audits.

Many FDM companies have implemented an EMS and some are certified or in the process of being certified to ISO 14001 or the EU Eco-Management and Audit Scheme (EMAS). In 2003, the FDM sector had the highest number of EMAS registered organisations in any sector and represented 9% of all EMAS registered organisations. The FDM sector is one of the industrial sectors with the most EMAS-registered organisations [179, European Commission 2015] (for further information see Section 2.3.1.1).

1.7.1 Key environmental issues

Being a diverse industrial sector, the different FDM sectors have different environmental issues and challenges. Although the paragraphs below streamline impacts throughout the FDM sector, subsequent chapters will therefore reflect these divergences in terms of relevant emissions (direct, indirect and diffuse), outputs and subsequently BAT conclusions.

Water consumption is one of the key environmental issues for the FDM sector. Water, which is not used as an ingredient, ultimately appears in the waste water stream or is transformed into steam and emitted to air. Typically, untreated FDM waste water is high in both COD and BOD content. Emission levels can be 10–500 times higher than in domestic waste water. The TSS concentration varies from negligible to more than 100 g/l. Untreated waste water from some sectors, e.g. meat, fish, dairy and vegetable oil production, contains high concentrations of fats, oils and greases (FOG). Waste water from the FDM industry is, in most cases, biodegradable and hence can be treated together with domestic waste water or waste water from other industrial sectors (e.g. carbon source for denitrification or for biological phosphorus removal).

The main air pollutants from FDM processes are dust, volatile organic compounds (VOCs) and odour. Refrigerants containing ammonia and halogen may be accidentally released. Odour is a local problem either related to the process or to the storage of raw materials, by-products or waste.

Table 1.7 provides an overview of the key environmental issues agreed on at the kick-off meeting for the review of the FDM BREF across the 13 FDM sectors for which data were collected.
Table 1.7: Key environmental issues agreed on at the kick-off meeting for the review of the FDM BREF

<table>
<thead>
<tr>
<th>Sectors for data collection</th>
<th>Key environmental issues</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Emissions to water</td>
</tr>
<tr>
<td></td>
<td>Common parameters</td>
</tr>
<tr>
<td>Dairies</td>
<td>Chloride (Cl&lt;sup&gt;-&lt;/sup&gt;)</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>TVOC, NO&lt;sub&gt;x&lt;/sub&gt;, SO&lt;sub&gt;2&lt;/sub&gt;, CO</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>—</td>
</tr>
<tr>
<td>Meat processing</td>
<td>—</td>
</tr>
<tr>
<td>Animal feed</td>
<td>—</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td>TOC, COD, BOD&lt;sub&gt;5&lt;/sub&gt;, TSS, TN, TP, NH&lt;sub&gt;4&lt;/sub&gt;-N</td>
</tr>
<tr>
<td>Starch production</td>
<td>—</td>
</tr>
<tr>
<td>Brewing</td>
<td>—</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td>Chloride (Cl&lt;sup&gt;-&lt;/sup&gt;)</td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td>—</td>
</tr>
<tr>
<td>Soft drinks and juice made from concentrate</td>
<td>—</td>
</tr>
<tr>
<td>Grain milling</td>
<td>—</td>
</tr>
<tr>
<td>Ethanol production</td>
<td>—</td>
</tr>
</tbody>
</table>

NB: NA = not applicable.

Noise may also be a local problem for some installations, typically associated with vehicle movements, grinding and refrigeration.

The solid output from FDM installations is composed of by-products, residues co-products and waste. The main sources of solid waste output are inherent losses besides spillage, leakage, overflow, defects/returned products, retained material that cannot freely drain to the next stage in the process and heat deposited waste.

The FDM sector is dependent on energy for processes required for freshness and food safety. Mechanical processing, e.g. raw material preparation and sizing, and thermal processing, e.g. dehydration, are the most commonly used techniques for food preservation and processing. Both require significant amounts of energy. Process heating uses approximately 29% of the total energy used in the FDM sector. Process cooling and refrigeration accounts for about 16% of the total energy used.

Table shows the key environmental issues for some FDM sectors.
Chapter 1

### Table: Environmental issues for some FDM sectors

<table>
<thead>
<tr>
<th>Sector</th>
<th>Water use</th>
<th>Waste water</th>
<th>Chemicals use</th>
<th>Air pollution</th>
<th>Noise</th>
<th>Odour</th>
<th>Solid output</th>
<th>Energy use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Heating</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cooling and refrigeration</td>
</tr>
<tr>
<td>Meat and poultry</td>
<td>yes</td>
<td>yes</td>
<td>-</td>
<td>yes</td>
<td>-</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Fish and shellfish</td>
<td>yes</td>
<td>yes</td>
<td>-</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>yes</td>
<td>yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>yes</td>
</tr>
<tr>
<td>Vegetable oils and fats</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Dairy products</td>
<td>-</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Dry pasta</td>
<td>yes</td>
<td>-</td>
<td>-</td>
<td>yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>yes</td>
</tr>
<tr>
<td>Starch</td>
<td>yes</td>
<td>yes</td>
<td>-</td>
<td>yes</td>
<td>-</td>
<td>-</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Sugar</td>
<td>yes</td>
<td>yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Drinks</td>
<td>yes</td>
<td>yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Breweries</td>
<td>yes</td>
<td>yes</td>
<td>-</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Citric acid fermentation</td>
<td>yes</td>
<td>yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>yes</td>
<td>-</td>
</tr>
</tbody>
</table>

This table shows the key environmental issues for each sector and does not represent comparative quantitative data.
2 GENERAL PROCESSES AND TECHNIQUES ACROSS THE FDM SECTOR

2.1 Applied processes and techniques across the FDM sector

2.1.1 Introduction

Section 2.1 provides a short description of the processing techniques and unit operations commonly used in the FDM sector, including their objectives and field of application. The application of processing techniques and unit operations in some FDM sectors is described in Section 19.2 of this BREF, to avoid repetition throughout the document.

The most commonly used processing techniques and unit operations in the FDM sector are shown in Table 2.1. Some of these processing techniques are described in Annex II (Section 19.2) of this BREF.

Table 2.1: The processing techniques and unit operations most commonly used in the FDM sector

<table>
<thead>
<tr>
<th>Materials reception and preparation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials handling and storage</td>
</tr>
<tr>
<td>Sorting/screening, grading, dehulling, destemming/destalking and trimming</td>
</tr>
<tr>
<td>Peeling</td>
</tr>
<tr>
<td>Washing</td>
</tr>
<tr>
<td>Thawing</td>
</tr>
<tr>
<td>Size reduction, mixing and forming</td>
</tr>
<tr>
<td>Cutting, slicing, chopping, mincing, pulping and pressing</td>
</tr>
<tr>
<td>Mixing/blending, homogenisation and conching</td>
</tr>
<tr>
<td>Grinding/milling and crushing</td>
</tr>
<tr>
<td>Forming/moulding and extruding</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Separation techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction</td>
</tr>
<tr>
<td>Deionisation</td>
</tr>
<tr>
<td>Fining</td>
</tr>
<tr>
<td>Centrifugation and sedimentation</td>
</tr>
<tr>
<td>Filtration</td>
</tr>
<tr>
<td>Membrane separation</td>
</tr>
<tr>
<td>Crystallisation</td>
</tr>
<tr>
<td>Removal of free fatty acids by neutralisation</td>
</tr>
<tr>
<td>Bleaching</td>
</tr>
<tr>
<td>Deodorisation by stream stripping</td>
</tr>
<tr>
<td>Decolourisation</td>
</tr>
<tr>
<td>Distillation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product processing technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soaking</td>
</tr>
<tr>
<td>Dissolving</td>
</tr>
<tr>
<td>Solubilisation/alkalising</td>
</tr>
<tr>
<td>Fermentation</td>
</tr>
<tr>
<td>Coagulation</td>
</tr>
<tr>
<td>Germination</td>
</tr>
<tr>
<td>Brining/curing and pickling</td>
</tr>
<tr>
<td>Smoking</td>
</tr>
<tr>
<td>Hardening</td>
</tr>
<tr>
<td>Sulphitation</td>
</tr>
<tr>
<td>Carbonation</td>
</tr>
<tr>
<td>Carbonation</td>
</tr>
<tr>
<td>Coating/spraying/enrobing/agglomeration/encapsulation</td>
</tr>
</tbody>
</table>
The raw materials used by the FDM sector are natural products, which may vary from season to season and from year to year. It may, therefore, be necessary to adapt production processes to accommodate the changes in characteristics of the raw materials.

To process a raw material into a product normally involves applying a range of processing techniques linked together into a production line.

Providing a detailed description of every process applied in the FDM sector is beyond the scope of this document, which is why only the most common processing techniques applied were described in the previous section.

The major processes in some FDM sectors are described in the following sections. The intention is to provide a degree of information rather than to give every detail about the processes.

The use of these unit operations in some of the specific sectors is summarised in Table.

Table: Unit operations applied in different sectors
<table>
<thead>
<tr>
<th>Meat</th>
<th>Fish</th>
<th>Meat</th>
<th>Potato</th>
<th>Fruit and veg.</th>
<th>Oil</th>
<th>Milk</th>
<th>Starch</th>
<th>Confectionery</th>
<th>Sugar</th>
<th>Beer</th>
<th>Malt</th>
<th>Non-alcoholic drinks</th>
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<td>E.8</td>
<td>Pasteurisation, sterilisation and UHT</td>
<td>yes yes - yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes</td>
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<td>E.1</td>
<td>Evaporation (liquid to liquid)</td>
<td>yes yes yes yes - - - yes yes - - - yes yes yes yes yes yes yes yes yes yes</td>
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<td>E.2</td>
<td>Drying (liquid to solid)</td>
<td>- - yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes</td>
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<td>E.3</td>
<td>Dehydration (solid to solid)</td>
<td>yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes</td>
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<td>G.1</td>
<td>Cooling, chilling and cold storage</td>
<td>yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes</td>
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<td>G.2</td>
<td>Freeze</td>
<td>yes yes yes yes - - - yes yes - - - yes yes yes yes yes yes yes yes yes yes</td>
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<td>G.3</td>
<td>Freeze-drying/lyophilisation</td>
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<td>H.1</td>
<td>Packing and filling</td>
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<td>H.2</td>
<td>Gas flushing and storage under gas</td>
<td>yes yes - - yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes</td>
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<td>U.1</td>
<td>Cleaning and disinfection</td>
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<td>U.2</td>
<td>Energy generation and consumption</td>
<td>yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes</td>
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<td>U.3</td>
<td>Water use</td>
<td>yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes</td>
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<td>U.4</td>
<td>Vacuum generation</td>
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<td>L.5</td>
<td>Refrigeration</td>
<td>yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes</td>
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<td>L.6</td>
<td>Compressed air generation</td>
<td>yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes yes</td>
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Source: [1, CIAA 2002] [51, Ullmann 2001] [54, Italian contribution 2001]
2.1.2 Energy consumption

FDM manufacturing requires electrical and thermal energy for virtually every step of the process. Electricity is needed for lighting, for process control of the installation, for heating, for refrigeration and as the driving power for machinery. It is usually generated and supplied by utility companies. When steam and electricity are generated on site, the efficiency factor can be considerably higher.

Thermal energy is needed for heating processing lines and buildings. The heat generated by the combustion of fossil fuels is transferred to the consumers by means of heat transfer media, which, depending on the requirements, are steam, hot water, air or thermal oil.

The basic boiler/generator design generally consists of a combustion chamber, where fuel combustion takes place. The heat is initially transferred by radiation, followed by a tubular heat exchanger for heat transfer by convection. The hot flue-gas and heat transfer media are separated from each other by a specially designed heat-exchange system. Thermal efficiencies of heat generators very much depend on the application and fuel type. Efficiencies, calculated on the basis of lowest calorific value, range from 75% to 90%. Some products are heated up by means of direct radiation with open flames or convection with directly heated process air. In this particular case, natural gas or extra light fuel oil is burned.

On-site combined generation of heat and power (CHP) is a valuable alternative for FDM manufacturing processes for which heat and power loads are balanced. The following cogeneration concepts are used in the FDM sector: high pressure steam boilers/steam turbine, gas turbines or gas engines or diesel generators with waste heat recovery for steam or hot water generation. The overall fuel utilisation factor of CHP systems exceeds 70% and is typically about 85%. Energy efficiency can be up to 90% or 95% when the exhaust gases from a waste heat recovery system, such as a steam boiler, are used for other drying purposes. A dryer uses the hot gases from a combustion plant for direct contact with the product to be dried (e.g. sugar beet pulp, green fodder, starch). A similar principle is used by a smoke kiln, which uses the hot gas to smoke and/or cook the product (e.g. meat, fish).

The fuel conversion efficiency greatly exceeds that of any design of a commercial power station, even the latest generation of combined cycle gas turbines, which can achieve a conversion efficiency of 55%. Sometimes surplus electricity can be sold to other users. Natural gas and fuel oil are the most convenient fuels. However, a few installations still burn solid fuels such as coal or process wastes. The utilisation of process wastes can be a convenient and competitive source of energy, and additionally helps to reduce the cost of off-site waste disposal.

The high energy usage in the FDM industry allied to the rising cost and decreasing availability of fossil fuels means that alternative, long-term energy supplies must be investigated. The extent of generation of electricity by the food industry itself is currently low, meaning that there is a big gap between its consumption and generation which could be filled, to some extent, by appropriate renewable energy recovery from wastes. Given the nature of the raw materials available, one technology which seems well suited to the FDM industry is anaerobic digestion, a process in which biodegradable material is broken down by microorganisms, in the absence of oxygen, to yield biogas (see Section 2.3.5.1) [262, Hall et al. 2012].

In the FDM sector, a number of common techniques are applied with the aim of reducing energy consumption. A summary is presented below. Most of these techniques are described in more detail in the ENE BREF [261, COM 2009].
2.1.2.1 General processing techniques

2.1.2.1.1 Combined heat and power generation (CHP)

Combined heat and power (CHP) generation, also known as co-generation, is a technique through which heat and electricity are produced in one single process. In-house combined generation of heat and power can be used in food manufacturing processes for which heat and power loads are balanced. For example, sugar manufacturing requires electrical and thermal energy in every step of the process. Electricity is needed for lighting, for installation process control, and as the driving power for machinery. Steam and hot water are needed for heating process vessels and buildings. As the size of dairies increases, the amounts of thermal and electrical energy needed for evaporation/drying steps is growing, making CHP a feasible alternative.

The energy efficiency of CHP can be as high as 90%. This optimises the use of fossil fuels and reduces the production of CO\textsubscript{2}. New CHP installations save at least 10% of the fuel otherwise used in the separate production of heat and electricity. Furthermore, gas-fired CHP schemes can eliminate SO\textsubscript{2} emissions and NO\textsubscript{X} can be controlled to meet environmental legislation. Modern CHP equipment is likely to require less effort to operate and maintain than many older boiler systems, as they are equipped with automatic control and monitoring systems.

It is reported that most of the energy required in sugar manufacturing is obtained by burning gas, heavy fuel oil or coal in a boiler house, which converts it, by means of CHP equipment, into steam and electricity. In this sector, the overall fuel utilisation factor of CHP exceeds 70% and is typically above 80%. This fuel conversion efficiency greatly exceeds that of any design of commercial power stations whose steam is not used further, including even the latest generation of combined cycle gas turbines, which are around 55% efficient. Excess electricity produced may be sold to other users [192, COM 2006].

2.1.2.1.2 Standard and condensing economiser

The economiser is already a very common and standard solution to recover energy in steam boilers and other heat sources. Very briefly, it is a heat exchanger located in the flue-gas of combustion, which can be useful for low-grade heat applications, such as water preheating. There are two types of economisers: standard and condensing. Flue-gases contain water vapour from combustion. A standard economiser uses the remaining flue-gas heat above the condensation temperature of this vapour (sensible heat), whereas a condensing economiser extracts heat from flue-gases below the condensation temperature of this vapour (thus also recovering the latent heat). This condensed vapour mixes with sulphur and NO\textsubscript{X} from the combustion, becoming acidic, therefore the condensing economiser, despite allowing a higher energy recovery, is more expensive as it requires acid-proof material (stainless steel).

2.1.2.1.3 Multistage evaporation systems

Evaporators may operate singly, or evaporation may take place in stages using several evaporators operating in series. Each evaporator is referred to as an effect. With multistage or multi-effect evaporator systems, the product output from one effect in the evaporator is the feed for the next effect, and the high temperature vapour that is removed from one effect of the evaporator is used to heat the lower temperature product in the next evaporator effect. Multistage evaporator systems are based on the combination of mechanical vapour recompression (MVR) and thermal vapour recompression. More information on this technique is available in the ENE BREF [261, COM 2009].

In the MVR, the evaporated vapour is compressed by a mechanical compressor and then reused as a heat source. The latent heat is higher than the power input of the compressor and a large...
COP is available. With MVR, all the vapour is compressed, so a high degree of heat recovery is achieved. The system is driven by electricity, but needs a steam heated finisher to attain high temperatures. Two types of compressors are in operation, i.e. a fan and a high speed turbine. In practice, the fan is the most widely used compressor type as it has better energy efficiency. The principle of an MVR operation is shown in Figure 2.1.

![Figure 2.1: MVR evaporator principle](#)

TVR makes use of steam injection compressors to compress the vapour. Steam injection compressors may have fixed or variable injection nozzles. The thermal energy needed for compression is live steam from a boiler.

### 2.1.2.1.4 Heat pumps for heat recovery

The working principle of a heat pump is based on heat transfer from a lower temperature to a higher temperature by aid of electrical power. For example, the recovery of heat from warm cooling water. The cooling water is cooled down and the heat can be used for heating another stream of water.

Heat pumps are generally only a good solution when the site energy recovery has been fully optimised and only low-grade heat remains [203, FEFAC 2015].

### 2.1.2.1.5 Use of permanent magnet synchronous motors

In the case of a permanent magnet synchronous (PMAC) motor, the rotor itself contains permanent magnet material, which is either surface-mounted to the rotor lamination stack or embedded within the rotor laminations. Electrical power is supplied through the stator windings.

PMAC motors are more efficient due to the elimination of rotor conductor losses, lower resistance winding and flatter efficiency curve. Due to their synchronous operation, PMAC motors offer more precise speed control. PMAC motors provide a higher power density due to the higher magnetic flux compared to induction machines. Finally, PMAC motors generally operate at cooler temperatures, resulting in a longer lifetime [193, TWG 2015].
2.1.2.2 Techniques related to cooling/freezing

The typical cooling processes applied in the FDM sector are presented in Table 2.2. It should be noted that the selection of cooling agents and refrigerants is influenced by Regulation (EC) No 1005/2009 [269, COM 2009] and Regulation (EU) No 517/2014 [259, EC 2014].

Table 2.2: Typical cooling processes in the FDM sector

<table>
<thead>
<tr>
<th>Cooling of products</th>
<th>Brief description / application examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast cooling, batch cooling</td>
<td>Batch cooling in dedicated chilling rooms or cabinets. Cooling of unpacked or packed products.</td>
</tr>
<tr>
<td>Spiral cooling</td>
<td>Continuous cooling in dedicated equipment. Air speed of approximately 6 m/s. Cooling of unpacked or packed products.</td>
</tr>
<tr>
<td>Impingement cooling</td>
<td>Continuous cooling in dedicated equipment. Air speed of approximately 20–30 m/s. Cooling primarily of unpacked products.</td>
</tr>
<tr>
<td>Water spray</td>
<td>Spraying of water directly at the product. Cooling of unpacked or packed products.</td>
</tr>
<tr>
<td>Immersion in water (spin chiller)</td>
<td>Products immersed in chilled water, e.g. spin chiller. Cooling of unpacked or packed products.</td>
</tr>
<tr>
<td>Brine cooling (superchill)</td>
<td>Products immersed in brine superchill to −3 °C. Cooling of packed products.</td>
</tr>
<tr>
<td>Ice, flake ice</td>
<td>Addition of flake ice to the product during the process to reach the optimal product temperature.</td>
</tr>
<tr>
<td>Evaporative cooling</td>
<td>Alternating addition of water spray and air to exploit both the media temperature and the heat used for vaporisation of the water. Cooling of unpacked and packed products.</td>
</tr>
<tr>
<td>Liquid CO$_2$</td>
<td>Continuous or batch process. Shell freezing before slicing of products. Freezing of unpacked products.</td>
</tr>
<tr>
<td>CO$_2$ pellets</td>
<td>Addition of CO$_2$ pellets to the product. Post-chilling of products.</td>
</tr>
</tbody>
</table>

Source: [220, Clitravi-Avec 2016]

Table 2.3 shows the typical freezing processes applied in the FDM sector. For more information about freezing see Section 19.2.6.1.

Table 2.3: Typical freezing processes in the FDM sector

<table>
<thead>
<tr>
<th>Freezing of products</th>
<th>Brief description / application examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast freezing</td>
<td>Batch freezing in cabinets. Packed products.</td>
</tr>
<tr>
<td>Spiral freezing</td>
<td>Continuous freezing system. Air speed of approximately 6 m/s. Freezing of unpacked or packed products.</td>
</tr>
<tr>
<td>Impingement freezing</td>
<td>Continuous freezing system. Air speed at approximately 20–30 m/s. Freezing of unpacked products.</td>
</tr>
<tr>
<td>Plate freezing</td>
<td>Batch freezing. Direct contact between product and evaporator. Freezing of packed or unpacked products.</td>
</tr>
<tr>
<td>Liquid CO$_2$</td>
<td>Continuous or batch process. Shell freezing before slicing of products. Freezing of unpacked products.</td>
</tr>
</tbody>
</table>

Source: [220, Clitravi-Avec 2016]
2.1.2.2.1 Heat recovery from cooling systems

Heat can be recovered from cooling equipment and compressors. This involves the use of heat exchangers and storage tanks for warm water. Depending on the cooling equipment, 50–60 °C temperatures can be achieved.

2.1.2.2.2 Using high efficiency motors for driving fans

The motors for driving the fans are set up in the freezing tunnel. The electrical energy supplied to the motors must, therefore, be dissipated by the freezer unit. By opting for high efficiency motors for driving the fans, not only is there a direct saving in electricity, e.g. lower consumption by the fans, but also an indirect saving, e.g. through the lower cooling load on the refrigeration unit.

2.1.2.2.3 Dynamic cooling condensation control

Dynamic cooling condensation control is a programmable logic control-based copyright system for condensation pressure optimisation. By monitoring the external temperature, atmospheric pressure and moisture, the system determines the best \( \text{NH}_3 \) (or other cooling gas used) condensation pressure value. Consequently, the \( \text{NH}_3 \) plant works between 8.5 bar and 11 bar, rather than 11 bar all the time, saving compressor energy. By applying this process, the electric energy usage can be reduced by as much as 50 % [193, TWG 2015].

2.1.2.3 Techniques related to compressed air systems

2.1.2.3.1 Optimise pressure settings

The pressure at the compressor can be set at the maximum required and then regulated at each individual application to minimise the energy required to produce compressed air and reduce leakage. For applications which require higher pressures or have longer operating hours than the majority of the applications which use compressed air, it may be more energy- and cost-effective to install a dedicated compressor [39, Environment Agency of England and Wales 2001]. Moreover, consumption losses during production downtime can be avoided by sectorisation of pressure (multiple changes to the pressure distribution). Several additional techniques can be implemented to optimise compressed air generation and use [193, TWG 2015], [203, FEFAC 2015]:

- replace pneumatic installations with electric ones;
- use a variable speed compressor;
- adjust the pressure level (more pressure is provided with a separate compressor);
- adapt the compressor to the need (flow/pressure);

2.1.2.3.2 Optimise the air inlet temperature

Compressors operate more efficiently using cool air. This is generally achieved by ensuring the air is taken from outside the building. This can be checked by measuring the dryer inlet temperature, which should not exceed 35 °C with the compressors on full load. The temperature of the dryer room should be within 5 °C of the outside ambient temperature. If the room temperature is too high, this lowers the compressor’s performance [39, Environment Agency of England and Wales 2001].
2.1.2.4 Techniques related to steam systems

2.1.2.4.1 Minimising the blowdown of a boiler

The blowdown of a boiler is used to limit the accumulation of salts (e.g. chlorides, alkalis and silicic acid) and is, therefore, necessary to keep these parameters within prescribed limits. It is also used to remove the sludge deposits (e.g. calcium phosphates) and corrosion products (e.g. ferric oxides) from the boiler and to keep the water clear and colourless. Waste water at high pressure and temperature is always discharged, either for a set time or continuously. It is, therefore, preferable to restrict the blowdown as far as possible.

The total dissolved solids content of the boiler water is best kept as close as possible to the maximum authorised value. This can be done via an automated system consisting of a conductance probe in the boiler water, a blowdown regulator or a blowdown regulating valve. The conductance is continually measured. If the measured conductance exceeds the maximum value, then the regulating valve is opened more.

Pretreatment by reverse osmosis can allow lower boiler blowdown rates and hence lower energy losses. Energy needed for reverse osmosis is only electrical, i.e. to put water under pressure so that it can be pushed through the osmosis membrane (< 0.001 µm). A reduction of pretreatment of the boiler feed water with chemicals is also achieved [193, TWG 2015].

2.1.2.4.2 Avoid losses of flash steam from condensate return

When condensate is discharged from steam traps and flows along the return pipework, some flash steam is formed. Often flash steam is vented to the air and the energy it contains is lost. It may be possible to capture and use the flash steam, e.g. in the boiler.

Leak detection in steam and compressed air systems can be performed with the use of an ultrasound-measuring microphone [193, TWG 2015].

2.1.3 Water consumption

A large part of the FDM sector cannot operate without a substantial amount of good quality water. In the FDM sector, hygiene and food safety standards have to be maintained. A systematic approach to control the use of water and reduce water consumption and its contamination is generally effective.

Each application of water requires its own specific quality. In the FDM sector, the quality requirements depend on whether or not contact between water and the food product is possible. Water that comes into contact with the product must, with a few exceptions, at least be of drinking water standard. Both chemical and microbiological quality aspects are important. It is advisable to conduct a regular check of the microbiological parameters of the water at the most critical places, i.e. at the point of use. This is normally incorporated in the hazard analysis critical control point system (HACCP). The quality standards for drinking water are laid down in the Council Directive 98/83/EC [36, EC 1998].

The treatment required to produce safe water quality depends very much on the water source and its analysis. A minimum treatment concept involves water filtering, disinfecting and storage, but depending on the water requirements, may also include de-ironing, desilication, or active carbon filtering. Treated drinking water is pumped from the storage tank and distributed through the installation pipework network to the users.
Additional treatment, such as softening, dealkalising, demineralising or chlorinating the water, is needed for usage in specific food processes or utilities. Ion exchangers or membrane filtration processes are the most common techniques used for this purpose.

The following sources of water are used in the FDM sector: tap water, groundwater, surface water, rainwater, and water originating from the raw material and reused water.

Tap water is distributed by a water main. The supplier is usually responsible for the quality of the water delivered and for checking the quality of the water regularly.

The composition of groundwater is generally reasonably constant and microbiological counts are mostly low, especially in deep bore holes. In most cases, little treatment is necessary before groundwater can be used as process water or cooling water. In most countries, a licence is needed for the extraction of groundwater. The quality of the groundwater is monitored by the user. Sometimes the authorities require notification of the results of regular water quality analyses.

Surface water cannot be used for process water unless it is treated first. When available, it is often used for cooling water. A licence may be required for such use.

Depending on the region, rainwater may be a source of water. This requires a storage basin. After appropriate treatment and control, rainwater may be used for process water, in open cooling systems.

Some raw materials that are processed in the FDM sector contain a considerable percentage of water as a liquid water phase, which can be separated from the solid constituents for separate utilisation. This separation can be carried out, e.g. by pressing, centrifuging, evaporation or by using membrane techniques. Some examples are fruit juice, potato juice, sugar beet juice and milk. Such liquids can mostly be utilised if they are not used as a primary product. Sometimes they can be used without further treatment, e.g. condensate of the first stages of evaporators for boiler feed-water, but otherwise appropriate treatment is necessary.

Reused water may be come from, e.g. chilled water, pump seal water, recovered condensate, or final cleaning rinses.

2.1.3.1 Types of water consumption

Water is used in the FDM sector for:

- food processing, where the water either comes into contact with, or is added to, the product;
- equipment and installation cleaning;
- washing of raw materials;
- water which does not come into contact with the product, e.g. boilers, cooling circuits, refrigeration, chillers, air conditioning and heating;
- firefighting.

In general, the water used in the FDM sector may be used as process water, cooling water or boiler feed-water.

2.1.3.1.1 Process water

In the FDM sector, process water is used for direct preparation of products or other items which come into direct contact with the products, cleaning and disinfection, regeneration of water treatment equipment and for various technical purposes. Water that comes into contact with the product must, with a few exceptions, at least be of drinking water standard. For the production
of soft drinks and beer, often special quality characteristics are required that sometimes exceed those of drinking water quality.

Examples of uses of process water that is used for direct preparation of products or other items which come into direct contact with the products include:

- starting up of continuous process lines such as in pasteurisers and evaporators;
- flushing out the product from the process equipment at the end of a production run;
- washing raw materials and products;
- wet transport, e.g. in a flume;
- dissolving ingredients;
- production of drinks;
- cooking in water bath or shower ovens.

Water of varying quality can be used for cleaning and disinfection purposes. The main steps involved in these processes are pre-rinsing with water, cleaning with cleaning agents, post-rinsing with water, and disinfection. Water is also needed for cleaning the outside of equipment, walls and floors. In this case, contact with the food product is rather unlikely, so drinking water quality is not required. However, often drinking water quality is used, to avoid any hazard.

Large quantities of process water for the regeneration of water treatment equipment are required for the removal of iron and/or manganese and for product softening and demineralisation. This water needs to be of good quality, to prevent bacteriological contamination of the filter material and the need for the water to be treated afterwards. Furthermore, it is preferable if water has a low iron content and low hardness, to prevent rapid fouling and scaling of equipment.

Finally, process water is also used for other technical purposes, e.g. cooling water is used for pump seals, seal water for vacuum pumps and water in closed circuits for hot water systems and heat-exchange systems. Water is also used for air conditioning humidity control in storage areas and for processing raw materials. If there is a risk that in the event of equipment failure, contact with the food product is possible, the water needs to be of drinking water quality.

### 2.1.3.1.2 Cooling water

Cooling water is the water used for the removal of heat from process streams and products. In the FDM sector, the cooling systems commonly applied are once-through cooling systems with no recirculation of cooling water, closed circulation cooling systems, open circulation cooling systems or cooling towers and cooling by direct contact with cooling water.

Cooling water is used in direct contact with food, e.g. after blanching of fruit and vegetables and to cool, e.g. cans and glass bottles after sterilisation.

In open cooling systems, i.e. cooling towers, not only does evaporation of the water occur but also a small part of the water is sprayed. Furthermore, in a cooling tower the conditions for growth of *Legionella* bacteria are favourable. This means that the spray of cooling towers, if contaminated, may be a possible source of legionnaires’ disease. To prevent the occurrence of legionnaires’ disease, companies which operate these systems must comply with regulations requiring them to manage, maintain and treat them properly [101, Health and Safety Executive 2004]. Amongst other things, this means that the water must be treated and the system cleaned regularly. Air quality from cooling systems comes within the scope of the BREF for Industrial Cooling Systems [162, COM 2001].
2.1.3.1.3 Boiler feed-water

In the FDM sector, steam is generated using boilers with working pressures of up to about 30 bar. For power generation with steam turbines, higher steam pressures are needed. Steam is used for the sterilisation of tanks and pipelines. Another application is UHT treatment with direct steam injection. Sometimes steam injection is used for heating the product or for adjusting the water content of the raw material. In all these cases, more or less direct contact between steam and the food product is possible so drinking water quality is required.

Requirements generally depend on the working pressure and temperature of the boiler and the conductivity [38, CEOC 1984]. The higher the pressure and temperature, the higher the quality requirements are. This makes extensive water treatment necessary, e.g., removal of iron, softening and chemical conditioning. The quality of the boiler water is controlled by the quality of the boiler feed-water. The frequency of boiler water blowdown also controls the quality.

It is important that boiler feed-water does not cause scaling in the boiler or corrosion of the steam system. This means that boiler feed-water has to have a very low hardness and be deaerated. Returned condensate can also be used as boiler feed-water supplemented by suitably treated make-up water.

Waste water from water regeneration and residues from other processes are discharged to water. Minimisation of water consumption by process optimisation and water recycling can be applied. Mineral sludges and spent resins from water treatment processes need to be disposed of.

2.1.3.1.4 Water recycling and reuse

In line with the EU Action Plan for the Circular Economy [237, COM 2015], recycling and reuse of process and waste water aims to improve the resource efficiency of the FDM sector. The potential role of treated waste water as an alternative source of water supply is now well acknowledged and embedded within European and national strategies.

The distinction between the concepts of recycling and reuse is made in the Waste Directive [59, WFD 98/EC 2008]. Reuse means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived. Recycling means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes.

Depending on the local situation, there can be several types of water streams in a FDM installation. It can be divided into many sources according to its quality, e.g.:

- potable water of drinking quality;
- recycled water from the process (e.g. from filtration of milk, from starch slurry);
- uncontaminated water and surface water that is not of drinking water quality;
- water recovered from treatment of waste water and from anaerobic digestion of waste (e.g. for landspreading).

When it is decided which water sources can be reused and or recycled in the installation, several issues might require consideration.

- Legal requirements related to food safety and hygiene.
- Customer requirements related to food safety, cleaning, etc.
- Product-related issues, e.g. distinguish between products that the consumer will use without further preparation and products that the consumer will prepare before eating.
- Risks related to water consumption. The installation might consider the possibility of monitoring the hygiene quality of the water to assess the risk of contamination of products. If contamination of products may occur, the installation might weigh up the benefits and disadvantages of reusing a certain water source.
The consequences of reusing a specific water source, such as energy and chemical consumption for treatment of the water before reuse/recycling;

Possible water shortage.

When looking at water consumption, it is not only the volume that should be taken into consideration. As most water usage in the food industry will require some treatment, cooling and heating of the water before use, the water consumption should be reduced as much as possible. This will also reduce energy use, e.g. for pumping and treatment. Moreover, both water shortage and excess of water at local level should be considered, where relevant. Different requirements on food safety and hygiene for products also have an influence on the water consumption. Additionally, the water quality itself can have an influence on how much water is needed for a specific use, e.g. for CIP.

All the aforementioned issues must be taken into consideration when evaluating the water consumption and considering water reuse and recycling in a specific installation [236, EDA 2016].

A systematic analysis, taking into account all water uses and the quality required for each use and reuse can be undertaken. An example of a table for recording such opportunities is shown in Table:

Table: Examples of water reuse

<table>
<thead>
<tr>
<th>EXAMPLES</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water reuse applications</td>
<td>Processing techniques which do not require full WWT (specify any treatment which may be necessary first, e.g. screening or disinfection)</td>
<td>Cleaning (possibly differentiate between different cleaning stages)</td>
<td>All unit operations which require drinking water quality water.</td>
<td></td>
</tr>
<tr>
<td>Water use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indirect cooling (no contact with the product)</td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Reported opportunities for the reuse of water include:

- use of water that has not been contaminated in the process where water of non-drinking water quality is required;
- in dairies, cooling water, condensates generated in evaporation and drying operations, permeates generated in membrane separation processes and cleaning water can be reused;
- in fruit and vegetables installations, water is reused, either directly in a unit operation or indirectly as a source, e.g. either heat or cold;
- sequential re-use, where water can be used for two or more processes or operations before disposal, e.g. using gluten process water in protein separation steps for germ and fibre...
washing, steeping processes in maize starch processing, or using evaporator condensate for sugar extraction from sugar beets;

- recycling within a unit process or group of processes without treatment;
- recycling with treatment;
- condensates produced during evaporation may be reused in the process depending on their quality, e.g. content of organic and/or inorganic matter and TSS. Steam condensate may be used as boiler feed water. This leads to recovery of a considerable amount of heat, as well as savings in the use of chemicals for the treatment of boiler feed water. If condensate is reused this can be optimised by maximising the condensate return and avoiding losses of flash steam from condensate return;
- water which has not been in contact with the product, such as cooling water from refrigeration systems, some condensate and RO water which has been contaminated slightly can be used for cleaning less sensitive areas, e.g. yard washing, or for the preparation of cleaning solutions. It is reported that the reuse of cooling water for other purposes may not be possible if it contains biocides.

2.1.3.2 Cleaning and disinfection

Processing equipment and production installations are cleaned and disinfected periodically to comply with legal hygiene requirements. The frequency can vary considerably depending on the products and the processes. The aim of cleaning and disinfection is to remove product remnants, other contaminants and microorganisms.

Before starting the cleaning process, equipment is emptied as far as possible. Cleaning and disinfection can be carried out in various ways. Traditionally, it has been carried out manually. Cleaning in place (CIP), washing in place and, cleaning out of place are all expressions used for different ways of cleaning. Cleaning agents are delivered in a variety of ways, e.g. in bags, e.g. powdered cleaning agents, drums or bulk tankers. Many cleaning agents are potentially hazardous to the health and safety of the operator and systems can be provided to minimise the risk during the storage, handling, use and disposal.

CIP is used especially for closed process equipment and tanks, whether stationary or small mobile, processing units. The cleaning solution is pumped through the equipment and distributed by sprayers in vessels, tanks and reactors. The cleaning programme is mostly run automatically, and applies the following steps; pre-rinse with water, circulation with a cleaning solution, intermediate rinse, disinfection, and final rinse with water. In automatic CIP systems, the final rinse-water is often reused for pre-rinsing or may be recycled/reused in the process. In CIP, high temperatures of up to 90 °C are used, together with strong cleaning agents. CIP systems used for open systems like freezers are almost entirely automatic, except for some dry clean-up and opening of hatches. Temperatures for medium pressure systems are normally below 50 °C and the pressure is 10 to 15 bar.

Cleaning out of place is used when several of the machine’s components need to be dismantled, usually before the manual or automated cleaning of the machine is started. The dismantled components are cleaned separately outside the machine. Forming machines are one example of this. There are augers, pistons, valves, forming plates and seals which all have to be dismantled before cleaning the machine. High pressure jet cleaning, using gels and foams can be carried out manually or automatically. The appropriate cleaning method is an appropriate combination of cleaning factors such as water, temperature of the cleaning solution, cleaning agents, i.e. chemicals, and mechanical forces. Only mild conditions, with regard to temperature and cleaning agents, can be used for manual cleaning.

High pressure jet cleaning and foam cleaning are generally applied for open equipment, walls and floors. Water is sprayed at the surface to be cleaned usually at a pressure of about 40 bar to 65 bar. Cleaning agents are injected into the water, at moderate temperatures of up to 60 °C. An important part of the cleaning action takes place due to mechanical forces.
Chapter 2

In foam cleaning, a foaming cleaning solution is sprayed onto the surface to be cleaned. The foam adheres to the surface. It stays on the surface for about 10 to 20 minutes and is then rinsed away with water. Foaming can be carried out both manually and automatically. Gel cleaning is similar to foam cleaning.

Product residues may be recovered during cleaning.

2.1.3.2.1 Selection of cleaning agents

In some cases, cleaning is undertaken using hot water only, however, this depends on the nature of the product and the process, nevertheless, cleaning agents are normally used in the FDM sector. Cleaning agents are typically alkalis, i.e. sodium and potassium hydroxide, meta-silicate and sodium carbonate; acids, i.e. nitric acid, phosphoric acid, citric acid and gluconic acid; composed cleaning agents containing chelating agents, i.e. EDTA, NTA, phosphates, polyphosphates; and phosphonates, surface active agents, and/or enzymes. Disinfectants, such as hypochlorites, iodophors, hydrogen peroxide, peracetic acid and quaternary ammonium compounds, can be used.

The selection of the cleaning agents is subject to several criteria, including the installation design, cleaning techniques available, type of soiling and nature of the production processes. Cleaning agents must be fit for their use but other aspects are also important, e.g. gluconic acid is less corrosive than the other acids. Furthermore, cleaning in the FDM sector does not just mean the removal of impurities; disinfection is equally important.

The selection and use of cleaning and disinfection agents must ensure effective hygiene control but with due consideration of environmental implications [45, FoodDrinkEurope 2002]. When the use of cleaning agents is essential, it is necessary to first check that they can achieve an adequate level of hygiene and then to assess their potential environmental impact. The design of equipment for food processing also has a significant effect on the level of food security; a relevant consortium of equipment manufacturers, food industries, research institutes as well as public health authorities is the European Hygienic Engineering & Design Group.

Typical cleaning agents used in the FDM sector are:

- alkalis, e.g. sodium and potassium hydroxide, meta-silicate, sodium carbonate;
- acids, e.g. nitric acid, phosphoric acid, citric acid, gluconic acid;
- pre-prepared cleaning agents containing chelating agents such as EDTA, NTA, phosphates, polyphosphates, phosphonates or surface-active agents;
- oxidising and non-oxidising biocides.

The detergents are the most important type of cleaning agent and are usually mixed with water before use. They can be divided into three broad groups, depending on the kind of solution they form: acidic, neutral or alkaline [205, Nordic Council of Ministers 2015].

Acid detergents are generally based on phosphoric or sulphuric acid, and their use is limited. They are extremely effective in removing salts precipitated from water in hard water areas, and in cleaning aluminium where the acids readily remove the white scale that forms on the surface of the metal.

Neutral detergents comprise a wide range of materials that are mainly suitable for light cleaning. They are generally similar to household detergents and their good wetting ability makes them ideal for the dispersal of grease and oil.

Alkaline detergents can vary in strength from those that are only a little stronger than the neutral types to ones that are strongly alkaline, consisting almost entirely of caustic soda, and requiring extreme care in use.
2.1.3.2.1.1 Selection of disinfectants and sterilants

The chemicals used for disinfection and sterilisation of equipment and installations operate on the principle that they affect the cell structure within bacteria and prevent their replication. Disinfectants used in the FDM sector are within the scope of the Directive 98/8/EC [226, EC, 1998]. Assessment of the environmental and human health effects of active substances in disinfectants is due to start in 2007 [199, Finland, 2003].

The most commonly used sanitiser in food processing is chlorine, in its various forms. Commonly used chlorine compounds include liquid chlorine, hypochlorite, inorganic chloramines, and organic chloramines. Chlorine is active at low temperature, is relatively cheap, and leaves minimal residue or film on surfaces. The major disadvantage of chlorine compounds is the corrosive effect it has on many metal surfaces (especially at higher temperatures) [205, Nordic Council of Ministers 2015].

Several other types of treatment can also be applied. These involve the use of oxidising biocides, non-oxidising biocides, UV radiation and heat. Information about the techniques which use oxidising biocides, UV radiation and steam is given in Sections 0, 0 and 2.3.6.3.8.

Non-oxidising biocides involve the use of, e.g. quaternary ammonium salts, formaldehyde and glutaraldehyde. These are generally applied using a technique called fogging where the substance is sprayed into the area to be sterilised as a mist and allowed to coat the exposed surfaces. This is carried out between process shifts, so the fog has dispersed before the operator enters the work area. Exposure can cause respiratory problems, so occupational health needs to be considered when selecting and using disinfectants and sterilants.

Use of chelating agents

In the FDM sector, chelating agents are primarily used in the dairy sector. Acidic, alkaline and surface-active cleansing agents, as well as prepared industrial cleaning agents, generally contain some chelating agents. They are able to dissolve and inactivate metal ions by complex formation. They are used to clear scale deposits and to prevent calcium and magnesium scaling, thus preventing sedimentation and incrustation in pipes, devices or containers.

One of the main applications of alkaline cleansing agents is in the dairy sector. They have various uses, e.g. in CIP; bottle and crate cleaning; foam and/or gel cleaning; membrane cleaning; and manual cleaning. The chemicals used in CIP are normally an alkaline solution, based on caustic, to detach and remove fat and protein layers, and an acid solution, e.g. based on HNO\textsubscript{3}, to detach and remove mineral layers.

In many cases in CIP, the acid step is not required and cleaning is undertaken using only the alkali step, i.e. single-phase cleaning. In these cases, if calcifications and deposits are present, it is reported that they can only be removed with the help of a chelating agent such as EDTA. The EDTA dissolves the calcium out of the precipitate and breaks up the structure of the deposits. Then the remaining organic substances, such as fat and protein layers can be degraded by the alkaline solution, which is usually based on caustic.

The most commonly used chelating agents are:

- ethylenediaminetetraacetic acid (EDTA)
- nitrilotriacetate (NTA)
- methylglycin diacetate (MGDA)
- phosphates (e.g. sodium triphosphate)
- phosphonates (e.g. DTPMP, ATMP)
- polyphosphates
- iminodisuccinat (IDS)
- enzymatic detergents.
2.1.3.2.1.2 EDTA

EDTA is the chelating agent used in the largest quantities. In 1999 in Western Europe, about \( \frac{1}{3} \) of the total use, 10685 tonnes, was used in industrial detergents. In 1997 it was reported that German dairies emitted 36 t/yr EDTA to water, i.e. 1\% of the country’s total.

EDTA is mainly used due to its property as a chelating agent for calcium. In the dairy sector, the calcium content in milk is related to its protein content as calcium phosphocaseinate. EDTA may be used during CIP in dairies, as follows:

- to remove the calcium fouling, (also known as milkstone) which occurs on the stainless steel surfaces of milk processing machinery at temperatures from 70–80 °C. EDTA is used particularly on UHT equipment; membranes, e.g. UF and RO and for the preliminary cleaning of evaporators and spray dryers. Most of this fouling is made up of stable denatured proteins. These are destabilised using EDTA, which then enables the surface to be cleaned. Scale also builds up in other applications and it is reported that skilled operators can tell when a periodic clean is required to prevent this. The deposits are composed of proteins, minerals and fat
- as a hardening stabiliser, to avoid precipitation of calcium when diluting concentrated alkaline detergents with water. High temperature alkaline cleaning may leave a carbonate layer that could cause biofilm build up. In multiple-phase cleaning, alkaline cleaning is followed, after intermediate rinsing, by nitric acid cleaning. The acid cleaning leaves a shiny surface in contact with the product. Single-phase cleaning, using EDTA to capture the calcium ions contained in water, reduces this effect and removes the acid step
- to bind calcium, magnesium and heavy metals to prevent sedimentation and incrustation, e.g. in the pipes and containers to be cleaned
- the bactericidal activity of cleaning and disinfection agents, especially towards gram-negative bacteria, increases when EDTA is incorporated, because of its ability to destroy the outer cell wall of these often resistant species
- to improve the reuse of chemicals and to reduce water and energy consumption related to single-phase cleaning compared with two-phase cleaning with caustic and nitric acid.

There are no EU-15 risk assessments available for the other chelating agents, so only the risks associated with EDTA are known in detail. EDTA forms very stable and water-soluble complexes which are not normally degraded in biological WWTPs, so the heavy metals remain in the waste water and not in the sludge, and they are discharged to surface water bodies. The EDTA can then also remobilise heavy metals from the sediment of rivers. Furthermore, nitrogen contained in EDTA may contribute to eutrophication of water. Many other chelating agents also contain either nitrogen or phosphorus.

Biological degradation of EDTA is slow and only proceeds under certain conditions, such as [67, Boehm et al. 2002], [68, Knepper et al. 2001]:

- having long hydraulic retention time and sludge age;
- maintaining slightly alkaline conditions;
- having a comparatively high EDTA concentration;
- EDTA should not be present as a heavy metal complex.

In addition, according to the draft risk assessment of 7 February 2003 under Regulation 793/93/EEC [111, COM 1993], EDTA causes a risk to the aquatic environment when used as a chelating agent in some industries. The predicted no-effect concentration in surface water bodies is 2.2 mg EDTA/l.

**Not using EDTA**

It is reported that EDTA is not required for cleaning equipment and vessels which have contained raw milk, e.g. milk delivery tankers, during reception and storage of equipment.
and/or filling of fluid milk, where it is only important to remove fat films, or where separate cleaning stations are available. It is also not required for the cleaning of PET and glass bottles.

By optimising the milk processing time and using good quality raw milk, in which proteins have a higher heat stability, the formation of milkstone can be reduced (see Section 5.4.1.1).

Multiple-phase cleaning, i.e. using both acids and alkalis, exposes the protein deposit to an acid environment before the alkaline cleaning of heating equipment, so that the alkaline cleaning is intensified. This is then followed by rinsing and further low concentration nitric acid cleaning. A changeover from single-phase cleaning with EDTA to two-phase cleaning with NTA as a substitute is possible at least for the lower temperature range of pasteurisers. The use of NTA is favoured in at least one MS and is banned in another. Furthermore, the degree of risk associated with the use of NTA or other chelating agents has not been investigated to the same extent as those of EDTA.

The replacement of ready-for-use cleaning agents by pure chemicals can possibly be efficient, but requires an optimal cleaning scheme and a precise design of flow dynamics, otherwise a loss of cleaning efficiency as well as substantial problems of hygiene are likely to occur. In addition, chelating agents are also necessary as solvents when pure chemicals are used. For this reason, a ready-for-use cleaning agent which is adjusted to special cleaning tasks and in which the combination of the individual components takes effect at a low concentration, can lead to much better cleaning results.[134, German Dairy Association 1997].

The FDM sector has not identified a way of totally eliminating the use of EDTA, although there may be scope for reducing the operations it is used for and/or the frequency with which it is used. An example of a strategy to minimise the use of EDTA is described in Section 2.1.3.2.2

**Sinner’s circle**

Sinner’s circle is a model used to describe factors that influence the efficiency of a cleaning procedure. Sinner’s circle describes the four main factors which influence cleaning efficiency. These four factors are cleaning time, temperature used, mechanics of cleaning and chemistry used. Ideally, these factors should influence the cleaning efficiency in equal parts, as is shown in Figure 2.2. But in fact, in most cases, Sinner’s circle is composed differently because each factor’s contribution to the cleaning efficiency varies.[210, EDA 2016].

![Figure 2.2: Ideal Sinner’s circle](source: [210, EDA 2016])
For example, mechanical forces exerting pressure on facility components may have a small influence on the cleaning efficiency of CIP cleaning of dairy facilities. This may be the case for example in pipes through which the production cycle's liquid components flow. For this reason, those mechanical forces do not contribute significantly to the cleaning process and the influence of added chemistry is much more important for cleaning efficiency. The cleaning temperature and time afforded for cleaning may contribute in equal parts.

How Sinner’s circle is composed for the purpose of proving the cleaning efficiency is to be examined for each individual cleaning situation and is up to the company. Sinner’s circle therefore provides a mathematical tool for calculating the proportion and intensity of each factor influencing cleaning efficiency.

2.1.4 Management of by-products, residues and waste

European estimations reveal that 70 % of EU food waste arises in the household, food service and retail sectors, with production and processing sectors contributing to the remaining 30 %. The EU Platform on Food Losses and Food Waste aims to support all actors in: defining measures needed to prevent food waste; sharing best practice; and evaluating progress made over time [263, COM 2016].

When higher loaded waste water streams (high COD) are treated in an anaerobic waste water treatment unit, this results in a higher amount of biogas, but also results in a higher concentration of recalcitrant COD. This COD will not be easily removed in the subsequent aerobic waste water treatment and will end up as emissions to water. Furthermore, in the case of intense reuse of water (e.g. reverse osmosis), the concentration of recalcitrant COD will increase. The reason why companies that do not have enough organic solid waste cannot install a digester is that a digester needs a constant feed. Small digesters do not deliver enough biogas to be profitable. Therefore it is recommended to reduce the load of solid materials to the anaerobic waste water treatment plant, and to send all collected solids to a digester. This can be achieved by:

- process-integrated techniques (e.g. preventing pulp, peels, etc. from ending up in the waste water);
- installing a sieve of at least 1.5 mm at the entrance of the anaerobic waste water treatment; problems, such as blocking of the sieve, occur when smaller sieves are used;
- installing a sedimentation unit at the entrance of the anaerobic waste water treatment [244, Belgium 2015].

In the anaerobic biological processes (anaerobic digestion), anaerobic bacteria convert part of the organic matter in the waste water into biogas. Temperature and pH conditions should be maintained within the optimum range. The technique could be generally applied at facilities where effluents with a high BOD/COD content are produced.

Generally, the biogas generated is a valuable source of renewable energy. Anaerobic digestion can be considered a sustainable method to manage organic waste. Furthermore, the overall energy requirement to treat waste water anaerobically is lower than that of aerobic treatment.

2.1.4.1 Packaging

The objective of packing is to use any products made of any materials of any nature for the containment, protection, handling, delivery and presentation of goods. Packing may be applied to raw materials and to processed goods. Filling is the process of putting the product in the package in a proper way.
The majority of food products are packaged before they enter the distribution chain. In some cases packing is an integral part of the production process, which means that the packaged product is further processed. An example of this is the canning and bottling of foods and subsequent heat conservation.


**Article 3**
Definitions for the purposes of this Directive:

1. “packaging” shall mean all products made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer. “Non returnable” items used for the same purposes shall also be considered to constitute packaging.

“Packaging” consists only of:

(a) sales packaging or primary packaging, i.e. packaging conceived so as to constitute a sales unit to the final user or consumer at the point of purchase;
(b) grouped packaging or secondary packaging, i.e. packaging conceived so as to constitute at the point of purchase a grouping of a certain number of sales units whether the latter is sold as such to the final user or consumer or whether it serves only as a means to replenish the shelves at the point of sale; it can be removed from the product without affecting its characteristics;
(c) transport packaging or tertiary packaging, i.e. packaging conceived so as to facilitate handling and transport of a number of sales units or grouped packagings in order to prevent physical handling and transport damage. Transport packaging does not include road, rail, ship and air containers;

Most FDM products involve primary, secondary and tertiary packaging processes throughout the manufacture and distribution chain.

The packaging materials used in the FDM sector are textiles, wood, metal, glass, rigid and semi-rigid plastic, flexible plastic films, paper and board. Regulation (EC) No 1935/2004 provides a harmonised legal EU framework. It sets out the general principles of safety and inertness for all food contact materials.

Textiles have poor barrier properties. Textile bags are still used to transport bulk products including grain, flour, sugar and salt. Wooden shipping containers have traditionally been used for a range of foods, such as fruits, vegetables, tea, wines, spirits and beer. Wooden containers were replaced a long time ago in some sectors, and are now increasingly being replaced everywhere by plastic drums and crates.

Hermetically sealed, metal cans have high barrier properties and can withstand high and low temperatures. The materials used for metal cans are steel (tinplate or tin-free), and aluminium, but they may also be coated with tin or lacquers to prevent interactions with the foods within the can. Metal cans are widely used for soft drinks and beer. They are also used for canning sterilised foods, e.g. fruit, vegetables, condensed milk and meat products. Metal cans are recyclable. Aluminium foil is also widely used to pack several types of food.

Glass has high barrier properties, is inert, and is suitable for heat and microwave processing. However, two disadvantages of glass are the weight and the risk of fracturing. Glass bottles and jars are widely used for milk, beer, wines and spirits, preserves, pastes and purées and also for some foods and instant drinks. Glass bottles and jars are reusable and recyclable.

Rigid and semi-rigid plastic containers include bottles, jars, cups, trays and tubs made from single or co extruded polymers. They are low weight, tough and unbreakable, easy to seal, have reasonably high barrier properties and great chemical resistance. Several techniques are available for the production of these containers, such as thermoforming, blow moulding,
injection blow moulding, extrusion blow moulding and stretch blow moulding. Typical materials used are PVC (polyvinylchloride), PS (polystyrene), PP (polypropylene), XPP (expanded polypropylene, for thermoforming), HDPE (high density polyethylene), PET (polyethylene terephthalate), and polycarbonate. The containers are often made on site. Some of the containers are reusable, e.g. polycarbonate bottles for milk. Rigid and semi-rigid plastic containers are typically used for milk, soft drinks, dairy products, margarine, dried foods and ice cream.

Flexible films are formed from non-fibrous plastic polymers, which are normally less than 0.25 mm thick. Typical materials used for flexible films are PE (polyethylene), LDPE (low density polyethylene), PP, PET, HDPE, PS, and PVC. In general, flexible films are relatively cheap; they can be produced with a range of barrier properties; they are heat sealable; and little weight; can be laminated to paper, aluminium and other plastics; and are easy to handle. Flexible films are used for packaging a large range of both wet and dry food products.

Finally, paper and board can be produced in many grades and many different forms. It is recyclable and biodegradable and can easily be combined with other materials. Laminated cardboard packs are used on a large scale for milk and fruit juices. Paper and board are also extensively used for food packaging and often as secondary packaging.

An important step in the packing process is the sealing of the container or packs. The maintenance of the food quality depends largely on adequate sealing of the packs. Seals are usually the weakest part of the packs and also suffer most frequent faults during production, e.g. when food is trapped in a seal, incorrect sealing temperatures or incorrect can seamer settings. Cans are seamed and bottles and jar glass are sealed with metallic caps, plastic caps or cork. Form-fill-sealing is now a well-established technique. In this process, the container is formed and partly sealed, filled and then finally closed by full sealing.

The requirements for filling are accuracy, to ensure that the required amount of product is packed and hygiene, to ensuring that the product is hygienically filled at the correct temperature to guarantee the highest possible quality and optimum shelf-life. The selection of an appropriate filling technique depends on the nature of the product and the production rate required. The filling can be by level, volume or weight.

Level filling is most frequently used in the drink industry, especially for beer. Volumetric filling is applied to liquids, pastes and powders. The most common is the piston filler. Finally, weight filling is applied to large particulate materials, e.g. confectionery. These are filled into containers using a photoelectric device, to count individual pieces. Also multi-head weighers are being developed which aim to weigh different products simultaneously, prior to filling into the same container.

Containers need to be filled accurately without spillage and without contamination of the seal. The filling of liquid foods like milk and fruit/vegetable juices can be categorised by the temperature of the food at the time of filling, e.g. hot, ambient or fresh cold filling, or as aseptic filling. The temperature ranges involved in the filling process are best illustrated by the hot filling and fresh cold filling processes. Hot filling is undertaken at temperatures of up 95 ºC, to inactivate certain relevant microorganisms, whilst many drink products are formulated with ingredients that do not need to be heat treated to be microbiologically safe and these are, therefore, fresh cold filled at between 0 and 5 ºC. For aseptic packing, pre-sterilised, e.g. by hydrogen peroxide, containers are necessary, and the filling needs to take place in a sterile zone.

Solid waste includes cast-offs due to, e.g. packaging machine faults/inefficiencies during filling, and capping process waste, especially during machine start-ups and shut-downs. Processes such as glass bottle blowing are usually completed off site by suppliers but waste can result from breakages in situ. Bottle blowing of PET may be carried out on site using either PET pellets or supplied pre-forms. This produces waste from off-cuts. Aluminium or steel can cylinders and aluminium can ends are pre-manufactured, off site. Laminated cartons and pouches are formed.
on site. This results in waste from off-cuts. Small amounts of solid waste are produced from inks and from the cleaning of printing equipment. The lubrication of equipment and the transport systems also produce waste. Some packaging is recycled.

2.1.5 Waste water treatment

2.1.5.1 Introduction

Water pollution control can be carried out by reducing the volume and pollutant load strength of the waste water generated, by an appropriate combination of:

• process-integrated techniques such as eliminating or decreasing the concentration of certain pollutants, e.g. dangerous and priority hazardous substances, reducing water consumption, recycling/reducing raw materials and by-products, recycling or reusing water;
• end-of-pipe techniques, i.e. waste water treatment; or a combination of these, the techniques for waste water treatment are listed in Section 2.1.5.3. These techniques include those that may or may not be considered as BAT.

Chapter 2 covers the processing unit operations used in the FDM sector, but does not include the unit operations used in end-of-pipe treatment techniques. In the following sections, general issues about FDM waste water and its treatment are introduced. The most commonly applied treatments are then described individually and this is followed by information about waste water treatment in some of the FDM sectors. Waste water treatment is an end-of-pipe treatment which is required because waste water is produced from various sources. Although the FDM sector is an extremely diverse sector, certain sources of waste water are common to many of its sectors. These sources may include:

• washing of the raw material;
• steeping of raw material;
• water used for transporting or fluming raw material or waste;
• cleaning of installations, process lines, equipment and process areas;
• cleaning of product containers;
• blowdown from steam boilers;
• once-through cooling water or bleed from closed-circuit cooling water systems;
• backwash from regeneration of the WWTP;
• freezer defrost water;
• storm-water run-off.

These include water from vehicles; equipment and installation cleaning and from the washing of raw materials. Waste water also arises from, e.g. evaporation or drying of foods. WWTPs consume energy and produce residues which usually have to be disposed of.

Waste water treatment is applied after process-integrated operations have minimised both the consumption and the contamination of water. Techniques widely applicable in the FDM sector achieve environmental benefits such as waste minimisation and may achieve some or all of the following effects related to a specific waste water stream:

• reduction in the volume;
• reduction in the pollutant load;
• elimination of, or decrease in, the concentration of certain substances;
• increase in the suitability for recycling or reuse.

These techniques are discussed throughout this document. Some are applicable in the whole FDM sector and others are only applicable in individual unit operations or sectors.
Chapter 2

Chapter 2 covers the processing unit operations used in the FDM sector but does not include the unit operations used in end-of-pipe treatment techniques. This section therefore covers the abatement techniques used to treat waste water discharges within the FDM sector. Sections 2.3.6.1 to 2.3.6.5 inclusive, describe techniques generally used in most of the sectors. Sections inclusive, describe their application in some of the individual sectors.

There are many factors which influence the choice of waste water treatment. The main factors are:

- volume and composition of waste water being discharged;
- the local situation in terms of the receiver of the discharge, e.g. MWWTP, river, estuary, lake, sea and any discharge limits applied;
- economics;

2.1.5.2 Discharge of waste water from installations

When choosing a discharge option many factors are considered, including but not necessarily limited to [ 8, Environment Agency of England and Wales 2000 ]:

- whether the waste water is clean or contaminated;
- the availability of suitable space for on-site treatment;
- the proximity and capacity of off-site WWTP(s);
- the proximity and characteristics of potential receiving waters;
- the availability of other off-site treatment or disposal facilities;
- on site treatment costs versus off site treatment/disposal costs;
- the relative effectiveness, e.g. based on reduction of load, of on-site and off-site treatment;
- the assessment of environmental risks associated with each option;
- the disposal of secondary wastes arising from on-site treatment;
- the ability to operate and maintain on-site treatment facilities;
- negotiations with the permitting authority and/or WWTP operator and likely permit conditions;
- projected trends in waste water volume and composition;
- proximity of local residents.

The three main options for discharging waste water from a FDM installation are:

- direct discharge to a receiving water body;
- indirect discharge to a WWTP;
- landspreading of waste water.
- to off site, e.g. MWWTP without treatment;
- to off site, e.g. MWWTP after partial treatment;
- to watercourse after full on site WWTP;
- off site reuse of certain waste water streams, e.g. as a feed stream in another industry, or for irrigation;
- off site land application (see Section).

Of the 353 questionnaires received during the FDM data collection, 136 concern WWTPs that discharge directly to a receiving water body, 146 concern indirect discharges, while 13 concern landspreading. Most of the direct discharges were to a river and most of the indirect discharges were to municipal WWTPs (Figure 2.3).
Where it is essential for the installation to be close to the source of its raw material, i.e. in a remote location, there may be no alternative but to carry out full treatment and discharge to a local watercourse. In most cases, however, two or more options will merit detailed consideration. Waste water disposal may be a major factor in the choice of site for new installations.

The advantages of the treatment of individual waste water streams on-site are reported to be [8, Environment Agency of England and Wales 2000]:

- more flexibility for increased production, or for reacting to changing conditions;
- facilities for treatment at source are usually tailor-made and so normally perform well;
- operators of the production units demonstrate a more responsible attitude towards waste water treatment when they are made responsible for the quality of their own waste water discharge.

The advantages of the treatment at a combined/mixed waste water on-site or off-site installation are reported as follows:

- making use of mixing effects, such as temperature or pH;
- lower capital costs due to economy of scale;
- more effective use of chemicals and equipment, thus decreasing relative operating costs;
- dilution of certain contaminants which may be difficult to treat individually; e.g. emulsified fats and sulphates.

Where waste water is treated in an off-site WWTP, the above advantages apply, provided that:

- the treatment at the off-site WWTP is as good as would be achieved if treated on site, particularly in terms of the load, but not the concentration, of each substance to the receiving water;
- there is an acceptably low probability of the treatment plant being by-passed, via surface/emergency overflows, or at intermediate pumping stations;
- there is a suitable monitoring programme in place for emissions to an off-site WWTP, taking into consideration the potential inhibition of any downstream biological processes.

Additionally, the off-site WWTP may benefit by receiving the FDM waste water, e.g. because of its biodegradability.
2.1.5.2.1 Waste water landspreading

Effluents of FDM industries contain water and fertilising nutrients coming mainly from the raw materials. Their return to agriculture is an option, considering the large amounts of fertilisers replaced when landspreading is done according to the crops’ needs. Waste water landspreading allows the recycling of organic matter and fertilising elements to agricultural soil. It has benefits in terms of:

- substitution of chemical fertilisers (N, P, K) which sometimes represent very important amounts, with a subsequent positive economic impact;
- improvement of soil conditions as a consequence of the addition of organic matter;
- reduction of water use and soil erosion.

Waste water landspreading allows the recycling of organic matter and fertilising elements to agricultural soil. It has benefits in terms of:

- substitution of chemical fertilisers (N, P, K) which sometimes represent very important amounts, with a subsequent positive economic impact;
- improvement of soil conditions as a consequence of the addition of organic matter;
- reduction of water use and soil erosion.

Waste water treatment prior to landspreading may be performed for different reasons, e.g.:

- to recover the residual energy (biogas) in the waste water;
- to reduce odour emissions during storage (aerated tanks or lagoons, reduced storage time, etc.);
- to separate the solid phase to be exploited separately, for example for material landspreading.

Effluent landspreading is a practice applied in some MS (e.g. DE, DK, ES, FI, FR, IE and PL). It is estimated that around 10% of the French IED FDM installations apply landspreading of waste water [222, France 2015].

Waste water for landspreading can be generated from different FDM installations, e.g.:

- starch sector: potato food juice, starch purification;
- fruit and vegetable sector: washing water (washing of vegetables) and blanching water;
- sugar sector: earthy water (washing of beetroots) and decanted water.

There is a proposal for a Regulation of the European Parliament and of the Council on minimum quality requirements for reused water in the EU¹. Published in April 2016, the Inception Impact Assessment on the 'Minimum quality requirements for reused water in the EU (new EU legislation)' initiative sets out in greater detail the background and the policy objectives and options as well as their likely impacts.

Waste water landspreading should be carried out in line with legal requirements (IED, Nitrates Directive) and according to the agricultural needs. Only waste water beneficial to the soil or crop nutrition can be spread and landspreading is subject to strict regulation, local threshold values and monitoring measures. Waste water is spread only when there is an available crop that can benefit from the nutrients applied to the field. Waste water landspreading is especially prohibited in the following situations:

- during periods when the soil is largely frozen or covered in abundant snow;
- during heavy rain periods and periods with a risk of flooding;
- outside regularly cultivated land and operated pastures or forests;
- on steep-sloped terrains, under conditions that would lead to run-off outside the scope of the landspreading process;
- using air sprays generating fine mist when the waste water is likely to contain pathogenic microorganisms.

In a French potato starch installation, the effluent is spread on fields by the means of a network of hundreds of kilometres of underground pipes. Fertilising elements (including N, CaO, P and K₂O) and micropollutants are monitored. Controls on underground water are made through

piezometers or analysis of drinking water boreholes. Analysis is also carried out on soil, with an agronomic analysis coupled with a residual nitrogen test and followed by fertilisation advice. Every parcel is monitored all along its life cycle. Rotations avoid any over-fertilisation, thus the authorised surface is five times larger than the yearly surface actually spread. The landspreading is also controlled by the competent authorities [222, France 2015].

In some specific cases, some authorities regard or accept landspreading to be recycling or recovery. Some authorities prohibit it by legislation. In any case, landspreading should only be done in accordance with EU environmental legislation including the Nitrates Directive [104, EEC 1991], which requires measures to be taken concerning the storage and the application on land of all nitrogen compounds and deals with certain land management practices and contains provisions about when spreading is forbidden or inappropriate. Before any substance is spread on land, there are a number of important considerations which need to be assessed, e.g. agronomic interests, i.e. relating to the science of soil management and crop production; hygiene and traceability. It is reported that some transport/washing/process water, surplus biomass from biological WWTPs and other solid residues are sometimes spread on land. For example, potato fruit water, wheat solubles and the sludge from the waste water treatment in the starch industry and sugar beet transport water, possibly after settlement, can potentially be sent for landspreading. Some examples of issues to consider when assessing whether landspreading is a possible option are [37, France 2001]:

- whether the substances spread have a real nutritional benefit to plants. Such benefits might include, e.g. improving the pH balance of the soil, or providing fertilising elements such as phosphorus and nitrogen;
- whether there are geographic, pedologic (i.e. the branch of science which deals with soil, especially its formation, nature and classification), climatic and hydrogeologic data which may affect either food or livestock hygiene or the environmental impact of spreading the substance;
- whether, at all stages in the operation, it is possible to identify the origin and the destination of the spread substances, it depends on close co-operation between the producer of the substance to be spread and the person controlling the landspreading operation, e.g. the farmer;
- the requirement for monitoring the predicted effect, e.g. by analysis of the soil and the groundwater.

### 2.1.5.3 Waste water treatment techniques

#### 2.1.5.3.1 Introduction

The descriptions of the various waste water treatment techniques in the following sections show the sequence that the techniques typically follow to achieve progressively a better quality of waste water. Due to the nature of the raw materials used and the products produced, waste water arising from the FDM sector is primarily biodegradable in nature. However, cleaning and disinfection agents may represent a problem if they are poorly degradable.

Table 2.4 shows the waste water treatment techniques described in Section 2.3.6, and in which FDM sectors and how many FDM installations they are applied, according to the FDM data collection. Table summarises their typical application in the FDM sector.
### Table 2.4: Waste water treatment techniques reported in the FDM data collection

<table>
<thead>
<tr>
<th>Code</th>
<th>Technique</th>
<th>BREF Section</th>
<th>FDM sectors (number of FDM reference installations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Screening</td>
<td>Section 2.3.6.1.1</td>
<td>AN (1), BR (15), DA (14), FR (15), ME (9), OI (2), SO (2), ST (2), SU (6)</td>
</tr>
<tr>
<td>T2</td>
<td>Fat trap for the removal of FOG and light hydrocarbons</td>
<td>Section 2.3.6.1.2</td>
<td>AN (2), DA (14), FR (2), ME (11), OI (9), OL (1), SU (1)</td>
</tr>
<tr>
<td>T3</td>
<td>Flow and load equalisation</td>
<td>Section 2.3.6.1.3</td>
<td>AN (1), BR (14), DA (26), ET (1), FR (9), ME (1), OI (8), ST (8), SU (6)</td>
</tr>
<tr>
<td>T4</td>
<td>Neutralisation</td>
<td>Section 2.3.6.1.4</td>
<td>BR (14), DA (28), FR (3), ME (3), OI (5), SO (5), ST (3), SU (2)</td>
</tr>
<tr>
<td>T5</td>
<td>Sedimentation</td>
<td>Section 2.3.6.1.5</td>
<td>AN (2), BR (7), DA (16), FR (12), ME (2), OI (7), SO (3), ST (9), SU (12)</td>
</tr>
<tr>
<td>T6</td>
<td>Dissolved air flotation (DAF)</td>
<td>Section 2.3.6.1.6</td>
<td>BR (3), DA (21), FR (2), ME (7), OI (13), ST (1)</td>
</tr>
<tr>
<td>T7</td>
<td>Buffer storage for waste water incurred during other than normal operating conditions (Diversion (emergency) tank)</td>
<td>Section 2.3.6.1.7</td>
<td>BR (10), DA (11), FR (3), ME (1), OI (1), ST (4), SU (1)</td>
</tr>
<tr>
<td>T8</td>
<td>Centrifugation</td>
<td>Section 2.3.6.1.8</td>
<td>BR (2), DA (8), FR (2), OI (6)</td>
</tr>
</tbody>
</table>

#### Secondary treatment

<table>
<thead>
<tr>
<th>Code</th>
<th>Technique</th>
<th>BREF Section</th>
<th>FDM sectors (number of FDM reference installations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T10</td>
<td>Activated sludge</td>
<td>Section 2.3.6.2.1.1</td>
<td>BR (12), DA (27), ET (1), FR (9), ME (4), OI (13), SO (4), SU (10), SU (13)</td>
</tr>
<tr>
<td>T11</td>
<td>Pure oxygen systems</td>
<td>Section 2.3.6.2.1.2</td>
<td>BR (1), DA (1), FR (1), ME (2), ST (1)</td>
</tr>
<tr>
<td>T12</td>
<td>Sequencing batch reactors (SBR)</td>
<td>Section 2.3.6.2.1.3</td>
<td>BR (2), DA (2), FR (1), ME (1), OI (1)</td>
</tr>
<tr>
<td>T13</td>
<td>Aerobic lagoons</td>
<td>Section 2.3.6.2.1.4</td>
<td>AN (1), BR (1), DA (4), FR (3), ME (2), OI (2), SU (2), ST (1)</td>
</tr>
<tr>
<td>T14</td>
<td>Trickling filters</td>
<td>Section 2.3.6.2.1.5</td>
<td>OI (1)</td>
</tr>
<tr>
<td>T15</td>
<td>Bio-towers</td>
<td>Section 2.3.6.2.1.6</td>
<td>BR (3), DA (5), ST (1)</td>
</tr>
<tr>
<td>T16</td>
<td>Rotating biological contactors</td>
<td>Section 2.3.6.2.1.7</td>
<td>DA (1)</td>
</tr>
<tr>
<td>T17</td>
<td>BAFF-SBAF</td>
<td>Section 2.3.6.2.1.8</td>
<td>ST (2)</td>
</tr>
<tr>
<td>T18</td>
<td>High and ultrahigh rate filters</td>
<td>Section 2.3.6.2.2.1</td>
<td>SU (5)</td>
</tr>
<tr>
<td>T19</td>
<td>Anaerobic lagoons</td>
<td>Section 2.3.6.2.2.2</td>
<td>BR (2), DA (2), FR (1), SO (1), ST (1), SU (7)</td>
</tr>
<tr>
<td>T20</td>
<td>Anaerobic contact processes</td>
<td>Section 2.3.6.2.2.3</td>
<td>DA (2)</td>
</tr>
<tr>
<td>T21</td>
<td>Anaerobic filters</td>
<td>Section 2.3.6.2.2.4</td>
<td>BR (5), DA (1), FR (5), ST (2), SU (2)</td>
</tr>
<tr>
<td>T22</td>
<td>Upflow anaerobic sludge blanket (UASB)</td>
<td>Section 2.3.6.2.2.5</td>
<td>BR (6), DA (2), OI (2), ST (1)</td>
</tr>
<tr>
<td>T23</td>
<td>Internal circulation reactors</td>
<td>Section 2.3.6.2.2.6</td>
<td>OI (1)</td>
</tr>
<tr>
<td>T24</td>
<td>Hybrid UASB</td>
<td>Section 2.3.6.2.2.7</td>
<td>BR (3), ET (1), SU (1)</td>
</tr>
<tr>
<td>T25</td>
<td>Fluidised and expanded bed reactors</td>
<td>Section 2.3.6.2.2.8</td>
<td>BR (3), ET (1), SU (1)</td>
</tr>
<tr>
<td>T26</td>
<td>Expanded granular sludge bed reactors</td>
<td>Section 2.3.6.2.2.9</td>
<td>BR (3), ET (1), SU (1)</td>
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<tr>
<td>T27</td>
<td>Membrane bioreactors</td>
<td>Section 2.3.6.2.3.1</td>
<td>DA (5), FR (1), OI (1)</td>
</tr>
<tr>
<td>T28</td>
<td>Multistage systems</td>
<td>Section 2.3.6.2.3.2</td>
<td>DA (1), SO (1), ST (1), SU (1)</td>
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</table>

#### Tertiary treatment

<table>
<thead>
<tr>
<th>Code</th>
<th>Technique</th>
<th>BREF Section</th>
<th>FDM sectors (number of FDM reference installations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T29</td>
<td>Biological nitrification and</td>
<td>Section 2.3.6.3.1</td>
<td>BR (4), DA (22), FR (7), ME (2),</td>
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<tr>
<td>Code</td>
<td>Technique</td>
<td>BREF Section</td>
<td>FDM sectors (number of FDM reference installations)</td>
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<td>------</td>
<td>-----------------------------------------------</td>
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<td>---------------------------------------------------</td>
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<tr>
<td>T30</td>
<td>Ammonia stripping</td>
<td>Section 2.3.6.3.2</td>
<td>OI (1), ST (5), SU (11)</td>
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<tr>
<td>T31</td>
<td>Enhanced biological phosphorus removal (EBPR)</td>
<td>Section 2.3.6.3.3</td>
<td>BR (3), DA (13), FR (2), ME (2)</td>
</tr>
<tr>
<td>T32</td>
<td>Phosphorus removal by chemical precipitation</td>
<td>Section 2.3.6.3.4</td>
<td>BR (2), DA (9), FR (1), OI (1), SO (1), ST (2), SU (1)</td>
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<tr>
<td></td>
<td>Phosphorus recovery as struvite</td>
<td>Section 2.3.6.3.5</td>
<td>FR (2)</td>
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<tr>
<td>T33</td>
<td>Dangerous and priority hazardous substances removal</td>
<td>Section 0</td>
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<td>T34</td>
<td>Filtration</td>
<td>Section 2.3.6.3.6</td>
<td>AN (1), BR (2), DA (9), FR (5), ME (3), OI (1), SO (1)</td>
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<tr>
<td>T35</td>
<td>Membrane filtration</td>
<td>Section 2.3.6.3.7</td>
<td>BR (1), DA (2), FR (2), OI (1)</td>
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<td>T36</td>
<td>UV radiation</td>
<td>Section 2.3.6.3.8</td>
<td>BR (1), DA (1)</td>
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<td>T37</td>
<td>Biological nitrifying filters</td>
<td>Section 0</td>
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<tr>
<td>T38</td>
<td>Disinfection and sterilisation</td>
<td>Section 0</td>
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### Natural treatment

<table>
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<td>T37</td>
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### Sludge treatment

<table>
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<th>Code</th>
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<tr>
<td>T38</td>
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<tr>
<td>T39</td>
</tr>
<tr>
<td>T40</td>
</tr>
<tr>
<td>T41</td>
</tr>
<tr>
<td>T42</td>
</tr>
</tbody>
</table>

NB: figures between brackets indicate the number of installations per FDM sector, having implemented the technique.

Source: [193, TWG 2015]

### Table: The typical application of Key parameters associated to waste water treatment

<table>
<thead>
<tr>
<th>Emission type</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soluble organic material (BOD/COD)</td>
<td>T10, T11, T12, T13, T14, T15, T16, T17, T18, T20, T21, T22, T23, T24, T25, T26, T27, T32, T33, T34, T35, T36, T37</td>
</tr>
<tr>
<td>Total TSS</td>
<td>T1, T5, T8, T9, T33, T44, T47</td>
</tr>
<tr>
<td>Acids/alkalis</td>
<td>T3, T4</td>
</tr>
<tr>
<td>FOG (free)</td>
<td>T4, T6, T8, T9</td>
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<tr>
<td>FOG (emulsified)</td>
<td>T10, T12, T13, T14, T19, T20, T21, T28</td>
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<tr>
<td>Nitrogen</td>
<td>T40, T41, T12, T13, T14, T15, T16, T29, T30, T35, T37</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>T9, T10, T12, T14, T15, T16, T31, T32</td>
</tr>
<tr>
<td>Dangerous and priority hazardous substances</td>
<td>T5, T9, T10, T14, T32</td>
</tr>
</tbody>
</table>

NB: (1) Enhanced by using chemicals
(2) Includes ammonia removal

Source: [58, FoodDrinkEurope 2002]

Waste water in the FDM sector may have the following typical characteristics:

- solids (gross and finely dispersed/suspended);
- low and high pH level;
- free edible fat/oil;
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- emulsified material, e.g. edible fat/oil;
- soluble biodegradable organic material, e.g. BOD;
- volatile substances, e.g. ammonia and organics;
- plant nutrients, e.g. phosphorus and/or nitrogen;
- pathogens, e.g. from sanitary water;
- heavy metals;
- dissolved non-biodegradable organics.

Waste water produced in the various sectors may vary considerably in composition and pollution levels, and a variety of techniques may be used to treat it. Combinations of techniques are frequently used to treat heavily polluted waste water.
<table>
<thead>
<tr>
<th></th>
<th>Meat</th>
<th>Potato</th>
<th>Fruit and vegetable oil</th>
<th>Vegetable oil</th>
<th>Dairy</th>
<th>Starch</th>
<th>Confectionery</th>
<th>Sugar</th>
<th>Brewing</th>
<th>Malting</th>
<th>Soft and alcoholic drinks</th>
<th>Distilleries and spirits</th>
<th>Wine and sparkling wine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary treatments</strong></td>
<td></td>
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<td>Screening</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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</tr>
<tr>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td></td>
</tr>
<tr>
<td>Fat trap</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
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<tr>
<td>Centrifugation</td>
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<td></td>
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<td>Yes</td>
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</tr>
<tr>
<td>Flow and load equalisation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Precipitation</td>
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<tr>
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<td>Yes</td>
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<tr>
<td><strong>Secondary treatments</strong></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Aerobic treatment</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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</tr>
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<td>Anaerobic treatment</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
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</tr>
<tr>
<td>Activated sludge</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Multistage activated sludge</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
<td>Yes</td>
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<tr>
<td>SBR</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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</tr>
<tr>
<td>Trickling filters</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerobic lagoons</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Yes = treatment applied in that sector

* Used in the Netherlands
** Anaerobic batch reactors
*** In connection with anaerobic treatment

Table: A summary of waste water treatment processes used in different sectors [65, Germany, 2002]
2.1.5.3.2 Primary treatment

Primary treatment is designed to remove gross, suspended and floating solids from raw sewage. It includes screening to trap solid objects and sedimentation by gravity to remove suspended solids. This level is sometimes referred to as mechanical treatment, although chemicals are often used to accelerate the sedimentation process. Primary treatment can reduce the BOD of the incoming waste water by 20–30% and the total suspended solids by some 50–60%. Primary treatment is usually the first stage of waste water treatment [235, World Bank Group 2016].

Typical techniques for primary treatment are screening, fat trap for the removal of FOG and light hydrocarbons, flow and load equalisation, neutralisation, sedimentation, dissolved air flotation, centrifugation or precipitation.

2.1.5.3.3 Secondary treatment

Secondary treatment is directed principally towards the removal of biodegradable organics and suspended solids using biological methods. Adsorption of pollutants to the organic sludge produced will also remove non-biodegradable materials, e.g. heavy metals. Organic nitrogen and phosphorus can also be partially removed from the waste water. Secondary treatment options can be used alone or in combination, depending on the characteristics of the waste water and the requirements before discharge. When they are applied in combination arranged in series, the technique is called multistage systems (see Section 2.3.6.2.3.2).

There are essentially three types of metabolic processes, i.e. aerobic processes, using dissolved oxygen; anaerobic processes, without oxygen supply and anoxic processes, using biological reduction of oxygen donors [58, FoodDrinkEurope 2002] [8, Environment Agency of England and Wales 2000] [35, Germany 2002]. This section will describe techniques that use mainly aerobic and anaerobic metabolic processes.

Aerobic processes

Aerobic processes are only generally applicable and cost-effective when the waste water is readily biodegradable. Microorganisms in the mixed liquor can receive the oxygen input from either the surface or from diffusers submerged in the waste water. Surface injection of oxygen is carried out by means of either surface aerators or oxygenation cages. The advantages and disadvantages of aerobic waste water treatment processes are shown in Table 2.15.

Table 2.5: Advantages and disadvantages of aerobic waste water treatment processes

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degradation into harmless compounds</td>
<td>Large quantities of sludge produced</td>
</tr>
<tr>
<td></td>
<td>Stripping results in fugitive releases that may cause odours/aerosols</td>
</tr>
<tr>
<td></td>
<td>Bacterial activity is reduced at low temperatures. Nevertheless, surface aeration and the injection of pure oxygen can be used to enhance the process</td>
</tr>
<tr>
<td></td>
<td>If FOG is not removed prior to aerobic biological treatment, it may hinder the operation of the WWTP as it is not easily degraded by bacteria</td>
</tr>
</tbody>
</table>

Source: [1, CIAA 2002], [8, Environment Agency of England and Wales 2000], [35, Germany 2002]
Anaerobic processes

In the absence of oxygen, organic matter is broken down, producing methane (CH\textsubscript{4}) as a by-product, which is used to heat the reactors. In standard anaerobic processes, the reactors are usually unheated, but in high rate anaerobic processes, the reactors are usually heated. In both cases, the temperature of the reactor has to be maintained at around 30–35 °C (mesophilic) or 45–50 °C (thermophilic), and whether heat is required depends essentially on the temperature of the feed [78, Metcalf & Eddy 1991], [110, CIAA 2003]. The main advantages and disadvantages of anaerobic waste water treatment processes, compared to aerobic processes are shown in Table 2.6.

Table 2.6: Advantages and disadvantages of anaerobic waste water treatment processes

<table>
<thead>
<tr>
<th>Advantages of anaerobic treatment</th>
<th>Disadvantages of anaerobic treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low specific surplus sludge production; the lower growth rates mean lower macro/micro nutrient requirements</td>
<td>Mesophilic bacteria, which thrive at 20–45 ºC, may require an external source of heat</td>
</tr>
<tr>
<td>Low energy requirements due to lack of forced ventilation</td>
<td>Low growth rate requires good biomass retention</td>
</tr>
<tr>
<td>Generally lower capital and running costs per kg COD removed. These are associated with a decreased in sludge production and lower mixing costs</td>
<td>Initial commissioning/acclimatisation phase can be long (Not for reactors with granular sludge, e.g. EGSB, seeded with the sludge of operating plants)</td>
</tr>
<tr>
<td>Produces biogas that can be used for power or heat generation</td>
<td>Anaerobic systems are more sensitive than aerobic systems to fluctuations in temperature, pH, concentration and pollution loads</td>
</tr>
<tr>
<td>Small space requirements</td>
<td>Some constituents of treated waste water can be toxic/corrosive, e.g. H\textsubscript{2}S</td>
</tr>
<tr>
<td>Can be easily decommissioned for extended periods and remain in a dormant state (useful for seasonal manufacturing processes, e.g. sugar beet)</td>
<td>A particular advantage of the process is the formation of pellets. This permits not only rapid reactivation after month-long breaks in operation, but also the sale of surplus sludge pellets, e.g. for the inoculation of new systems</td>
</tr>
<tr>
<td>A particular advantage of the process is the formation of pellets. This permits not only rapid reactivation after month-long breaks in operation, but also the sale of surplus sludge pellets, e.g. for the inoculation of new systems</td>
<td>Some substances that cannot be degraded by aerobic means can be degraded anaerobically, e.g. pectin and betaine</td>
</tr>
<tr>
<td>Less odour problems, if appropriate abatement techniques are employed.</td>
<td>No aerosol formation, can assimilate FOG (not for UASB)</td>
</tr>
<tr>
<td>No aerosol formation, can assimilate FOG (not for UASB)</td>
<td></td>
</tr>
</tbody>
</table>

Source: [8, Environment Agency of England and Wales 2000], [35, Germany 2002], [58, FoodDrinkEurope 2002]

Although anaerobic growth is slower than in an aerobic process, higher BOD loadings are achievable with an anaerobic technique (in terms of kg BOD/m\textsuperscript{3} of reactor volume) for highly polluted waste water. Anaerobic techniques are generally utilised in those industries where there is a high level of soluble and readily biodegradable organic material and the concentration of the waste water, expressed in COD, is generally greater than 1500–2000 mg/l. For the FDM sector, the application of anaerobic waste water treatment is largely confined to relatively heavily polluted waste water with a COD between 3000 and 40000 mg/l, e.g. in the sugar, starch, fruit and vegetable and alcoholic drinks sectors. There has recently been some success in using certain anaerobic systems even for less heavily polluted waste water with a COD between 1500 and 3000 mg/l, e.g. in breweries, dairies and in the fruit juice, mineral water and the soft drinks sectors [35, Germany 2002]. Where there are large fluctuations in volume and pollutant load, e.g. for waste water in the fruit and vegetable sector, this treatment is less effective.
One of the most fundamental aspects of anaerobic waste water treatment is that the vast majority of organic carbon associated with the influent BOD is converted to methane as opposed to being used for new cell growth. The opposite is true with aerobic processes, which convert most of the organic carbon to new cells which eventually form waste biosolids that require either further treatment or off-site disposal. Anaerobic processes produce much less waste sludge. Also the methane produced has a high calorific value and as such can be reused as fuel, e.g. elsewhere in an installation.

An anaerobic system alone would not achieve a final waste water quality high enough for discharge to a watercourse. Therefore anaerobic installations are usually followed by an aerobic system (see Section 2.3.6.2.1), as the latter achieves lower absolute emissions levels, and will remove hydrogen sulphide ensuring that the final waste water is well aerated to assist in the breakdown of the remaining BOD. The energy gained from the anaerobic plant can be equivalent to that consumed by the aerobic plant. In certain circumstances the aerobic treatment may be the municipal WWTP. This will depend upon the receiving WWTP and the balance between waste water treatment charges and an on-site aerobic treatment stage. The anaerobically treated waste water may be surface aerated on site prior to transfer to a municipal WWTP. This is normally carried out in a post treatment holding tank providing positive dissolved oxygen levels before being discharged to a WWTP.

The methanogenic bacteria involved in the final stage of the anaerobic process, producing the methane gas, need to be protected from excessive chlorinated and sulphur compounds, pH and temperature fluctuations. In the acidification stage other bacteria will predominate and break down many of the substances which cause the problems. Due to the slow microbial growth there is no phosphorus removal. No nitrification and denitrification occurs so nitrogen cannot be removed by anaerobic treatment.

Modern reactor designs permit higher loading rates, increase biogas production or offer greater stability. Once the bacterial populations in such systems are adapted to the waste water then increased stability occurs.

On-site treatment facilities relying upon an anaerobic reactor as the main treatment process have a similar layout. They have a waste water collection sump/vessel or equalisation tank from which the waste is pumped/flows to a primary treatment tank. The primary treatment processes are as described for aerobic systems.

From the primary treatment stage, the waste water is passed to a conditioning or buffer tank where the waste water is conditioned, e.g. pH correction or nutrient addition, before it is passed via the influent distribution system through to the bioreactor. Early anaerobic reactors allow the initial stages of the anaerobic metabolism to be initiated in the conditioning tank (often referred to as the acidification tank). Modern reactor designs allow all the metabolic pathways to take place in the reactor. The conditioning tank is, therefore, generally only required for pH correction and nutrient addition.

Treatment occurs in the reactor, producing biogas which is collected. Other components often included are a sludge storage tank, vent gas disposal and primary treatment facilities.

Some common operational problems experienced with anaerobic treatment processes are given in Table 2.7.
Table 2.7: Common operational problems experienced with biological treatment processes

<table>
<thead>
<tr>
<th>Problem</th>
<th>Possible solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of macro-nutrients</td>
<td>BOD:N:P ratios are normally maintained at 500:5:1</td>
</tr>
<tr>
<td>pH</td>
<td>The pH is maintained at 6.8–7.5</td>
</tr>
<tr>
<td>Temperature</td>
<td>The optimum temperature for mesophilic bacteria is 35–37 °C</td>
</tr>
<tr>
<td>Lack of micro-nutrients</td>
<td>Minimum quantities of micro-nutrients are maintained, especially for Fe, Ca, Mg and Zn, according to the specific process employed</td>
</tr>
<tr>
<td>Physical blockage of the reactor inlet pipework</td>
<td>Effective screening and primary treatment is essential</td>
</tr>
<tr>
<td>Overloading</td>
<td>Care needs to be taken to ensure the original hydraulic, solid and organic loading design rates do not exceed the manufacturer’s recommendations</td>
</tr>
</tbody>
</table>

Source: [8, Environment Agency of England and Wales 2000]

2.1.5.3.4 Tertiary treatment

After secondary treatment, further treatment may be needed either to enable the water to be reused as process water or low grade wash-water, or to meet discharge requirements. Tertiary treatment refers to any process that is considered a polishing step, up to and including disinfection and sterilisation systems.

In this document, tertiary treatment means an advanced treatment of the waste water to remove constituents of particular concern including ammonia, plant nutrients, dangerous and priority hazardous substances or residual TSS and organics.

Plant nutrients, i.e. nitrogen and phosphorus, need to be removed before discharge into surface water in sensitive areas [165, EEC 1991]. In selecting an appropriate nutrient control strategy, it is important to assess:

- the characteristics of untreated waste water;
- the type of WWTP to be used;
- the level of nutrient control required;
- the need for seasonal or year-round nutrient removal.

2.1.5.3.5 Natural treatment

In the natural environment, biological and physico-chemical processes occur when water, soil, plants, microorganisms and the atmosphere interact. Natural treatment systems are designed to take advantage of these processes, to provide waste water treatment. The processes involved include many of those used in conventional waste water treatment systems, such as sedimentation, filtration, precipitation and chemical oxidation, but occur at natural rates [78, Metcalf & Eddy 1991]. They are slower than conventional systems.

The soil-based systems mainly use the complex purification mechanism of the soil and uptake by crops and other vegetation. In the aquatic-based systems, e.g. natural and constructed wetlands and aquatic plant systems, the vegetation provides a surface for bacterial growth. Natural treatments are prohibited by law in some MSs, due to concerns about hazards to groundwater [94, Germany 2003].

2.1.5.3.6 Sludge treatment

This section covers the treatment of waste water sludge. Techniques for the use and disposal of waste water sludges off site are not covered in this document. The choice of sludge treatment
may be influenced by the use and disposal options available to the operator. These include, e.g. landspending, disposal by landfill, use as a sealing material, incineration, co-incineration, wet oxidation, pyrolysis, gasification, vitrification.

The capital and operating costs associated with sludge treatment can be high compared with the rest of the WWTP activities and consequently merit consideration, to minimise costs, at an early stage in designing an installation. Environmental legislation is increasingly limiting the disposal options available or significantly increasing their cost.

Sludge treatment techniques on site generally either reduce the volume for disposal, or to change its nature for disposal or reuse. Typically, volume reduction through dewatering can occur on site, whereas further sludge treatment is generally carried out off-site. Reducing the volume of sludge for disposal leads to reduced transport costs and, if going to landfill, reduced landfill charges [8, Environment Agency of England and Wales 2000]. The on-site treatment techniques normally applied in the FDM sector are detailed in Section 2.3.6.5.

### 2.1.6 Treatment of emissions to air

Emissions to air can be divided into ducted, diffuse, and fugitive emissions. Fugitive emissions are a subset of diffuse emissions. Only ducted emissions can be treated. Diffuse and fugitive emissions can, however, also be prevented and/or minimised. The CWW BREF gives an indication of the techniques for the prevention and reduction of VOC emissions [242, COM 2016]. The sources of ducted emissions in the FDM sector are:

- process emissions, released through a vent pipe by the process equipment and inherent to the running of the installation, e.g. in frying, boiling, cooking operations;
- waste gases from purge vents or preheating equipment, which are used only on start-up or shut-down operations;
- emissions from vents from storage and handling operations, e.g. transfers, the loading and unloading of products, raw materials and intermediates;
- flue-gases from units providing energy, such as process furnaces, steam boilers, combined heat and power units, gas turbines, gas engines;
- waste gases from emission control equipment, such as filters, thermal oxidisers or adsorbers;
- waste gases from solvent regeneration, e.g. in vegetable oil extraction installations;
- discharges of safety relief devices, e.g. safety vents and safety valves;
- exhaust of general ventilation systems;
- exhaust of vents from captured diffuse and/or fugitive sources, e.g. diffuse sources installed within an enclosure or building.

The main sources of diffuse and fugitive emissions in the FDM sector are:

- process emissions by the process equipment and inherent to the running of the installation, released from a large surface or through openings;
- working losses and breathing losses from storage equipment and during handling operations, e.g. filling of drums, trucks or containers;
- emissions from flares;
- secondary emissions, resulting from the handling or disposal of waste, e.g. volatile material from sewers, waste water handling facilities or cooling water.
- odour losses during storage, filling and emptying of bulk tanks and silos;
- stripping of malodorous compounds from a WWTP resulting in releases to air and/or odour problems;
- storage tank vents;
- fumigation;
- pipework leaks;
vapour losses during storage, filling and emptying of bulk solvent tanks and drums, including hose decoupling;
burst discs and relief valve discharges;
leakages from flanges, pumps, seals and valve glands;
building losses from windows, doors, etc.;
settling ponds;
cooling towers and cooling ponds.

The main air pollutants from FDM processes, not including the pollutants released in associated activities such as energy production, are:
- dust;
- VOCs and odour (some caused by VOCs);
- refrigerants containing ammonia and halogen;
- products of combustion, such as CO\(_2\), NO\(_X\) and SO\(_2\).

2.1.6.1 Process-integrated techniques

Process-integrated procedures to minimise emissions to air generally have other environmental benefits, such as optimising the use of raw materials and minimising waste generation. These environmental benefits are listed where they are associated with techniques in this chapter. Some of the techniques described as air abatement techniques are also integrated in the process and enable the recovery of materials for reprocessing, e.g. cyclones (see Section 2.3.4.6).

2.1.6.2 Treatment techniques for emissions to air

End-of-pipe Measures are designed to reduce not only the mass concentrations, but also the mass flows of the air pollutants originating from a unit operation or a process. Table 2.8 lists some widely used end-of-pipe air treatment techniques and the number of FDM installations in which they are applied, according to the FDM data collection.

Table 2.8: End-of-pipe Treatment techniques for emissions to air reported in the FDM data collection

<table>
<thead>
<tr>
<th>Technique</th>
<th>BREF Section</th>
<th>FDM sectors (number of FDM reference installations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separator</td>
<td>2.3.7.2.1</td>
<td>AN (1), OI (2)</td>
</tr>
<tr>
<td>Bag filter</td>
<td>2.3.7.2.2</td>
<td>AN (44), BR (55), DA (57), GR (63), ME (1), OI (70), ST (31), SU (13)</td>
</tr>
<tr>
<td>Cyclone</td>
<td>2.3.7.2.3</td>
<td>AN (34), BR (42), DA (38), ET (1), GR (4), ME (3), OI (73), ST (40), SU (23)</td>
</tr>
<tr>
<td>Wet scrubber</td>
<td>2.3.7.3.1</td>
<td>AN (1), DA (9), ET (1), ME (1), OI (13), ST (8), SU (12)</td>
</tr>
<tr>
<td>Electrostatic precipitator</td>
<td>2.3.7.2.4</td>
<td>OI (1)</td>
</tr>
<tr>
<td>Carbon adsorption</td>
<td>2.3.7.3.3</td>
<td>ME (1)</td>
</tr>
<tr>
<td>Bioscrubber</td>
<td>2.3.7.3.5</td>
<td>AN (1), OI (2)</td>
</tr>
<tr>
<td>Biofilter</td>
<td>2.3.7.3.4</td>
<td>AN (1), DA (1), ME (1), OI (5)</td>
</tr>
<tr>
<td>Thermal oxidation</td>
<td>2.3.7.3.6</td>
<td>ME (1), OI (1), ST (2), SU (1)</td>
</tr>
<tr>
<td>Catalytic oxidation</td>
<td>2.3.7.3.7</td>
<td>DA (1), OI (1)</td>
</tr>
</tbody>
</table>

NB: figures between brackets indicate the number of installations per FDM sector, having implemented the technique.

Source: [193, TWG 2015]
Treatment processes

<table>
<thead>
<tr>
<th>Solid and liquid pollutants</th>
<th>Gaseous pollutants and odour/VOCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic separation</td>
<td>Absorption</td>
</tr>
<tr>
<td>Wet separation</td>
<td>Carbon adsorption</td>
</tr>
<tr>
<td>Electrostatic precipitation</td>
<td>Biological treatment</td>
</tr>
<tr>
<td>Filtration</td>
<td>Thermal treatment</td>
</tr>
<tr>
<td>Aerosol/droplet separation*</td>
<td>Non-thermal plasma treatment</td>
</tr>
<tr>
<td></td>
<td>Condensation*</td>
</tr>
<tr>
<td></td>
<td>Membrane separation*</td>
</tr>
</tbody>
</table>

*Not described as an air emission minimisation technique in this document

Source: [16, Willey A R and Williams D A 2001] [35, Germany 2002]

The characteristics of the emission determine the selection of the most appropriate end-of-pipe technique. This may need some flexibility, to enable the treatment of additional sources identified at a later date. Table 2.9 shows the key parameters for the selection procedure.

Table 2.9: Key parameters for the end-of-pipe selection procedure

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flowrate</td>
<td>m³/hr</td>
</tr>
<tr>
<td>Temperature</td>
<td>ºC</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>%</td>
</tr>
<tr>
<td>Typical range of components present</td>
<td>–</td>
</tr>
<tr>
<td>Dust level</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Organic level</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Odour level</td>
<td>OUé/Nm³</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

In some cases, the components of the emission are easily identified. In the case of odour, the emission to be treated usually contains a complex cocktail and not just one or two readily definable components. The abatement plant is, therefore, often designed based on experience within other similar installations. The uncertainty caused by the presence of a considerable number of airborne components may necessitate the need for pilot plant trials. The flowrate to be treated is a major parameter in the selection process and very often the abatement techniques are listed against the optimum flowrate range for their application.

Transport of ducted emissions to the treatment plant needs careful consideration, to minimise any operational problems. In particular, the potential for particulate deposition and the potential for condensation of water and other airborne contaminants can result in severe fouling, requiring frequent cleaning and may lead to hygiene problems. Incorporating cleaning points and drain valves in the ventilation ductwork enables cleaning to remove accumulated material.

The purchase of an abatement plant will normally include a number of guarantee statements, e.g. relating to mechanical and electrical reliability for a period of at least one year. As part of the selection and procurement procedure, the supplier will also require information regarding the removal efficiency of the process. The form of the process guarantee is an important part of the contract. For example, guarantee statements relating to odour removal performance can take a number of forms. In the absence of any olfactometric data then the guarantee might simply state no perceivable odour outside the process boundary or outside the installation site.

Extremely high standards for clean gas dust concentrations can be achieved by using two-stage layouts of high performance separation techniques, e.g. using two fabric filters or using them in combination with HEPA filters (described in the CWW BREF [242, COM 2016]) or with ESP filters.

Table 2.10 shows a comparison of the performance of some separation techniques.
Table 2.10: Comparisons of some separation techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Dust particle size (µm)</th>
<th>Collection efficiency at 1 µm (%)</th>
<th>Maximum operation temperature (°C)</th>
<th>Range of achievable emission levels (mg/Nm³)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclone</td>
<td>10</td>
<td>40*</td>
<td>1100</td>
<td>25–100</td>
<td>Coarse particles. Used to assist other methods</td>
</tr>
<tr>
<td>Wet separation</td>
<td>1–3</td>
<td>&gt;80–99</td>
<td>Inlet 1000 Outlet 80</td>
<td>≤4–50</td>
<td>Good performance with suitable dust types. Acid gas reduction</td>
</tr>
<tr>
<td>Dry ESP</td>
<td>&lt;0.1</td>
<td>&gt;99 depending on design</td>
<td>450</td>
<td>≤5–15</td>
<td>Four or five zones. Usual application is pre-abatement</td>
</tr>
<tr>
<td>Wet ESP</td>
<td>0.01</td>
<td>&lt;99</td>
<td>80</td>
<td>≥1–5 optically clear</td>
<td>ESP with two zones in series. Mainly mist precipitation</td>
</tr>
<tr>
<td>Filtration - i.e.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fabric filter</td>
<td>0.01</td>
<td>&gt;99.5</td>
<td>220</td>
<td>0.1–4</td>
<td>Good performance with suitable dust type</td>
</tr>
<tr>
<td>Filtration - i.e.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ceramic filter</td>
<td>0.01</td>
<td>99.5</td>
<td>900</td>
<td>0.1–4</td>
<td>Very good performance with suitable dust types</td>
</tr>
</tbody>
</table>

* For larger particle sizes and high-performance cyclones, collection efficiencies of around 99% can be achieved.  
Source: [35, Germany 2002], [109, Finland 2003]

More information about techniques for reducing emissions to air is given in the following chapters.

2.1.6.2.1 Dynamic separation techniques

The basis for the separation and removal of particles in dynamic separators are the field forces, which are proportional to the mass of the particles. Hence, gravity separators, deflection or inertia separators and centrifugal separators such as cyclones, multicyclones and rotary flow dedusters, are all dynamic separators. They are mainly used for separation of large particles (>10 µm) only or as an initial step before the removal of fine dust by other means. Separation of dispersed particles/dust uses the application of external forces, i.e. primarily gravitational, inertial and electrostatic forces. Use of physical dispersion, via chimney stacks and increasing the dispersion potential by extending the height of the discharge stack or increasing the discharge velocity, is also practised.

2.1.6.2.2 Filters

Filter separators are typically used as final separators, after preliminary separators are used, e.g. where the waste gas contains components with properties damaging to filters, e.g. abrasive dust or aggressive gases. This ensures adequate filter life and operating reliability.

In filter separators, the gas is fed through a porous medium in which the dispersed solid particles are held back as a result of various mechanisms. Filter separators can be classified on the basis of filter medium, performance range and filter cleaning facilities, as summarised in Figure 2.4.
In a fabric or fibre filter, waste gas is passed through a tightly woven or felted fabric, causing dust to be collected on the fabric by sieving or other mechanisms. Fabric filters can be in the form of sheets, cartridges or bags (the most common type) with a number of the individual fabric filter units housed together in a group. The dust cake that forms on the filter can significantly increase the collection efficiency.

Cleanable filters are among the most important types of filter separators used in industrial particulate removal. The practice of using a woven fabric filter material has largely changed to the use of non-woven and needle-felt materials. The most important parameters in cleanable filters are the air to cloth ratio and the pressure loss.

The filter material performs the actual separation and is the essential component of a filter separator. Woven fabrics have threads which cross at right angles. Non-wovens and needle-felts, by contrast, are flat three-dimensional structures that may be stabilised by the adhesion of the fibres or by alternating the insertion and removal of fibres. Non-wovens and needle-felts may also contain an internal supporting woven fabric, e.g. polyester or glass fibre fabric, to reinforce them. Needle-felts made of synthetic fibres are being increasingly used.

Non-wovens and needle-felts possess three-dimensional filtering characteristics. Dust particles are caught in the filter structure, forming an ancillary filter layer that ensures good separation of even the finest particles. One characteristic of this deep filtration is a large effective specific surface area. Regular intensive cleaning removes the accumulated dust layer and prevents excessive pressure losses. Problems, however, may be caused by sticky, fatty, agglomerating, adhesive, abrasive and/or hygroscopic dust particles.

2.1.6.2.3 Absorption

The words absorber and scrubber are sometimes used simultaneously and this can cause confusion. Absorbers are generally used for trace gas removal and scrubbers for particulate abatement. This distinction is not always so rigid, as odour and gaseous components in the air may also be removed together with dust by using vapour condensation or wet scrubbing (see wet separators in Section 2.3.7.3.1).

The aim of absorption is to make the largest possible liquid surface available and provide a good countercurrent flow of gas and liquid. The absorption process relies on the preferential solubility of the polluting components present in the exhaust stream within the absorption medium. There are a number of different types of absorber design and many variations with removal efficiency performances on the contact between the gas and the liquid. Three types of
Principle of operation
The process involves a mass transfer between a soluble gas and a liquid solvent in a gas-liquid contacting device. The rate at which a substance is removed from an airstream depends upon its degree of saturation at the solvent surface within the absorber, which in turn depends upon its solubility and its rate of removal from the circulating solvent by reaction and bleed-off. This rate mechanism determines the efficiency of removal for a particular size of absorption plant and a particular air flowrate. Thus, the efficiency of removal depends on the reaction time, the degree of saturation at the surface of the liquor and the reactivity of the gas components within the absorbing solvent.

Providing the airborne components to be removed are reasonably soluble in water, then an absorber can be designed to achieve a desired removal efficiency. The problem arises in the need to maintain a low enough concentration within the absorbing liquor at the surface to maintain the driving force for dissolution. This often results in excessive volumes of water being needed to achieve a reasonable efficiency. It is, therefore, generally impractical to remove different components effectively using water alone and other absorbents are typically employed.

Water only systems can, however, be considered as a first stage before other absorbers, but much of their effectiveness is due to mechanisms other than absorption. For example, water absorption of a non-saturated airstream will result in a cooling of the airstream to saturation via the process of adiabatic cooling. This cooling effect can lead to a condensation and the removal of components from the airstream as they cool to a temperature below their boiling point.

Design considerations
Effective liquid and air distribution are fundamental requirements in all absorber designs. Optimal design according to standard chemical engineering principles, requires data on concentration, solubility and mass transfer for the components to be removed from the gas stream. Most emissions to air from the FDM sector are complex mixtures for which it is difficult to ascertain all the chemical species present and even more difficult to determine their concentrations. The nature and kinetics of the oxidation reactions are generally not known and these are very difficult to determine even for individual compounds. It is claimed that the design of absorption equipment should be empirical rather than scientific. Thus, the volume of packing is chosen according to the volume previously found to give reasonably complete absorption of those compounds that can be absorbed. If there is only limited operational experience with the discharge in question, then pilot plant trials can be undertaken.

Pilot plant trials or previous experience can, therefore, be used to determine the height of the packing required to achieve a given performance. The packing is chosen to allow the required number of unit height for the required efficiency. The packing size and type, the linear gas velocity, which determines the absorber diameter, the linear liquid velocity, the gas pressure drop and the absorber efficiency per unit height, which determines the packed height, are all interrelated. The design procedure, therefore, looks towards optimising the design in terms of capital and operating costs, taking into consideration the required volumetric throughput, absorption efficiency and constraints such as possible clogging of the packing and the maximum allowable pressure drop. Typical ranges of the parameters detailed above are shown in Table 2.11.
### Table 2.11: Typical absorber design guidelines

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas velocity</td>
<td>m/s</td>
<td>0.5–2.0</td>
</tr>
<tr>
<td>Gas flowrate</td>
<td>kg/m²/hr</td>
<td>2 500–5 000</td>
</tr>
<tr>
<td>Liquid flowrate</td>
<td>kg/m²/hr</td>
<td>25 000–50 000</td>
</tr>
<tr>
<td>Gas residence time</td>
<td>sec</td>
<td>1–3</td>
</tr>
<tr>
<td>Pressure drop</td>
<td>mm/metre</td>
<td>20–50</td>
</tr>
<tr>
<td>Liquid bleed rate</td>
<td>% of recycle flow</td>
<td>0–10</td>
</tr>
<tr>
<td>Flooding</td>
<td>% of flooding</td>
<td>40–60</td>
</tr>
</tbody>
</table>

**Source:** [192, COM 2006]

### Absorbing reagents

The efficiency of absorption can be increased if the absorbing liquid contains a reagent which reacts with the components present in the airstream. This effectively reduces the concentration of the airborne components at the liquid surface and thereby maintains the driving force for absorption without the need for vast amounts of absorbing liquid. There are a number of specific reagents that can be employed within absorption systems to remove malodorous and other organic components from an airstream. These reagents are generally oxidising solutions.

The most widely applied agents include sodium hypochlorite, hydrogen peroxide, ozone and potassium permanganate. The use of acids and alkalis as absorbing mediums is also fairly widespread and often the acid/alkali system is employed in conjunction with an oxidising absorbent. Due to the considerable number of components that can be present in the emissions to air from a food processing installation, multistage absorbers are often used. Thus, an absorbing system could comprise an initial water scrubber followed by an acid or alkali stage and finally an oxidising stage.

Sodium hypochlorite is a very widely applied oxidising agent, primarily due to its high reactivity. Hypochlorite has been found to be particularly useful in installations with significant emission levels of sulphur and nitrogen based malodorous compounds.

Hypochlorite is generally used at an alkaline pH to prevent dissociation into free chlorine. There is a tendency for the hypochlorite to react with certain components via a chlorination rather than an oxidation reaction. This is a particular concern where an airstream contains aromatic material which could generate chlorinated aromatic compounds in the treated gas stream. The chlorination potential is greater at higher hypochlorite concentrations, so a design incorporating lower hypochlorite concentrations in the absorbing liquor than is actually required for optimal absorption reduces the risk of this occurring.

To address this, a new process was developed which is essentially a conventional hypochlorite absorber, but with a catalyst incorporated into the liquid recycling system. The catalyst is based on nickel oxide and the system is claimed to dramatically increase the hypochlorite reaction rate and prevent any chlorination reactions. The potential chlorination reaction is avoided as the catalyst promotes the decomposition of the hypochlorite into gaseous oxygen and sodium chloride as opposed to free chlorine. This in turn, allows the use of increased hypochlorite concentrations in the absorbing liquor than is actually required for optimal absorption reduces the risk of this occurring.

Hydrogen peroxide is generally less effective than hypochlorite, due to its lower oxidising power. It does, however, have the advantage that its reaction product is water and can be used for applications where aromatics are present, for reasons mentioned above. Hydrogen peroxide is usually used under acidified conditions, primarily to control its rate of decomposition.

Ozone is also a powerful oxidising agent, although its oxidative power is more pronounced in the liquid phase than in the gas phase. A recent application that incorporates ultraviolet light to enhance the oxidative performance of ozone is discussed further in Section 0.
A number of surfactant-based absorbing solutions have been used in recent years, although there is limited information available on their performance. In particular, a non-ionic based surfactant system with reduced foaming, such as the material used for dishwasher rinse-aids, has been employed successfully.

Solid oxidising agents are also used, e.g. a calcium oxide scrubber, where particulate calcium oxide is put into contact with the malodorous gas stream producing a solid residue of calcium carbonate. A limited odour removal performance and severe operational problems in terms of solids handling are reported. It is, therefore, more common for only liquid absorbing agents to be used.

2.1.6.2.4 Biological treatment

The process of using microorganisms to breakdown airborne odour emissions is used extensively. The reaction speed of the biodegradation process is relatively low, and optimising operating conditions can have a crucial influence.

There are two types of biological treatment, biofilters (see Section 2.3.7.3.4) and bioscrubbers (see Section 2.3.7.3.5). The most popular type of biological treatment is the biofilter. There are a number of design considerations which need to be taken into account to ensure effective operation; these are residence time, temperature, humidity, effects of dust and fat on the filter, organic/odour load, and design and characteristics of the filter material. Advantages and disadvantages of biological treatment methods are shown in Table 2.12.

Table 2.12: Advantages and disadvantages of biological treatment

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relatively low capital cost</td>
<td>Restricted to wet bulb temperatures &lt;40 °C</td>
</tr>
<tr>
<td>Relatively low operating costs</td>
<td>High land area requirements</td>
</tr>
<tr>
<td>Potentially high odour removal ~ 90–99%</td>
<td>Potential for visible plume formation</td>
</tr>
<tr>
<td>Simple design and operation</td>
<td>Requires control of pH and water content</td>
</tr>
<tr>
<td>-</td>
<td>Slow adaptation to fluctuating concentrations</td>
</tr>
</tbody>
</table>

Source: [16, Willey et al. 2001]

Principle of operation

The biofilm is the water layer prevailing around individual particles of the filter material where microorganisms are present. When the airstream to be treated flows around the particles, there is a continuous mass transfer between the gas phase and the biolayer. Volatile components present in the exhaust gas, together with oxygen, are partially dissolved in the liquid phase of the biolayer. The second reaction step is the aerobic biological degradation of the components in the liquid phase. In this way, a concentration gradient is created in the biolayer which maintains a continuous mass flow of the components from the gas to the wet biolayer.

Transport across the phase boundary and diffusion into the biolayer provide food for the microorganisms living in the biolayer. Nutrients, required for cell growth, are provided from the filter material.
2.1.6.2.5 Thermal treatment of waste gases

Certain gaseous pollutants and odour can be oxidised at high temperatures. The speed of the reaction increases exponentially with temperature. Oxidisable pollutants include all organic compounds, as well as inorganic substances such as carbon monoxide and ammonia. Given complete combustion, carbon and hydrogen react with oxygen to form $\text{CO}_2$ and water. Incomplete combustion can result in new pollutants such as carbon monoxide and in totally or partially unoxidised organic compounds. If the waste gas contains elements such as sulphur, nitrogen, halogens and phosphorus, combustion gives rise to inorganic pollutants such as oxides of sulphur, oxides of nitrogen and hydrogen halides, which subsequently have to be removed by means of other waste gas purification processes if the concentrations are too high. This restricts the field of applications for the combustion of pollutants.

There are a number of safety requirements, in particular:

- the need for protection against flame flashback between the thermal oxidiser and the gas stream to be treated. This can generally be achieved via a flame arrestor or water seal;
- on start-up, before the burner is ignited, the thermal oxidiser needs to be purged with air by a volume equivalent to five times the plant volume. Any re-ignition of burners during the operation is preceded by a burner purge period;
- when the air is rich in solvents, a risk assessment is required.

2.1.6.3 Odour

Odour is mostly a local problem. Some emissions to air which are harmful may also be malodorous. For two identical installations producing the same products and using the same raw materials and process operations, one may be subject to considerable complaints whilst for the other, the odour emission may not be a problem. There are many cases where installations, previously situated in rural areas on the outskirts of a town or city, are now faced with odour problems as new housing estates have been constructed near the site as the town has grown. Odour problems are usually related to waste water treatment operations. Ammonia used in cooling systems may leak or accidental releases may occur which also result in odour complaints.

In the vast majority of countries, odour emissions are regulated under the laws of nuisance. Some countries have quantified legislation. This quantified legislation can relate to either the magnitude of the malodorous emission or alternatively to a maximum concentration of a component or group of components which are known to cause malodorous emissions. The internationally accepted units of odour are odour units per cubic metre ($\text{OU}_E/\text{m}^3$). Instrumental odour measurements exist but the quantification of odour is still based on olfactometry to a great extent.

In Germany, e.g. the legislation for malodorous processes is largely directed towards ensuring that the outlet concentration of organics is limited related to the process being conducted and the efficiency of the chosen abatement plan. The legislation, under TA Luft [46, BMU 1986], contains a general statement about odour emissions and describes the need to consider containment, the surroundings and the ability of the abatement plan to achieve 99 % odour reduction for odour emissions greater than 100 000 $\text{OU}_E/\text{m}^3$. For specific process operations TA Luft provides maximum outlet concentrations of organics that should not be exceeded.

The Netherlands Emissions Guideline for Air [91, InfoMil 2001] states that the national goal is the prevention or reduction of odour nuisance. It sets an upper limit of 5 $\text{OU}_E/\text{m}^3$ associated to a 98 % reduction for existing installations and suggests that a limit of 0.5 $\text{OU}_E/\text{m}^3$ associated to a 99.5 % reduction will have to be satisfied for new installations; the latter is not an upper limit.
For odour, an acceptable solution is to reduce the impact on the surroundings by emission through a suitable stack. However, in many cases, this is not enough and other abatement systems should be applied [246, Nordic Council of Ministers 2016].

Dispersion is sometimes used via existing installations on the site, e.g. using a high discharge boiler stack. The legislation governing malodorous emissions, if they are not also considered to be harmful, is impact related and not source controlled. This means that, the need to treat a malodorous emission is governed by the impact it has on the surrounding environment following dispersion in the air. Controls of the dispersion of the emission to air typically consider both the prevention of complaints as well as legal requirements associated with odour emissions and their composition, e.g. if they contain VOCs.

For example, reduced ground level concentrations could be achieved without any reduction in the magnitude of the odour emission, but merely by enhancing its dispersion in the air. Adding a perfumed component, i.e. a masking agent, is another option of physically treating the odour, but it is not recommended.

The dispersion of an exhaust emission in the air, and hence its resultant ground level odour concentration, will depend upon a variety of factors, including:

- the prevailing climatic conditions;
- the height of the discharge;
- positioning of nearby buildings or structures;
- stack temperature (thermal buoyancy) and discharge velocity;
- configuration of the discharge stack.

With the exception of the prevailing climatic conditions, all of the above-mentioned factors can be altered with the desired intention of improving the dispersion potential of the discharge. The influence of the above factors can be examined in a computer-based dispersion model which incorporates these factors in the computation of ground level odour concentrations. The model allows the sensitivity of stack height or increases to the discharge velocity to be quantitatively judged related to resultant ground level concentrations.

This section and its sections make reference to the use of computer-based air dispersion models to identify optimum discharge conditions to minimise the ground level concentrations of odour. The computer-based air dispersion models are not described in this document. There are also equations available to calculate optimum stack characteristics and these can be determined without using an expensive air dispersion model. These procedures can be used as a guideline and can, therefore, be used as an initial check to see whether increases to either the stack height or stack velocity are possible. The practicality of carrying out such changes, can also be assessed.

2.1.6.4 Emissions to air control strategy

The strategy is divided into a number of evaluation stages. The extent to which each stage needs to be applied depends on the particular installation situation and certain stages may or may not be required to achieve the levels of protection sought. The strategy can be used for all emissions to air, i.e. gases, dust and odours, some of which are caused by VOC emissions. Odour is mainly a local issue based on nuisance, but as it often arises due to the emission of VOCs, these also need to be considered. For each stage, odour is used as an illustrative example. The approach of this example, summarised in Figure 2.5, is particularly useful for large operating sites where there are a large number of discrete odour sources and where the major contributors to the overall malodorous discharge are not fully understood.
2.1.6.4.1 Step 1: Definition of the problem

Information is gathered about legislative requirements regarding emissions to air. The local setting, e.g. weather and geographical conditions, may also be relevant when defining the problem, e.g. for odour.
2.1.6.4.1.1 Odour example

People working at the installation will generally know well what the odour problems are and can assist a consultant or person unfamiliar with the local situation.

First, the number and frequency of complaints and the characteristics related to odour can be reviewed. The location of the complainants related to the installation, together with any comments made by the complainants or the local authority representatives help to identify what needs to be addressed. A complaints logging system can be set up, which includes a system for answering all complaints made directly to the installation with either a telephone call or personal visit. If the exact processing conditions at the time of the complaint are examined and documented, this can assist in locating the odour sources which need to be controlled.

Any correspondence with the local authority or the local community can be reviewed. The level of activity of the local community together with the approach and actions taken by the local authority representatives can enable the severity of the problem to be established and influence the likely time-scale available to modify the process or install an abatement plant.

Finally, the prevailing local climatic conditions can be established. In particular, the prevailing wind direction and wind speed and the frequency of inversions. This information can be used to ascertain whether the complaints are largely generated as a result of certain weather conditions or are generated by specific operations carried out at the installation.

2.1.6.4.2 Step 2: Inventory of site emissions

The inventory includes normal and abnormal operational emissions. Characterising each emission point allows subsequent comparison and ranking with other site emission points.

A systematic way to identify normal operational emissions to air is to work through each process and identify all potential emissions. For example, this study may cover from raw material delivery and storage, production to packaging and palletising/warehousing.

The study can be conducted with varying degrees of sophistication. Process flow sheets or process and instrumentation diagrams can be used during a tour around the site to systematically identify all the emission sources.

Depending on the severity of the problem and the key site operations that cause the problem, it may be necessary to extend this analysis to cover abnormal and even emergency situations. A checklist approach in conjunction with a process and instrumentation diagram, may be used. The range of keywords to incorporate into the checklist will probably differ considerably from operation to operation.

2.1.6.4.2.1 Odour example

An odour problem may be related to a continuous discharge from the installation that conveys a distinctive odour to the surroundings. Treating the major emission will, in many cases, alleviate the problem and reduce or eliminate the receipt of complaints. In other cases, the removal of the major odour source will result in other odour sources from the site becoming more prominent. These odour sources may have characteristic odours different from those of the major odour source. This situation can subsequently result in further complaints and require further capital expenditure in addition to that already assigned to treat the major odour source. It is important to fully evaluate the range of malodorous emissions from the site and to identify the discrete emissions with the greatest potential to cause odour complaints.

Table 2.13 shows one way of recording information of normal operational odour sources. It may be the case that odour problems only arise during abnormal operations. A typical checklist for abnormal operations is shown in Table 2.14.
Table 2.13: Data sheet for collecting information on malodorous emissions

<table>
<thead>
<tr>
<th>Odour Source: _________________</th>
<th>Examples: _________________</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of discharge</td>
<td>Forced/natural/ventilation</td>
</tr>
<tr>
<td>Process operation conducted</td>
<td>Heating/cooling/maintenance/cleaning</td>
</tr>
<tr>
<td>Continuity of emission</td>
<td>Continuous/discontinuous/periodic</td>
</tr>
<tr>
<td>Operational time</td>
<td>Duration per hour/per day/per production cycle</td>
</tr>
<tr>
<td>Discharge arrangement</td>
<td>Stack/manhole/in building/atmospheric</td>
</tr>
<tr>
<td>Discharge configuration</td>
<td>Stack diameter/elevation of discharge</td>
</tr>
<tr>
<td>Description of odour</td>
<td>Sweet/sour/pungent/fruity</td>
</tr>
<tr>
<td>Strength of odour</td>
<td>Very faint/faint/distinct/strong/very strong</td>
</tr>
<tr>
<td>Estimated flowrate</td>
<td>Measurement/fan curves/estimate</td>
</tr>
<tr>
<td>Location in installation site</td>
<td>Co-ordinates of discharge</td>
</tr>
<tr>
<td>Operation</td>
<td>Normal/abnormal/emergency</td>
</tr>
<tr>
<td>Overall ranking</td>
<td>E.g. -10 to +10 or 0 to 10</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

Table 2.14: Checklist for abnormal operation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of containment</td>
<td>Overfilling/leaks/failure control</td>
</tr>
<tr>
<td>Disposal emptying</td>
<td>Waste materials and process materials</td>
</tr>
<tr>
<td>Potential for material to enter process</td>
<td>Steam coil breakage</td>
</tr>
<tr>
<td>Runaway reaction</td>
<td>Failure to input a material or to control temperature</td>
</tr>
<tr>
<td>Corrosion/erosion</td>
<td>Inspection frequency</td>
</tr>
<tr>
<td>Loss of services</td>
<td>Fail safe instrumentation</td>
</tr>
<tr>
<td>Control/manning</td>
<td>Level of control and supervision</td>
</tr>
<tr>
<td>Ventilation/extraction</td>
<td>Design basis correct</td>
</tr>
<tr>
<td>Maintenance/inspection</td>
<td>Frequency, what is required?</td>
</tr>
<tr>
<td>Start-up/shut-down</td>
<td>Implications for downstream operations</td>
</tr>
<tr>
<td>Throughput changes</td>
<td>100 %, 110 % of production + low production</td>
</tr>
<tr>
<td>Formulation changes</td>
<td>Malodorous ingredients</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

The malodorous emissions can be ranked in terms of the severity of their impact on the surrounding environment. A possible system to devise a ranking order could start with grouping the emissions into categories such as major, medium and minor according to their odour characteristics and the related complaints. The ranking within each category is strongly influenced by the strength of the perceived odour from the source together with the associated airflow and nature of operation, i.e. continuous or non-continuous. This process may require a degree of professional judgement in addition to the factors detailed above.

2.1.6.4.3 Step 3: Measurement of major emissions

Emissions to air are quantified for determining priorities for prevention and treatment. The measurement will allow the emissions to be ordered in terms of the magnitude of their impact.

2.1.6.4.3.1 Odour example

The quantification of the major malodorous emissions is undertaken using the following formula:

$$\text{Odour emission (OU}_\text{E}/\text{s)} = \text{measured odour level (OU}_\text{E}/\text{m}^3) \times \text{associated volumetric airflow (m}^3/\text{s)}$$
Odour measurement is difficult and the results may have a wide statistical deviation. Nevertheless, a quantitative measurement of odour may ultimately be required by a contractor supplying abatement equipment or to demonstrate compliance with legislation.

If the key malodorous emissions are known, together with the related flowrates and with the physical location of the emissions within the site, this will allow a possible treatment scenario to be developed. Table 2.15 is based on a real, but unspecified situation simplified to illustrate the principle. It shows the calculation of odour emissions and, based on this level, this technique proposes an emission ranking. This allows a tentative treatment strategy to be developed, however it does not yet examine whether further account needs to be taken of the operational hours or the impact of the major emissions, including their individual characteristics such as whether the odour is strong, sweet or pungent.

Table 2.15: A typical odour measurement programme, using simplified measurements from an unspecified food manufacturing site

<table>
<thead>
<tr>
<th>Source</th>
<th>Flowrate (m$^3$/s)</th>
<th>Odour level (OU/m$^3$)</th>
<th>Odour emission (OU/s)</th>
<th>Emission ranking based on the odour emission*</th>
<th>Operational hours (h/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material handling</td>
<td>180 000</td>
<td>1 610</td>
<td>22</td>
<td>5</td>
<td>480</td>
</tr>
<tr>
<td>Raw material heating</td>
<td>172 800</td>
<td>1 250</td>
<td>16</td>
<td>6</td>
<td>960</td>
</tr>
<tr>
<td>Process heating</td>
<td>3 960</td>
<td>11 290</td>
<td>3.4</td>
<td>7</td>
<td>2 100</td>
</tr>
<tr>
<td>Vacuum generation</td>
<td>1 440 000</td>
<td>17 180</td>
<td>1 909</td>
<td>2</td>
<td>5 760</td>
</tr>
<tr>
<td>Fat trap</td>
<td>5 760</td>
<td>90</td>
<td>0.04</td>
<td>8</td>
<td>6 240</td>
</tr>
<tr>
<td>Vent to air from process plant</td>
<td>6 912 000</td>
<td>350</td>
<td>190</td>
<td>4</td>
<td>48</td>
</tr>
<tr>
<td>Packing hall</td>
<td>45 720 000</td>
<td>80</td>
<td>275</td>
<td>3</td>
<td>5 760</td>
</tr>
<tr>
<td>Waste facility</td>
<td>12 600 000</td>
<td>2 690</td>
<td>2 611</td>
<td>1</td>
<td>387</td>
</tr>
</tbody>
</table>

NB: *This does not take account of odour impact, exposure times or other characteristics. Number 1 has the highest priority for treatment as it has the highest emission level, down to 8 which is the lowest.

Source: [16, Willey et al. 2001]

Air dispersion modelling can enable the impact of the major measured emissions to be fully quantified. The impact, in this respect, is the resultant ground level odour concentration of the total emissions from the site at varying distances from the site boundary related to climatic conditions, to determine any required action to control odour emissions. If there are several odours or components from the same source, which is usually the case, these may all be considered together. If there is more than one odour source, it is necessary to consider each one separately.

2.1.6.4.4 Step 4: Selection of air emission control techniques

An inventory of emissions, immissions and complaints, e.g. in the case of odour, which often arises due to the emission of VOCs, can identify the major sources of emissions to air from the site that need to be part of a treatment plan or strategy. It enables any sources whose impact can be eliminated or, if not, reduced to be identified. Control techniques include process-integrated and end-of-pipe treatment.

Process-integrated treatment includes substance related measures, such as selecting substitutes for harmful substances such as carcinogens, mutagens or teratogens; using low emission materials, e.g. low volatility liquids and low fine dust solids and process related measures, such
as using low emission systems and production processes. If, after applying process-integrated measures, emission reduction is still required, further control of gases, odour/VOCs and dust by the application of end-of-pipe techniques may be needed.

When selecting odour abatement techniques, the first stage is to analyse the flowrate, temperature, humidity, and the particulate and contaminant concentrations of the malodorous emission. Odours often arise due to the emissions of VOCs, in which case the abatement technique applied needs to take account of toxic and flammable hazards. A summary of generalised criteria for selecting odour/VOC abatement techniques is shown in Table 2.16, where these parameters are shown in a matrix against some generic types of abatement equipment available. Table 2.16 is a guideline and does not contain the full details about the advantages and limitations of individual techniques. Each property of the malodorous emission has been segregated into two or three ranges. In this example, flowrate is segregated into two ranges, i.e. above and below 10 000 m$^3$/h. Each cell in the matrix has been assigned a value of 0 to 3, with a value of 3 representing the optimum operating condition.

For each of the abatement techniques, the relevant range of each of the malodorous emission properties is totalled. This allows a simple ranking system, by which the techniques with the highest scores are considered further. Typically, three to five abatement techniques are carried forward to the next stage in the selection procedure.

### Table 2.16: Summary of generalised criteria for selecting odour/VOC abatement techniques

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Flowrate (m$^3$/hr)</th>
<th>Temperature (°C)</th>
<th>Relative humidity (%)</th>
<th>Particulate (mg/Nm$^3$)</th>
<th>Contaminant concentration (mg/Nm$^3$)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;10000</td>
<td>&gt;10000</td>
<td>&lt;50</td>
<td>&gt;50</td>
<td>&lt;75</td>
<td>&gt;75</td>
</tr>
<tr>
<td>Physical</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Absorption-water</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Absorption-chemical</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Adsorption</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Biological</td>
<td>3*</td>
<td>2*</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Thermal oxidation</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Catalytic oxidation</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Plasma</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1–2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

**Score rating**  
0  This treatment is not suitable or unlikely to be effective, so is not considered as part of the selection procedure.
1  Worthwhile considering although unlikely to be the best choice
2  The abatement technique is well suited for this condition
3  Represents the best operating condition for the given treatment system
*  Depends on the surface area

**Source:** [16, Willey et al. 2001]

The effectiveness or required performance is considered next. This can be assessed using professional guidance and information from the manufacturers of the abatement techniques. The next step in the selection procedure is a feasibility assessment. The capital and operating costs, space requirements and whether the abatement technique has been proven to be applicable in a similar process, are all considered. Figure 2.6 shows a flow sheet that summarises this process of selecting end-of-pipe odour/VOCs abatement techniques.
Figure 2.6: Flow sheet for the selection of odour abatement equipment

(Source: 16, Willey et al, 2001)
2.1.7 Accidental release

One of the most significant potential environmental impact associated with an FDM installation is an accident which could pollute the environment, this is usually characterised by an accidental release of material directly to air, water or land, although it may also be a failure that leads to the generation of otherwise avoidable waste. For example, the accidental release of the contents of a tank containing raw material, e.g. milk; or product, e.g. vegetable oil, or an auxiliary material such as, ammonia, can have a significant detrimental impact on a local watercourse or water supply. Such accidents may occur during routine or non-routine operations.

There are a number of stages in the management of accidental releases:

- identify potential accidents that could pollute the environment;
- conduct a risk assessment on the identified potential accidents to determine their probability of occurrence and potential specific type and severity of harm to the environment;
- develop control measures to prevent, eliminate or reduce, to an acceptable level, the risks associated with identified potential accidents;
- develop and implement an emergency plan;
- investigate all accidents and near misses, to identify their causes and take action to prevent recurrence.

Identification of potential accidents

Description

Accidents may occur as the result of, e.g.

- loss of containment from bulk storage, e.g. leakage, spillage and vessel failure
- loss of containment from in process control failures
- failure or malfunction of end-of-pipe techniques
- failure of utilities supply, e.g. water or electricity.

Information about potential accidents identified can then be used to assess the risk (see Section).

Information that can be used includes, e.g.

(a) Information about substances on site

The potential for accidents is significantly influenced by the raw materials, auxiliary materials, intermediate products, products and the waste on the site, so it is important to:

- maintain an inventory of substances. It may be a legal requirement to provide this to the emergency services
- assess their potential environmental (and safety) hazards. A good source of safety and environmental information is material safety data sheets, which are supplied by the substance supplier and product data sheets, which are normally developed internally within the company
- information on quantities stored on-site and their location.

(b) Identification of the emissions from unit processes/emission inventory

It is important that all streams/emissions or potential streams/emissions which could give rise to an abnormal occurrence/accidental release are identified.
The most systematic way to do this is to work through each process and identify all the potential emissions. This will typically include:

- raw material delivery
- bulk raw material storage
- minor raw material storage, egg drums, sacks, intermediate bulk containers
- production
- packaging
- palletising
- warehousing.

As well as considering the processes, the ancillary equipment/processes on the site will also need to be considered. This will typically consist of:

- utilities, e.g. boiler house, compressed air, water treatment, ammonia systems
- internal transport on the site, e.g. forklift trucks.

Possible scenarios that may result in an accidental sudden increase in the noise levels at the site boundary are also considered.

(c) Installation/site plan

The installation/site plan is used to show the site drainage system and control/abatement mechanisms already in place, the location of bulk storage and drum storage facilities for materials stored in bulk and for materials that are particularly hazardous, transfer systems, such as pipelines for hazardous substances, major air emission points and sensitive boundaries and receptors. It is important that the plan is kept up to date.

(d) Location related to environmental receptors

Depending on the substance released due to an accident, the harm may be considered as a global issue or the pollution impact may only be significant within an area surrounding the installation. To understand the potential environmental impact an accidental release may have, it is important to have knowledge of the local environment situation. Although there are areas of similarity between sites, there will also be differences, e.g. installations located in rural areas, residential areas and industrial areas are likely to have different environmental issues. Accidental releases of emissions to air, odour and sudden increases in noise levels are all likely to be key issues for installations located close to residential areas, whereas the impact on the local watercourses and wildlife may be more of a concern in rural areas. Public amenities will need to be considered, particularly where surface water or treated waste water is discharged into a local river or where there is potential for groundwater contamination.

In addition, it is useful to have a basic knowledge of the geology and hydrogeology of the area on which the installation is built. If it is located on clay soils, then a spillage will take a longer time to permeate through to groundwater beneath it than if it is on sandy or permeable soil.

A site survey can identify all the environmental receptors for the site and identify any which are particularly sensitive, e.g.

- a receiving watercourse collecting treated water and/or surface water
- housing on the site boundary
- a local tourist attraction adjacent to the site
- local schools/hospitals
- sensitive aquifers
- sites of specific scientific interest
- an area of outstanding natural beauty.
(e) Site history

The objective in documenting the site history is to demonstrate that a site is free from environmental problems which might arise from past activities. The information gathered can also provide a baseline from which to assess the impact of any accidental releases that may occur in the future.

The main issue is normally one of contaminated land or contaminated groundwater. This can arise from sources such as underground storage tanks, poor bunding and spill protection, on-site landfilling or leaking drains. By documenting the past land use, areas where contamination might have occurred can be identified and, if necessary, investigations involving soil/groundwater sampling and analysis can be undertaken. Investigations of this type are typically only carried out if it is believed that there is a reasonable risk that the land or groundwater is contaminated.

(f) Other information

Other factors which assist in the identification of potential sources of environmental incidents include:

- previous incidents including near misses
- technological and management/operational controls that are in place and the potential failure of these controls
- human behaviour, the interaction between operators and manufacturing operations and the potential of an environmental incident occurring due to human behaviour.

(g) Structured techniques

Structured techniques can be used to identify potential accidents. These techniques examine in detail flow diagrams of the manufacturing operation under study. HAZOPS (Hazard and Operability Studies), FMEA (Failure Mode and Effects Analysis) and SWIFT (Structured What-If Technique) are examples of such methods. These techniques can be time consuming and resource intensive and are typically not used for installations where processes and unit operations are relatively simple.

Achieved environmental benefits

Reduced risk of accidents which may pollute the environment.

Technical considerations relevant to applicability

Applicable in all FDM installations; however, if potential accidents are identified at the design stage of an installation, their prevention can be more easily and economically incorporated than if they are added later.

Driving force for implementation

Reduced risk of accidents which may pollute the environment.

Example plants

Widely applied.

Risk assessment

Description

A risk assessment is an important part of the management procedure, as it is the application of this technique which will determine whether managers consider whether there is a significant risk of an accident occurring.
The depth and type of risk assessment carried out will depend on the characteristics of the installation and its location. The scale and nature of the activities taking place at the installation under investigation and the risks to the environment, including to people, need to be taken into account.

A hazard is anything with the potential to cause harm. A risk is the likelihood that a hazard will cause a specified harm to someone or something, i.e. whether the chance is high or low, that harm will be caused by the hazard.

(a) Severity

Some examples of severity, using a 0–4 scale, where 4 is the highest level of severity, are:

- a spillage of solid on-site that is completely contained and can be used would not cause any environmental harm so would be scored 0
- if the spillage caused very short term and low severity contamination of part of the land on-site, this would score 1. However, if the spillage penetrated into groundwater, and could cause damage on a regional scale by polluted water supplies, the score would be between 2 and 4 depending on the pollutant, the quantities involved and the sensitivity of the groundwater, e.g. is it being used as a source of drinking water
- if the spillage entered the surface water drainage system, then there could be minor, moderate or major damage to the local environment. Depending on the scale and toxicity of this release it would score 2, 3 or 4.

(b) Probability

The probability of occurrence depends on whether all the precautions necessary, e.g. by law and accepted as, e.g. national, international or industry standards are already in place and maintained, for the installation-specific processes and operations. The probability can also be given a score, e.g. on a 1–5 scale, where 5 is the highest probability.

(c) Overall risk assessment

The overall level of risk is obtained by multiplying the severity by the probability.

Application of an assessment allows a systematic analysis of the potential accidents to be made and helps prioritise risk control measures, making sure that the most important risks are tackled first.

Achieved environmental benefits

Reduced risk of accidents which may pollute the environment.

Environmental performance and operational data

Risk assessments become out of date when technological or operational conditions change. To ensure they are effective, they need to be updated periodically and when significant changes occur at the installation, such as the introduction of new unit operations.

Public sensitivity does not necessarily correlate with environmental harm or legal compliance. It is more likely to be assessed based on the number of complaints from the public and the regulatory authorities, and the interest shown by these parties over the activities associated with the site.

Technical considerations relevant to applicability

Applicable in all new and existing FDM installations.

Driving force for implementation

Reduced risk of accidents which may pollute the environment.
Identify potential accidents which need to be controlled

Description

Once the risk assessments have been completed, it is then necessary to identify accidents that may have a significant environmental impact and which are currently not adequately controlled. This is done using the results of the risk assessment. The scoring system can be used to identify priorities for action. These may change with time as part of a continuous environmental improvement programme.

Achieved environmental benefits

Reduced risk of accidents which may pollute the environment.

Technical considerations relevant to applicability

Applicable in all new and exiting FDM installations, however, if potential accidents are identified at the design stage of an installation, their prevention can be more easily and economically incorporated than if they are added later.

Driving force for implementation

Reduced risk of accidents which may pollute the environment.

Example plants

Widely applied.

Identify and implement control measures needed

Description

An evaluation has to be undertaken on the identified sources of potential accidents to determine whether new control measures are required or existing control measures need to be improved.

Typical control measures that can be considered are:

- management procedures
- operational procedures
- preventative techniques
- containment
- process design/process control.

(a) Management procedures

Management system procedures can be put in place to assess new activities on the site and to ensure that environmental issues, including the possibility of accidental releases, have been taken into account. These procedures may include:

- procedures to assess the environmental risk associated with new raw materials
- ensuring adequate control measures are in place
- checking compatibility with other materials and feedstocks with which they may accidentally come into contact
- implementing procedures to assess new processes to ensure adequate control measures are incorporated at the design stage to prevent or minimise accidental releases.

(b) Operational procedures

Operational procedures need to be developed covering critical process plant items to ensure that the risk of accidents is minimised.
Operator instructions for the process plant include, e.g.

- carrying out routine checks on potential sources of accidental releases and any control measures that may be in place
- carrying out regular checks on pollution abatement equipment such as bag filters, cyclones and waste treatment facilities
- carrying out regular inspections of underground storage tanks and containment bunding.

(c) Preventative techniques

One example is:

- incorporating suitable barriers to prevent damage to equipment from the movement of vehicles.

(d) Containment

These measures may include:

- applying bunding for bulk storage of materials
- using spillage equipment to minimise impact of an accidental release
- isolating drains
- the containment or abatement of accidental releases from safety relief valves or bursting discs.

(e) Process design/process control

The process plant needs to be designed and controlled so that the risk of accidental releases of material are either eliminated or minimised to acceptable levels.

Process design/control measures may include:

- applying techniques to monitor the efficiency of abatement equipment, e.g. pressure drop across bag filters
- applying techniques to prevent the overfilling of storage tanks, e.g. level measurement, high level alarms and high level cut off controls.

Achieved environmental benefits

Reduced risk of accidents which may pollute the environment.

Technical considerations relevant to applicability

Applicable in all new and exiting FDM installations.

Driving force for implementation

Reduced risk of accidents which may pollute the environment.

Example plants

Widely applied.

Develop, implement and test an emergency plan

Description

Emergency procedures/plans need to be developed and put in place to ensure that, if an event does occur, the normal situation can be restored with a minimum effect on the environment. If the plan is not tested, it may not work properly if an accident occurs and it is needed. If
conditions on the site or responsibilities are changed, then the emergency plan will need to be revised.

Normally, emergency plans need to be drawn up for the whole site and they cover safety and significant environmental risks. Emergency procedures covering the significant environmental risks identified can then be incorporated into the overall emergency plan. A typical emergency plan covering environmental incidents includes the following components:

- roles and responsibilities of individuals need to be clearly defined including:
  - procedures for operators who remain to operate critical plant operations
  - escape procedures and routes
  - procedures to account for all employees
- assignment of rescue and medical duties
- procedures for reporting emergencies and informing relevant environmental authorities and emergency services need to be put in place/agreed
- action needs to be taken to minimise the impact of any environmental incident
- names of employees need to be listed.

For example, it is recommended that emergency procedures are in place to cover incidents which might involve the accidental release of the following:

- ammonia
- liquid raw materials or product stored in bulk, e.g. edible oil and milk
- dust from drying operations, such as spray drying
- potentially hazardous auxiliary materials, e.g. biocides and diesel oil.

The main aim of an emergency plan is to restore the normal conditions as quickly as possible with the minimum effect on the environment. Emergency situations vary greatly in scale and complexity and it is important that emergency plans are flexible enough to deal with the minor as well as major events and that they are also simple enough to be quickly implemented.

The effects of potentially catastrophic incidents can be substantially reduced by systematically preparing, and regularly thoroughly testing, plans with informed and trained people. There is not enough time during an emergency to decide who is in charge, to survey outside agencies to identify sources of help, or to train people for emergency response. These should be provided for before an emergency situation occurs.

Some other reasons for preparing emergency plans are:

- reducing the thinking time once an accident has occurred can significantly reduce its consequences, in terms of, e.g. injuries to people, damage to property, environmental effects and loss of business
- to ensure that the situation is orderly, rather than chaotic
- to reduce bad publicity, since serious accidents can have a bad impact on an organisation’s image and subsequently on sales and public relations
- to fulfil legal requirements. Emergency plans are required in many countries
- to enable provisions to be in place for informing external agencies, the general public, the media and company senior management.

The emergency plan can also ensure that appropriate control techniques are put in place to limit consequences of any accident, such as oil spillage equipment, isolation of drains, alerting of relevant authorities, evacuation procedures, etc.

Achieved environmental benefits
Minimising the pollution resulting from accidents.
Technical considerations relevant to applicability
Applicable where there is a significant risk of pollution occurring from an accident.

Driving force for implementation
Minimising the pollution resulting from accidents, limiting the damage to a company’s image after an accident and limiting the various costs associated with restoring the site and legal fines and liabilities.

Example plants
Widely applied.

Investigate all accidents and near misses

Description
Lessons can be learned from investigating all accidents and near misses. The reasons for the accidents and near misses occurring can be identified and action can be taken to prevent them from happening again. If near misses are not investigated, the opportunity to prevent an accident may be missed. Keeping records can help to ensure actions are taken and preventive controls are maintained.

Achieved environmental benefits
Reduced risk of accidents which may pollute the environment.

Environmental performance and operational data
An example of a near miss is someone noticing that an empty storage tank valve has been left open, but with sufficient time to close it before the tank is refilled. Introducing and using a technical or operational solution to prevent this may prevent a future accident involving liquids being pumped into an open tank and directly to the WWTP or spilling into a yard and then to surface and/or groundwater. Waste generation and accidental releases are both then prevented.

Technical considerations relevant to applicability
Applicable in all new and exiting FDM installations.

Driving force for implementation
Reduced risk of accidents which may pollute the environment.

Example plants
Widely applied.
2.2 Current consumption and emission levels across the FDM sector

Benchmarking

This chapter presents the data and information provided about current consumption and emission levels in the FDM sector. Section gives general information about consumption and emission levels in the whole sector. Section gives more detailed information about the processing techniques and unit operations listed in. Section reports data for specific FDM sectors.

In the FDM sector, energy, water and chemicals are consumed and gaseous, solid and liquid outputs are generated. These may have a negative impact on the environment and may be due to the inefficient use of materials or processes.

This chapter also contains information about outputs that are not the main final product and are not disposed of as waste. The FDM sector distinguishes between main products, co-products, by-products, returned products and waste, as shown in Figure. Normally the main product has the highest economic value.
In this document, co-products, by-products and returned products have the following meanings.

A co-product is a material, intentionally and unavoidably, created in the same process and at the same time as the main product. Both a main product and a co-product may each meet a set specification or design, and individually each is capable of being used directly for a particular purpose. For example, in the FDM sector some co-products are wheat gluten, maize gluten feed, maize gluten meal, maize germ, wheat feed, corn steep liquor, fruit pulp, concentrated fruit water, potato fibres, potato proteins, potato fruit water, malt culms, small barley, beet pulp, vinasses, DDGS and husks.

A by-product is a residual material which arises during the manufacture of a product. It may be used directly itself as an effective substitute for a product or may be used as an ingredient in another manufacturing process to create a different product, e.g. sludge and filter residues from filtration.

Returned products are those returned from retailers and wholesalers because they do not meet the required specification or because their shelf-life has expired.

The consumption and emissions information is important as part of the benchmarking process, and in the selection of techniques considered to be BAT.

Benchmarking is a technique used to assess performance against either internal or industry standards [11, Environment Agency of England and Wales, 2000]. Operational or technological improvement measures first applied at one site, may be applicable at others, even in different FDM sectors. These techniques may be considered in addition to comparing numerical consumption and emission levels.

Typically, benchmarks are expressed as ratios, but can be expressed as percentages, e.g. of efficiency. In this respect, data on waste minimisation, water and energy consumption, odour, noise and emissions to air and waste water, are generally relevant. Table shows quantitative benchmarking parameters applicable in the FDM sector.
Table: Quantitative benchmarking parameters applicable in the FDM sector

Data on water and energy consumptions vary, not only with the type of process and how it is operated, but also with the size of operation.

Data on emissions to air and water are available for some sectors and even for some processes within installations, but the latter are scarce. In the future, more detailed information may be available about emissions to air and water, when this is reported to the EC’s European Pollutant Emission Register (EPER). This is a requirement under Commission Decision 2000/479/EC [221, EC, 2000]. Guidance from the EC [93, EC, 2000] includes an FDM sector-specific checklist for the pollutants likely to be emitted to air and water. For FDM activities under Annex I paragraph 6.4 of the IPPC Directive, six air pollutants, i.e. methane, carbon monoxide, carbon dioxide, HFCs, ammonia and NOx, and four water pollutants, i.e. total nitrogen, total phosphorus, TOC and chlorides, are listed.

Within the FDM sector, the most common benchmarks compare utilities’ consumption against production and, therefore, give a good indication of the efficiency and also of wastage occurring within the process. This is also called quantitative benchmarking. The percentage of raw materials going to the final main products is variable and waste minimisation is generally considered as a cost effective goal for all manufacturers but benchmarks are not readily available. Table shows some examples of the percentages of raw materials which end up in the final main product.

<table>
<thead>
<tr>
<th>Production process</th>
<th>% of raw material in the main final product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish canning</td>
<td>35–70</td>
</tr>
<tr>
<td>Fish filleting, curing, salting and smoking</td>
<td>25–50</td>
</tr>
<tr>
<td>Crustacean processing</td>
<td>40–50</td>
</tr>
<tr>
<td>Mollusc processing</td>
<td>50–80</td>
</tr>
<tr>
<td>Milk, butter and cream production</td>
<td>~99</td>
</tr>
<tr>
<td>Yoghurt production</td>
<td>99–98</td>
</tr>
<tr>
<td>Fresh, soft and cooked cheese production</td>
<td>10–15</td>
</tr>
<tr>
<td>White wine production</td>
<td>70–80</td>
</tr>
<tr>
<td>Red wine production</td>
<td>70–80</td>
</tr>
<tr>
<td>Fruit and vegetable juice production</td>
<td>50–70</td>
</tr>
<tr>
<td>Fruit and vegetable processing and preservation</td>
<td>70–95</td>
</tr>
<tr>
<td>Vegetable oils and fats production, i.e. crude vegetable oil, protein rich meal, lecithin and fatty acids from oilseeds</td>
<td>30–60</td>
</tr>
<tr>
<td>Maize starch production</td>
<td>62.5</td>
</tr>
<tr>
<td>Maize starch production (including animal feed)</td>
<td>90</td>
</tr>
<tr>
<td>Potato starch production</td>
<td>20</td>
</tr>
<tr>
<td>Potato starch production (including animal feed)</td>
<td>30–35</td>
</tr>
<tr>
<td>Wheat starch production</td>
<td>50</td>
</tr>
<tr>
<td>Wheat starch production (including animal feed)</td>
<td>90</td>
</tr>
<tr>
<td>Food and animal feed production from sugar beet</td>
<td>25–50</td>
</tr>
</tbody>
</table>

Table: Percentage of raw materials which end up in the final product in some processes
[113, AWARENET, 2002]
Consumption and emissions in unit operations

It is quite difficult to give quantitative data on the environmental aspects of individual processing techniques. This is due to a lack of reliable data or due to natural variations, e.g. seasonal, in many of the raw materials. This often leads to changes in the processing techniques applied. The ranges in the quantitative data are very largely due to the very wide variation in individual process applications. Often better quantitative information is available on the environmental aspects of the whole production line rather than on individual processing techniques, because measurements have not been made at unit operation level.

Examples are given of some qualitative and quantitative environmental aspects of typical production lines. In the description of environmental aspects of the various processing techniques, “solid output” covers both by-products from the process which could be valorised, as well as waste which cannot be valorised. For example, some by-products from the FDM sector can be used as animal feed.

The main sources of consumption and emissions are identified for each processing technique. The identified list of sources is not all encompassing, or every installation within an individual sector have every one of the emissions. The information is associated with the FDM sector as a whole. Local variations apply, depending on the raw materials used, the type of processes applied and how they are applied.

Some process emissions are considered to have little potential environmental significance and these are designated as minor, however, there could be specific installations where this designation may be incorrect. Such emissions are examined on a case-by-case basis.

The environmental impacts or process emissions for each of the unit operation described in Section 19.1 are summarised in Table. The symbols alongside each operation describe the characteristic of the emission. The meaning of the codes used are given in Table, Table and Table.

<table>
<thead>
<tr>
<th>Code</th>
<th>Unit Operation</th>
<th>Environmental Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Air</td>
</tr>
<tr>
<td>A.1</td>
<td>Materials handling and storage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tank vents</td>
<td>S1, S3</td>
</tr>
<tr>
<td></td>
<td>Silos</td>
<td>S2</td>
</tr>
<tr>
<td></td>
<td>Material handling/transport</td>
<td>S1, S2, S3</td>
</tr>
<tr>
<td>A.2</td>
<td>Sorting, screening, grading, dehulling, destemming/de-stalking and trimming</td>
<td>S1, S2</td>
</tr>
<tr>
<td>A.3</td>
<td>Peeling</td>
<td>N</td>
</tr>
<tr>
<td>A.4</td>
<td>Warming</td>
<td>N</td>
</tr>
<tr>
<td>A.5</td>
<td>Thawing</td>
<td>N</td>
</tr>
<tr>
<td>B.1</td>
<td>Cutting, slicing, chopping, mincing, pulping and pressing</td>
<td>N</td>
</tr>
<tr>
<td>B.2</td>
<td>Mixing/blending, homogenisation and conching</td>
<td>S1, S2, S3</td>
</tr>
<tr>
<td>B.3</td>
<td>Grinding/milling and crushing</td>
<td>S2, S3</td>
</tr>
<tr>
<td>B.4</td>
<td>Forming/moulding and extruding</td>
<td>N</td>
</tr>
<tr>
<td>C.1</td>
<td>Extraction</td>
<td>S1, S3</td>
</tr>
<tr>
<td>C.2</td>
<td>Deionisation</td>
<td>N</td>
</tr>
<tr>
<td>C.3</td>
<td>Fining</td>
<td>N</td>
</tr>
<tr>
<td>C.4</td>
<td>Centrifugation and sedimentation</td>
<td>N</td>
</tr>
<tr>
<td>C.5</td>
<td>Filtration</td>
<td>M</td>
</tr>
<tr>
<td>C.6</td>
<td>Membrane separation</td>
<td>N</td>
</tr>
</tbody>
</table>
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Table: Environmental impacts of the FDM unit operations

[1, CIAA, 2002]
2.2.1 Energy consumption

The FDM sector accounts for approximately 10% of the industrial final energy consumption and 25% of the total final energy consumption in the EU-28 [276, COM 2016]. Data on specific energy consumption are available in the sectorial chapters. The calculation of specific energy consumption is based on the following equation:

\[
\text{specific energy consumption} = \frac{\text{energy consumption}}{\text{production}}
\]

where:
- energy consumption, expressed in m$^3$/year, is the total amount of energy used by the FDM installation; it is obtained by subtracting the total amount of energy generated from by-products and effluents from the total energy consumption;
- production, expressed in tonnes/year, is the total amount of product (or raw material, depending on the specific sector).
The FDM sector depends on energy for processing, storage, to maintain freshness and to ensure food safety. Process heating uses approximately 29 % of the total energy used in the FDM sector. Process cooling and refrigeration accounts for about 16 % of the total energy used. Also, cleaning is commonly carried out at elevated temperatures, which, therefore, requires the use of energy to heat water and produce steam.

In Germany, the FDM sector consumed about 54500 MWh/yr in 1998, representing 6.7 % of the total German energy consumption making it the fifth largest energy consumer among all industrial sectors. The energy was produced using 49 % gas, 23 % electricity, 21 % oil, and 7 % coal. The energy consumption doubled in 30 years from 1950 to 1980. There was a slight decrease in the 1980s and 1990s [2, Meyer, et al., 2000].

**Boilers**

Boiler treatment chemicals, silica and other soluble minerals are concentrated within boilers. They are removed by blowing down the boiler at a rate of 1 % to more than 10 % of the steam production rate. The blowdown water is discharged and treated either in an on-site or off-site WWTP. Blowdown needs to take place to maintain the efficient, and ultimately safe, operation of the boiler.

The main products resulting from the combustion process are CO$_2$ and water vapour. CO$_2$ emissions from coal firing are almost twice as those from natural gas. The contaminants generated and emitted depend on the fuel type, combustion process and combustion plant design. These are SO$_2$, CO, NO$_x$ and dust. Emissions of SO$_2$ are a result of the sulphur content of the fuel. Gas has only trace amounts of sulphur. Gasoil has up to 0.1 % by weight of sulphur. Coal has between 0.5 % and 2.5 % by weight of sulphur. Fuel oil may have up to 3.5 % by weight of sulphur.

Emissions of NO$_x$ depend not only on the fuel, but also on the inherent design of the combustion unit and the flame temperature. Gas, generally, does not contain any significant amounts of nitrogen compounds but will produce NO$_x$ from the oxidation of the nitrogen in the combustion air. Therefore, NO$_x$ from gas combustion is the lowest of any fossil fuel. NO$_x$ emissions may be reduced by steam injection into the burning chamber of the gas turbine or by using low NO$_x$ burners.

When the product is heated and/or dried by direct contact with combustion gases, VOCs and odours are released with the process air. The heat released at a chimney depends on the fuel type and plant design. The consumption of purchased electricity does not cause emissions at FDM installations as the emissions take place at the power station. Information about emissions at large combustion plants, i.e. those with a rated thermal input exceeding 50 MW, is available in the Large Combustion Plants BREF [256, COM 2016].

Ashes from solid fuel fired boilers and scale and inert soot deposits which are removed during periodic boiler maintenance and cleaning, are produced. They are sent for landfill.

Normal boiler operations do not give rise to noise outside the installation, but this depends on the measures taken to contain the noise and the proximity of neighbouring premises. During process interruptions, and during periods of testing and commissioning, there may be short periods when the boiler safety relief valve operates. This effect is likely to be local to the installation but could be a source of nuisance during that period. Large relief valves can be provided with silencers.

**Combined heat and power generation (CHP)**

In the dairy sector, it is reported that CHP is a good option as evaporation/drying steps need both electricity and thermal heat in large amounts. For example, CHP is widely used during
whey and milk drying, where high steam temperatures and pressures are needed, e.g. 220–240 °C and 32–34 bar. Losses in the pipe system is also taken into consideration, so that steam generation occurs at 40 bar minimum. CHP on the basis of a back pressure steam turbine is used. In this type of CHP equipment, the steam pressure difference in the back pressure steam turbine generates mechanical energy for the propulsion of an electric generator. Before whey and milk drying, lower steam temperatures and pressures are needed. This low pressure steam can be provided either by steam pressure reduction with throttle valves or by CHP on the basis of a back pressure steam turbine. The CHP option is more energy efficient as steam pressure reduction with throttle valves “destroys” energy.

If drying is not carried out in the dairy and the required steam temperatures and pressures are considerably lower, the back pressure steam turbine is not useful because the steam pressure head is too small which results in poor efficiency. In these cases, block type thermal power stations with gas or diesel engines, or CHP equipment with gas turbines and downstream waste heat boilers, are reported to be more appropriate. Figure shows Sankey diagrams comparing energy efficiencies in a conventionally operated gas turbine and generator and CHP equipment in a dairy.

In an example brewery, a CHP system generates electrical power using a 4000 kW gas turbine generator. High pressure steam at 1.5 MPa is produced from exhaust gas from the turbine using an 11 t/h exhaust gas boiler. This steam merges with high pressure steam from existing boilers, and runs a back pressure steam turbine driven refrigerating machine with a 734 kW capacity. Exhaust steam from the back pressure turbine, with a pressure lowered to 0.6 MPa, is used as the heat source driving an ammonia absorption refrigerating machine with a 1.93 kW capacity, which supplies a secondary refrigerant, e.g. brine, used for cooling beer. The system thus makes cascading use of energy from steam and reduces the brewery’s electrical demand by 820 kW in total, 220 kW for the steam turbine driven engine and 600 kW for the ammonia absorption.
Chapter 2

refrigerator. If the process is run batch wise, the demand for steam is not constant. In this case, if a steam turbine-driven refrigerator alone was used to produce energy to chill, its availability would largely depend on this unstable demand for steam. This system can reportedly be used in ice-cream manufacturing installations, as they also consume large amounts of electricity and energy to chill. Figure shows a flow sheet of this CHP system in a brewery.

Figure: Flow sheet of a CHP system in a brewery.

The previously described CHP system reduced the energy consumption of the brewery, e.g. electricity and fuel by 14 % and the electrical demand by 40 %. The gas turbine had a rated output of 4 200 kW at 0 ºC and burned low CO₂ emitting natural gas in a low NOₓ premixed lean burn combustion system. The premixed lean burn combustion enhances turbine efficiency by 2–4 % and reduces NOₓ emissions to less than 50 ppm, i.e. half that of conventional systems where water or steam injection is used for NOₓ emissions reduction. The system reduced NOₓ emissions from the brewery by 14.8 % in comparison with a conventional system, and CO₂ emissions by 7.9 %.

It is also reported that gas engines using clean fuel and with high thermal efficiencies are suitable for small scale CHP equipment, i.e. 1 000 kW or below. An example brewery installed a 596 kW gas engine with a cooling system that uses boiling water for steam recovery. The CHP was mounted on a vibration proof foundation together with a generator of 560 kW in combination with a steam and water drum, which recovers 1 kg/cm² low pressure steam directly from the engine’s cooling water. The exhaust gas from the engine is used to generate 8 kg/cm² medium pressure steam by a waste heat boiler and to preheat feed-water to the boiler by an economiser. The CHP is equipped with a NOₓ removal three way catalytic converter, a silencer and other necessary control systems, and can be monitored from a central control room. The reported environmental benefits include a power generation of 541 kW, low NOₓ emissions and low noise. The power generating efficiency, the heat recovery efficiency and the overall efficiency of the CHP during 18 000 operating hours are 31.3, 45.6 and 76.9 %, respectively. The electricity generated by the CHP supplemented 25 % of the purchased power from an electricity supplier and the steam also satisfied 6–10 % of the operational requirements of the brewery. The payback period is within 4 years. [5, German Dairy Association 1999], [19, German Dairy Association 2001], [31, CEFS 2001], [39, Environment Agency of England and Wales 2001], [55, CADDET 2000].
2.2.2 Water consumption

Water consumption is one of the key environmental issues for the FDM sector. Water has many different uses, e.g.:

- for cooling and cleaning;
- as a raw material, especially for the drinks industry;
- as process water, e.g. for washing raw materials, intermediates and products;
- for cooking, dissolving and for transportation;
- as auxiliary water, e.g. for the production of vapour and vacuum;
- as sanitary water.

The quality of water needed depends on the specific use.

Generally, large quantities of water are required for cleaning and disinfection. In many installations, this is the main consumer of water, with the amount depending on the type and size of equipment to be cleaned and the materials processed. Cleaning and disinfection produces waste water. This typically contains soluble organic material, FOG, TSS, nitrate, nitrite, ammonia and phosphate from product remnants and removed deposited soil. It also contains residues of cleaning agents, e.g. acid or alkali solutions. In principle, the cleaning and disinfection agents that are used are discharged via the waste water, either in their original state or as reaction products.

In 1998 in Germany, the total industrial water consumption was 8500 million m$^3$ of which 304 million m$^3$ was used by the FDM sector. Nevertheless, the actual amount of water used in the FDM sector in that period was reported to be 1730 million m$^3$, i.e. more than the total consumption figure. This is because of the proportion of water that was recycled and reused. On average, the number of times water was reused in the German FDM sector increased from 3.4 times to 4.2 times between 1995 and 1998.

Of the 1730 million m$^3$ of water used by the German FDM sector in 1998, 834 million m$^3$, i.e. more than a half, was used as cooling water and 438 million m$^3$ was used as process water. The amount of water used from various sources by the German FDM sector in 1998 is shown in Figure.

**Figure: Water consumption by the German FDM industries in 1998 [182, Germany, 2003]**

In the FDM sector as a whole, about 66 % of the total fresh water used is of drinking water quality. In some sectors, like dairies, soft drinks and mineral water manufacturing and breweries, up to 98 % of the fresh water used is of drinking water quality.

Table shows a summary of reported water consumption and waste water volumes for some of the FDM sectors. Some of the consumption and emission values are inconsistent.
<table>
<thead>
<tr>
<th>Sector</th>
<th>Water consumption</th>
<th>Waste-water volume</th>
<th>Unit</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meat and poultry</td>
<td>2–20 m³/t</td>
<td>20–25 m³/t</td>
<td>**</td>
<td>[41, Nordic Council of Ministers, 2001, 89, Italian contribution, 2001]</td>
</tr>
<tr>
<td>Fish</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herring filleting</td>
<td>3.3–10 m³/t</td>
<td>2.40 m³/t</td>
<td>**</td>
<td>[27, ATV, 2000, 28, Nordic Council of Ministers, 1997]</td>
</tr>
<tr>
<td>Mackerel</td>
<td>20–32 m³/t</td>
<td>2–40 m³/t</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>White-fish</td>
<td>4.8–9.8 m³/t</td>
<td>10–25 m³/t</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>Shrimp processing</td>
<td>23–32 m³/t</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fruit and vegetable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canned fruit</td>
<td>2.5–4.0 m³/t</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fruit-juices</td>
<td>6.5 m³/t</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canned vegetables</td>
<td>3.5–6.0 m³/t</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frozen vegetables</td>
<td>5.0–8.5 m³/t</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preserved vegetables</td>
<td>5.5–11 m³/t</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potato</td>
<td>2.4–9.0 m³/t</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jam</td>
<td>6 m³/t</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baby-food</td>
<td>6.0–9.0 m³/t</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>1.7–3.3 m³/t</td>
<td>1.4 m³/t</td>
<td>**</td>
<td>[115, CIAA-AAC-UFE, 2002, 152, Austria, 2002]</td>
</tr>
<tr>
<td>Wheat</td>
<td>1.7–2.5 m³/t</td>
<td>1.8 m³/t</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>Potato</td>
<td>0.7–1.5 m³/t</td>
<td>2 m³/t</td>
<td>±</td>
<td></td>
</tr>
<tr>
<td>Dairy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk and yoghurt</td>
<td>0.6–1.1 l/l</td>
<td>1.1 l/kg</td>
<td>±</td>
<td>[152, Austria, 2002]</td>
</tr>
<tr>
<td>Cheese</td>
<td>1.2–3.8 l/l</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk powder, cheese and/or liquid products</td>
<td>0.69–6.3 l/l</td>
<td></td>
<td>±</td>
<td>[42, Nordic Council of Ministers, et al., 2001]</td>
</tr>
<tr>
<td>Milk and yoghurt</td>
<td>0.8–25 m³/t</td>
<td>0.1–25 m³/t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cheese</td>
<td>1.60 m³/t</td>
<td>0.7–60 m³/t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk powder, cheese and/or liquid products</td>
<td>1.2–60 m³/t</td>
<td>0.1–60 m³/t</td>
<td>±</td>
<td>[160, European Dairy Association, 2002]</td>
</tr>
<tr>
<td>Beer</td>
<td>0.32–1 m³/hl</td>
<td>0.3–0.9 m³/hl</td>
<td>±</td>
<td>[69, Environment Agency of England and Wales, 2001, 199, Finland, 2003]</td>
</tr>
<tr>
<td>Sugar-beet</td>
<td>0.23–1.5 m³/t</td>
<td></td>
<td>±</td>
<td>[139, Nielsen E.H. Lehmann, 2002, 152, Austria, 2002]</td>
</tr>
<tr>
<td>Sector</td>
<td>Water consumption</td>
<td>Waste water volume</td>
<td>Unit</td>
<td>Source</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------</td>
<td>--------------------</td>
<td>------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Vegetable oil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude oil production</td>
<td>0.2–14 m³/t</td>
<td>0.2–14 m³/t</td>
<td></td>
<td>[35, Germany, 2002]; [74, Greek Ministry for the Environment, 2001, 109, CIAA-FEDIOL, 2002, 134, AWARENET, 2002, 140, World Bank (IBRD), et al., 1998, 182, Germany, 2003, 185, CIAA-FEDIOL, 2004]</td>
</tr>
<tr>
<td>Chemical neutralisation</td>
<td>1–1.5 m³/t</td>
<td>1–1.5 m³/t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deodorisation</td>
<td>10–30 m³/t</td>
<td>10–30 m³/t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardening</td>
<td>2.2–7 m³/t</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical refining</td>
<td>0.25–0.8 m³/t</td>
<td>14–35 m³/t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olive oil production</td>
<td>5 m³/t</td>
<td></td>
<td></td>
<td>[142, IMPEL, 2002]</td>
</tr>
<tr>
<td>Traditional extraction</td>
<td></td>
<td>2–5 m³/t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three-phase extraction</td>
<td>6–8 m³/t</td>
<td></td>
<td></td>
<td>[74, Greek Ministry for the Environment, 2001, 86, Junta de Andalucia and Agencia de Medio Ambiente, 1994]</td>
</tr>
<tr>
<td>Two-phase extraction</td>
<td>0.33–0.35 m³/t</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soft and alcoholic drinks</td>
<td>6–14 m³/m²</td>
<td>0.8–3.6 m³/m²</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Not applicable for tomato processing**

**Not applicable for ice-cream processing**

**Excluding cooling water**

**Per unit of product**

**Per unit of raw material**

This table summarises the data reported in Section 3.3. Some water consumption and waste water volumes are inconsistent. Information on applied processes and techniques, operating conditions and sampling methods not provided.

Table: Summary of water consumption and waste water volumes in the FDM sector.
Ranges of specific water consumption are available in each specific chapter of this BREF. The calculation of specific water consumption is based on the following equation:

\[
\text{specific water consumption} = \frac{\text{water consumption}}{\text{production}}
\]

where:
- water consumption, expressed in m³/year, is the total amount of water used by the installation, excluding:
  - the total amount of recycled/reused water;
  - the cooling water and run-off water that are not reused and are discharged separately from process water;
- production, expressed in tonnes/year, is the total amount of all products (or all raw materials, depending on the specific sector), expressed in tonnes/year or hl/year.

Water recycling is a common technique in all FDM sectors. Raw materials in some FDM sectors (e.g. dairies, starch production, sugar manufacturing) are characterised by the high water content that is released. In these specific sectors, the amount of reused water can be several times the amount of water consumption. An indicative list of ways for recycling water is given in Section 2.3.3.1.1.

### 2.2.3 Emissions to water

The FDM sector has traditionally been a large user of water as an ingredient, cleaning agent, means of conveyance and feed to utility systems. Large FDM processing installations can use several hundred cubic metres of water a day. Most of the water not used as an ingredient, ultimately appears in the waste water stream.

Substantial reductions in the volume of waste water generated in this sector can be achieved through waste minimisation techniques (see, e.g. Section 2.3.5). There is no simple relationship between the amount of water used in cleaning and hygiene standards, and food safety legislation requirements prevent water use minimisation from causing unsatisfactory levels of cleanliness, hygiene or product quality.

Waste water flowrates may be very variable on a daily, weekly or seasonal basis. The waste water profile is largely dependent on production and cleaning patterns. In some sectors, e.g. sugar beet and olive oil production, processing takes place on a campaign basis and there is little or no waste water generated for part of the year.

FDM waste water is extremely variable in composition. It is, however, typically high in both COD and BOD. Emission levels can be 10–100 times higher than those of domestic waste water.

Data on yearly average concentrations and specific loads for different parameters in the effluent of the WWTP by FDM sector and type of discharge for the reference installations are shown from Table 2.17 to Table 2.32. The ranges of abatement efficiencies of the WWTP for each parameter are shown in Table 2.33.
### Table 2.17: Yearly average concentrations for COD in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average COD concentration (mg/l)</th>
<th>Direct discharge</th>
<th>Indirect discharge</th>
<th>Landspreading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal feed</td>
<td></td>
<td>19–778</td>
<td>778–8 890</td>
<td>NI</td>
</tr>
<tr>
<td>Brewing</td>
<td></td>
<td>16–72</td>
<td>111–5 779</td>
<td>NI</td>
</tr>
<tr>
<td>Dairies</td>
<td></td>
<td>9–68</td>
<td>40–4 475</td>
<td>20.1 and 1 001</td>
</tr>
<tr>
<td>Ethanol production</td>
<td></td>
<td>65</td>
<td>65</td>
<td>NI</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td></td>
<td>NI</td>
<td>5 741</td>
<td>NI</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td></td>
<td>18–114</td>
<td>2 319</td>
<td>2 203–5 402</td>
</tr>
<tr>
<td>Grain milling</td>
<td></td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Meat processing</td>
<td></td>
<td>26–260</td>
<td>406–3 800</td>
<td>1 692</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td></td>
<td>14–600</td>
<td>53–5 561</td>
<td>NI</td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td></td>
<td>NI</td>
<td>53–645</td>
<td>NI</td>
</tr>
<tr>
<td>Soft drinks and nectar/ juice</td>
<td></td>
<td>6–65</td>
<td>1 537–3 253</td>
<td>3 322</td>
</tr>
<tr>
<td>Starch production</td>
<td></td>
<td>42–284</td>
<td>76–25</td>
<td>513–11 333</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td></td>
<td>26–493</td>
<td>1 678</td>
<td>5 556</td>
</tr>
<tr>
<td>All FDM sectors</td>
<td></td>
<td>6–788</td>
<td>40–8 890</td>
<td>20.1–11 333</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.
Source: [193, TWG 2015]

### Table 2.18: Yearly average specific loads for COD in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average COD specific load</th>
<th>Unit</th>
<th>Direct discharge</th>
<th>Indirect discharge</th>
<th>Landspreading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal feed</td>
<td></td>
<td>g/t raw materials</td>
<td>85–4 778</td>
<td>403</td>
<td>NI</td>
</tr>
<tr>
<td>Brewing</td>
<td></td>
<td>g/hl products</td>
<td>4.4–40.2</td>
<td>11–1 595</td>
<td>NI</td>
</tr>
<tr>
<td>Dairies</td>
<td></td>
<td>g/t raw materials</td>
<td>0.8–649</td>
<td>28–18 631</td>
<td>74–1 258</td>
</tr>
<tr>
<td>Ethanol production</td>
<td></td>
<td>g/t products</td>
<td>NI</td>
<td>513</td>
<td>NI</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td></td>
<td>g/t raw materials</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td></td>
<td>g/t products</td>
<td>16–2 489</td>
<td>37</td>
<td>15 457–35 541</td>
</tr>
<tr>
<td>Grain milling</td>
<td></td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Meat processing</td>
<td></td>
<td>g/t raw materials</td>
<td>80–609</td>
<td>831–11 363</td>
<td>NI</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td></td>
<td>g/t products</td>
<td>0.01–221</td>
<td>108–4 984</td>
<td>NI</td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td></td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Soft drinks and nectar/ juice</td>
<td></td>
<td>g/hl products</td>
<td>0.7–4</td>
<td>170</td>
<td>390</td>
</tr>
<tr>
<td>Starch production</td>
<td></td>
<td>g/t raw materials</td>
<td>78–1 127</td>
<td>NI</td>
<td>572–23 743</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td></td>
<td>29–2 059</td>
<td>3 618</td>
<td>5 940</td>
<td></td>
</tr>
</tbody>
</table>

NB: NI = no information provided.
Source: [193, TWG 2015]
Table 2.19: Yearly average concentrations for TOC in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average TOC concentration (mg/l)</th>
<th>Direct discharge</th>
<th>Indirect discharge</th>
<th>Landspreading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal feed</td>
<td>NI</td>
<td>357</td>
<td>NI</td>
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<tr>
<td>Brewing</td>
<td>NI</td>
<td>50–911</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Dairies</td>
<td>3.81–6</td>
<td>462</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Ethanol production</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
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<tr>
<td>Fish and shellfish processing</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>40</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Grain milling</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Meat processing</td>
<td>22.2</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td>NI</td>
<td>310–970</td>
<td>NI</td>
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<tr>
<td>Olive oil processing and refining</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Soft drinks and nectar/juice</td>
<td>9–13.7</td>
<td>1 094</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Starch production</td>
<td>19.5–116</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>8.9–20.13</td>
<td>NI</td>
<td>1 433</td>
<td></td>
</tr>
<tr>
<td>All FDM sectors</td>
<td>3.81–22.2</td>
<td>50–1 094</td>
<td>1 433</td>
<td></td>
</tr>
</tbody>
</table>

NB: NI = no information provided.  
Source: [193, TWG 2015]

Table 2.20: Yearly average specific loads for TOC in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average TOC specific load</th>
<th>Unit</th>
<th>Direct discharge</th>
<th>Indirect discharge</th>
<th>Landspreading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal feed</td>
<td>g/t raw materials</td>
<td>NI</td>
<td>1 363</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Brewing</td>
<td>g/hl products</td>
<td>NI</td>
<td>14.7–254</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Dairies</td>
<td>g/t raw materials</td>
<td>8.95</td>
<td>299–1 568</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Ethanol production</td>
<td>g/t products</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td>g/t raw materials</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>g/t products</td>
<td>220</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Grain milling</td>
<td>g/t products</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Meat processing</td>
<td>g/t raw materials</td>
<td>25.15</td>
<td>NI</td>
<td>NI</td>
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</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td>g/t products</td>
<td>NI</td>
<td>178</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td>g/t raw materials</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Soft drinks and nectar/juice</td>
<td>g/hl products</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Starch production</td>
<td>g/t raw materials</td>
<td>3.23–10.01</td>
<td>NI</td>
<td>NI</td>
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</tbody>
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NB: NI = no information provided.  
Source: [193, TWG 2015]
### Table 2.21: Yearly average concentrations for BOD₅ in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average BOD₅ concentration (mg/l)</th>
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<tbody>
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<td>Direct discharge</td>
</tr>
<tr>
<td>Animal feed</td>
<td>3.3–36.4</td>
</tr>
<tr>
<td>Brewing</td>
<td>3.33–9</td>
</tr>
<tr>
<td>Dairies</td>
<td>1.46–16</td>
</tr>
<tr>
<td>Ethanol production</td>
<td>5.7</td>
</tr>
<tr>
<td>Fish and shellfish</td>
<td>NI</td>
</tr>
<tr>
<td>processing</td>
<td></td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>1.98–39</td>
</tr>
<tr>
<td>Grain milling</td>
<td>NI</td>
</tr>
<tr>
<td>Meat processing</td>
<td>1.1–111</td>
</tr>
<tr>
<td>Oilsseed processing and</td>
<td>5–41</td>
</tr>
<tr>
<td>vegetable oil refining</td>
<td></td>
</tr>
<tr>
<td>Olive oil processing and</td>
<td>NI</td>
</tr>
<tr>
<td>refining</td>
<td></td>
</tr>
<tr>
<td>Soft drinks and</td>
<td>4–16</td>
</tr>
<tr>
<td>nectar/ juice</td>
<td></td>
</tr>
<tr>
<td>Starch production</td>
<td>4.4–84</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>2.9–143</td>
</tr>
<tr>
<td>All FDM sectors</td>
<td>1.1–143</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.  
Source: [193, TWG 2015]

### Table 2.22: Yearly average specific loads for BOD₅ in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average BOD₅ specific load</th>
</tr>
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<tbody>
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<td>Direct discharge</td>
</tr>
<tr>
<td>Animal feed</td>
<td>g/t raw materials</td>
</tr>
<tr>
<td>Brewing</td>
<td>g/hl products</td>
</tr>
<tr>
<td>Dairies</td>
<td>g/t raw materials</td>
</tr>
<tr>
<td>Ethanol production</td>
<td>g/t products</td>
</tr>
<tr>
<td>Fish and shellfish</td>
<td>g/t raw materials</td>
</tr>
<tr>
<td>processing</td>
<td></td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>g/t products</td>
</tr>
<tr>
<td>Grain milling</td>
<td>NI</td>
</tr>
<tr>
<td>Meat processing</td>
<td>g/t raw materials</td>
</tr>
<tr>
<td>Oilsseed processing and</td>
<td>g/t products</td>
</tr>
<tr>
<td>vegetable oil refining</td>
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<tr>
<td>Olive oil processing and</td>
<td>274.58</td>
</tr>
<tr>
<td>refining</td>
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</tr>
<tr>
<td>Soft drinks and</td>
<td>g/hl products</td>
</tr>
<tr>
<td>nectar/ juice</td>
<td></td>
</tr>
<tr>
<td>Starch production</td>
<td>g/t raw materials</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>1–560</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.  
Source: [193, TWG 2015]
### Table 2.23: Yearly average concentrations for TSS in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
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<th>Indirect discharge</th>
<th>Landspreading</th>
</tr>
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<tbody>
<tr>
<td>Animal feed</td>
<td>4.9–120</td>
<td>91–303</td>
<td>NI</td>
</tr>
<tr>
<td>Brewing</td>
<td>3.76–21</td>
<td>1.58–1 095</td>
<td>NI</td>
</tr>
<tr>
<td>Dairies</td>
<td>0.62–25.86</td>
<td>18–1 095</td>
<td>NI</td>
</tr>
<tr>
<td>Ethanol production</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td>NI</td>
<td>1 570</td>
<td>NI</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>4.98–42</td>
<td>84</td>
<td>301–1 132</td>
</tr>
<tr>
<td>Grain milling</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Meat processing</td>
<td>0.02–51.21</td>
<td>135–1 440</td>
<td>481.25</td>
</tr>
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<td>Oilseed processing and vegetable oil refining</td>
<td>0.02–166</td>
<td>0.15–153</td>
<td>NI</td>
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<tr>
<td>Olive oil processing and refining</td>
<td>NI</td>
<td>130–300</td>
<td>NI</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td>0.05–27.93</td>
<td>29</td>
<td>88</td>
</tr>
<tr>
<td>Starch production</td>
<td>5.5–42.83</td>
<td>29</td>
<td>130–5 107</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>0.19–128</td>
<td>980</td>
<td>4 021</td>
</tr>
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<td>All FDM sectors</td>
<td>0.02–166</td>
<td>0.15–1 440</td>
<td>88–5107</td>
</tr>
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</table>

NB: NI = no information provided. 
Source: [193, TWG 2015]

### Table 2.24: Yearly average specific loads for TSS in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Unit</th>
<th>Direct discharge</th>
<th>Indirect discharge</th>
<th>Landspreading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal feed</td>
<td>g/t raw materials</td>
<td>21.8–675.3</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Brewing</td>
<td>g/hl product</td>
<td>0.05–11.73</td>
<td>4.81–279.21</td>
<td>NI</td>
</tr>
<tr>
<td>Dairies</td>
<td>g/t raw materials</td>
<td>0.04–299</td>
<td>87–2 572</td>
<td>3.52</td>
</tr>
<tr>
<td>Ethanol production</td>
<td>g/t product</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td>g/t raw materials</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>g/t products</td>
<td>3.43–902</td>
<td>1.32</td>
<td>2 110–7 448</td>
</tr>
<tr>
<td>Grain milling</td>
<td>g/t products</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Meat processing</td>
<td>g/t raw materials</td>
<td>0.22–64</td>
<td>206–2 134</td>
<td>1 377</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td>g/t products</td>
<td>0.006–63.13</td>
<td>19–681</td>
<td>NI</td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td>g/t products</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Soft drinks and nectar/juice</td>
<td>g/hl products</td>
<td>0.008–26.94</td>
<td>NI</td>
<td>10.22</td>
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<td>Starch production</td>
<td>g/t raw materials</td>
<td>11–476</td>
<td>NI</td>
<td>348</td>
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<td>Sugar manufacturing</td>
<td>g/t raw materials</td>
<td>6–535</td>
<td>NI</td>
<td>4 299</td>
</tr>
</tbody>
</table>

NB: NI = no information provided. 
Source: [193, TWG 2015]
Table 2.25: Yearly average concentrations for NH4-N in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average NH₄-N concentration (mg/l)</th>
</tr>
</thead>
<tbody>
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<td>Direct discharge</td>
</tr>
<tr>
<td>Animal feed</td>
<td>1–1.36</td>
</tr>
<tr>
<td>Brewing</td>
<td>0.03–1.06</td>
</tr>
<tr>
<td>Dairies</td>
<td>0.06–6.02</td>
</tr>
<tr>
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<td>NI</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td>NI</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>0.06–4.83</td>
</tr>
<tr>
<td>Grain milling</td>
<td>NI</td>
</tr>
<tr>
<td>Meat processing</td>
<td>0.57–9.12</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td>1.3–3.1</td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td>NI</td>
</tr>
<tr>
<td>Soft drinks and nectar/ juice</td>
<td>0.1–0.68</td>
</tr>
<tr>
<td>Starch production</td>
<td>0.14–3.2</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>0.1–8.6</td>
</tr>
<tr>
<td>All FDM sectors</td>
<td>0.03–8.6</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.
Source: [193, TWG 2015]

Table 2.26: Yearly average specific loads for NH4-N in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average NH₄-N specific load</th>
</tr>
</thead>
<tbody>
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<td>Unit</td>
</tr>
<tr>
<td>Animal feed</td>
<td>g/t raw materials</td>
</tr>
<tr>
<td>Brewing</td>
<td>g/hl products</td>
</tr>
<tr>
<td>Dairies</td>
<td>g/t raw materials</td>
</tr>
<tr>
<td>Ethanol production</td>
<td>g/t products</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td>g/t raw materials</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>g/t products</td>
</tr>
<tr>
<td>Grain milling</td>
<td>g/t products</td>
</tr>
<tr>
<td>Meat processing</td>
<td>g/t raw materials</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td>g/t products</td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td>g/t raw materials</td>
</tr>
<tr>
<td>Soft drinks and nectar/ juice</td>
<td>g/hl products</td>
</tr>
<tr>
<td>Starch production</td>
<td>g/t raw materials</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>g/t raw materials</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.
Source: [193, TWG 2015]
### Table 2.27: Yearly average concentrations for TN in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average TN concentration (mg/l)</th>
<th>Direct discharge</th>
<th>Indirect discharge</th>
<th>Landspreading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal feed</td>
<td></td>
<td>2.4–10.9</td>
<td>89–231</td>
<td>NI</td>
</tr>
<tr>
<td>Brewing</td>
<td></td>
<td>1.5–8.1</td>
<td>26.5–81.5</td>
<td>NI</td>
</tr>
<tr>
<td>Dairies</td>
<td></td>
<td>1.4–17</td>
<td>38–214</td>
<td>4.2–111</td>
</tr>
<tr>
<td>Ethanol production</td>
<td></td>
<td>2.7</td>
<td>6.2</td>
<td>NI</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td></td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td></td>
<td>1.4–20</td>
<td>10.2</td>
<td>9–105</td>
</tr>
<tr>
<td>Grain milling</td>
<td></td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Meat processing</td>
<td></td>
<td>2.9–17.9</td>
<td>33–358</td>
<td>53</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td></td>
<td>2.2–15.3</td>
<td>2.5–110</td>
<td>NI</td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td></td>
<td>NI</td>
<td>4</td>
<td>NI</td>
</tr>
<tr>
<td>Soft drinks and nectar/juice</td>
<td></td>
<td>1.3–3</td>
<td>10</td>
<td>11.7</td>
</tr>
<tr>
<td>Starch production</td>
<td></td>
<td>3–13.4</td>
<td>4.3</td>
<td>35–150</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td></td>
<td>2.1–22.1</td>
<td>265</td>
<td>86</td>
</tr>
<tr>
<td>All FDM sectors</td>
<td></td>
<td>1.3–22.1</td>
<td>4–358</td>
<td>4.2–150</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.

Source: [193, TWG 2015]

### Table 2.28: Yearly average specific loads for TN in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average TN specific load</th>
<th>Unit</th>
<th>Direct discharge</th>
<th>Indirect discharge</th>
<th>Landspreading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal feed</td>
<td></td>
<td>g/t raw materials</td>
<td>10.72</td>
<td>21.18</td>
<td>NI</td>
</tr>
<tr>
<td>Brewing</td>
<td></td>
<td>g/hl products</td>
<td>0.30–2.79</td>
<td>1.05–22.64</td>
<td>NI</td>
</tr>
<tr>
<td>Dairies</td>
<td></td>
<td>g/t raw materials</td>
<td>0.57–40.68</td>
<td>43–1 241</td>
<td>15.46</td>
</tr>
<tr>
<td>Ethanol production</td>
<td></td>
<td>g/t products</td>
<td>14.9</td>
<td>4.8</td>
<td>NI</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td></td>
<td>g/t raw materials</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td></td>
<td>g/t products</td>
<td>2.33–619</td>
<td>0.16</td>
<td>63–159</td>
</tr>
<tr>
<td>Grain milling</td>
<td></td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Meat processing</td>
<td></td>
<td>g/t raw materials</td>
<td>20–58</td>
<td>811</td>
<td>NI</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td></td>
<td>g/t products</td>
<td>0.60–17.07</td>
<td>3.56–36.24</td>
<td>NI</td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td></td>
<td>NI</td>
<td>9.15</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Soft drinks and nectar/juice</td>
<td></td>
<td>g/hl products</td>
<td>0.17–2.77</td>
<td>NI</td>
<td>1.36</td>
</tr>
<tr>
<td>Starch production</td>
<td></td>
<td>g/t raw materials</td>
<td>5.6–71.3</td>
<td>NI</td>
<td>860</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td></td>
<td>1.61–25.81</td>
<td>NI</td>
<td>91.94</td>
<td></td>
</tr>
</tbody>
</table>

NB: NI = no information provided.

Source: [193, TWG 2015]
Table 2.29: Yearly average concentrations for TP in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average TP concentration (mg/l)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct discharge</td>
<td>Indirect discharge</td>
<td>Landspreading</td>
</tr>
<tr>
<td>Animal feed</td>
<td>0.36–2.82</td>
<td>2.76–118</td>
<td>NI</td>
</tr>
<tr>
<td>Brewing</td>
<td>0.7–2.11</td>
<td>1.4–89</td>
<td>NI</td>
</tr>
<tr>
<td>Dairies</td>
<td>0.11–5.45</td>
<td>3.18–75</td>
<td>0.14–1.2</td>
</tr>
<tr>
<td>Ethanol production</td>
<td>0.9</td>
<td>0.75</td>
<td>NI</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>0.32–22.27</td>
<td>2.19</td>
<td>2.23</td>
</tr>
<tr>
<td>Grain milling</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Meat processing</td>
<td>0.43–6.21</td>
<td>3.91–47.15</td>
<td>0.4</td>
</tr>
<tr>
<td>Oilsed processing and vegetable oil refining</td>
<td>0.03–39</td>
<td>1.24–2 655</td>
<td>NI</td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td>NI</td>
<td>6</td>
<td>NI</td>
</tr>
<tr>
<td>Soft drinks and nectar/ juice</td>
<td>0.4–2.4</td>
<td>18–30</td>
<td>2.14</td>
</tr>
<tr>
<td>Starch production</td>
<td>0.25–4.11</td>
<td>0.85</td>
<td>4.4–380</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>0.12–2.7</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>All FDM sectors</td>
<td>0.03–22.27</td>
<td>0.35–2 655</td>
<td>0.14–380</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.

Source: [193, TWG 2015]

Table 2.30: Yearly average specific loads for TP in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average TP specific load</th>
<th>Unit</th>
<th>Direct discharge</th>
<th>Indirect discharge</th>
<th>Landspreading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>g/t raw materials</td>
<td>NI</td>
<td>7.85</td>
<td>NI</td>
</tr>
<tr>
<td>Brewing</td>
<td></td>
<td>g/l products</td>
<td>0.19–0.91</td>
<td>2.25–550</td>
<td>NI</td>
</tr>
<tr>
<td>Dairies</td>
<td></td>
<td>g/t raw materials</td>
<td>0.25–12.81</td>
<td>6.7–550</td>
<td>0.52 and 1.6</td>
</tr>
<tr>
<td>Ethanol production</td>
<td></td>
<td>g/t products</td>
<td>NI</td>
<td>0.58</td>
<td>NI</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td></td>
<td>g/t raw materials</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td></td>
<td>g/t products</td>
<td>0.7–99.61</td>
<td>0.03</td>
<td>14.02–35.05</td>
</tr>
<tr>
<td>Grain milling</td>
<td></td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Meat processing</td>
<td></td>
<td>g/t raw materials</td>
<td>7.03–11.93</td>
<td>142–150</td>
<td>NI</td>
</tr>
<tr>
<td>Oilsed processing and vegetable oil refining</td>
<td></td>
<td>g/t products</td>
<td>0.02–8.07</td>
<td>1.15–21.94</td>
<td>NI</td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td></td>
<td>g/t raw materials</td>
<td>13.72</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Soft drinks and nectar/ juice</td>
<td></td>
<td>g/hl products</td>
<td>0.029–1.55</td>
<td>NI</td>
<td>7.82–284</td>
</tr>
<tr>
<td>Starch production</td>
<td></td>
<td>g/t raw materials</td>
<td>0.28–24.04</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td></td>
<td>g/t raw materials</td>
<td>0.08–2.55</td>
<td>NI</td>
<td></td>
</tr>
</tbody>
</table>

NB: NI = no information provided.

Source: [193, TWG 2015]
### Chapter 2

#### Table 2.31: Yearly average concentrations for Cl⁻ in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average Cl⁻ concentration (mg/l)</th>
<th>Direct discharge</th>
<th>Indirect discharge</th>
<th>Landspreading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal feed</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Brewing</td>
<td>NI</td>
<td>60.49</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Dairies</td>
<td>153–687</td>
<td>78–1 569</td>
<td>167</td>
<td></td>
</tr>
<tr>
<td>Ethanol production</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td>NI</td>
<td>2 879</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Grain milling</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Meat processing</td>
<td>NI</td>
<td>969</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td>NI</td>
<td>480–763</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Soft drinks and nectar/ juice</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Starch production</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>All FDM sectors</td>
<td>153–687</td>
<td>60.49–1 569</td>
<td>167</td>
<td></td>
</tr>
</tbody>
</table>

NB: NI = no information provided.  
Source: [193, TWG 2015]

#### Table 2.32: Yearly average specific loads for Cl⁻ in the effluent of the WWTP

<table>
<thead>
<tr>
<th>FDM sector</th>
<th>Yearly average Cl⁻ specific load</th>
<th>Unit</th>
<th>Direct discharge</th>
<th>Indirect discharge</th>
<th>Landspreading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal feed</td>
<td></td>
<td>g/t raw materials</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Brewing</td>
<td></td>
<td>g/hl products</td>
<td>NI</td>
<td>17.8</td>
<td>NI</td>
</tr>
<tr>
<td>Dairies</td>
<td></td>
<td>g/t raw materials</td>
<td>200–17 139</td>
<td>78–9 542</td>
<td>618</td>
</tr>
<tr>
<td>Ethanol production</td>
<td></td>
<td>g/t products</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Fish and shellfish processing</td>
<td></td>
<td>g/t raw materials</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td></td>
<td>g/t products</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Grain milling</td>
<td></td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Meat processing</td>
<td></td>
<td>g/t raw materials</td>
<td>NI</td>
<td>6 890</td>
<td>NI</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td></td>
<td>g/t products</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Olive oil processing and refining</td>
<td></td>
<td>g/hl products</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Soft drinks and nectar/ juice</td>
<td></td>
<td>g/hl products</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Starch production</td>
<td></td>
<td>g/t raw materials</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td></td>
<td>g/t raw materials</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.  
Source: [193, TWG 2015]
Table 2.33: Abatement efficiencies for the WWTP in FDM reference installations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>For emissions expressed in concentrations</th>
<th>For emissions expressed in specific loads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct discharge</td>
<td>Indirect discharge</td>
</tr>
<tr>
<td>COD</td>
<td>40–99</td>
<td>18–98</td>
</tr>
<tr>
<td>TOC</td>
<td>96–99</td>
<td>19</td>
</tr>
<tr>
<td>TSS</td>
<td>38–99</td>
<td>10–96</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>23–99</td>
<td>28–85</td>
</tr>
<tr>
<td>TN</td>
<td>37–99</td>
<td>30–75</td>
</tr>
<tr>
<td>TP</td>
<td>38–99</td>
<td>6–39</td>
</tr>
<tr>
<td>Cl</td>
<td>13</td>
<td>NI</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.
Source: [193, TWG 2015]

The BOD₅ content of the main FDM constituents and some products is shown in.

**Table: BOD₅ equivalent of general FDM constituents and some products**

<table>
<thead>
<tr>
<th>BOD₅ content</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.65 kg/kg carbohydrate</td>
</tr>
<tr>
<td>0.89 kg/kg fat</td>
</tr>
<tr>
<td>1.03 kg/kg protein</td>
</tr>
<tr>
<td>0.07–0.10 kg/l milk</td>
</tr>
<tr>
<td>0.18–0.37 kg/kg meat</td>
</tr>
<tr>
<td>0.06–0.09 kg/kg fruit or vegetables</td>
</tr>
</tbody>
</table>

The TSS concentration varies from negligible to as high as 120000 mg/l. Waste water from, e.g. the meat and dairy sectors contain high concentrations of edible fats and oils.

Food processing waste water vary from very acidic, i.e. pH 3.5, to very alkaline, i.e. pH 11. Factors affecting waste water pH include:

- the natural pH of the raw material;
- pH adjustment of fluming water to prevent raw material deterioration;
- use of caustic or acid solutions in processing operations;
- use of caustic or acid solutions in cleaning operations;
- acidic waste streams, e.g. acid whey;
- acid-forming reactions in the waste water, e.g. high yeast content waste water, lactic and formic acids from degrading milk content;
- nature of raw water source, either hard or soft.

Waste water contains few compounds that individually have an adverse effect on a WWTPs or a receiving water body. Possible exceptions include:

- salt where large amounts are used, e.g. pickling and cheesemaking
- pesticide residues not readily degraded during treatment
- residues and by-products from the use of chemical disinfection techniques
- some cleaning products.

The presence of pathogenic organisms in the waste water may be an issue, particularly where meat or fish are being processed. The amount of plant nutrients may also be an issue. For the biological waste water treatment of the waste water, the ideal BOD:N:P ratio is about 100:5:1.
At this level, FDM processing waste water would be too deficient in N and/or P to support biological activity during treatment. Excessive emission levels of phosphorus can also occur, particularly where large quantities of phosphoric acid are used in the process, e.g. vegetable oil de-gumming, or in cleaning. If such waste water becomes anaerobic during treatment then there is a risk that constituents containing phosphate could release phosphorus to the final discharge water. The use of nitric acid in the process produces a similar effect, thereby increasing the emission levels of nitrate in the waste water.

Some common sources of fugitive and unscheduled emissions, i.e. accidental releases, are:

- contaminated storm waters
- storage tank leaks
- pipework leaks
- spillages
- bund drains
- leakages from flanges, pumps, seals and valve glands.

After treatment, the waste water quality in Table may be attained. For some sectors lower discharge levels may be possible. Information about some sectors is given in Sections inclusive. Local conditions may require lower emission levels to be achieved.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD&lt;sub&gt;5&lt;/sub&gt;</td>
<td>&lt;25</td>
</tr>
<tr>
<td>COD</td>
<td>&lt;125</td>
</tr>
<tr>
<td>TSS</td>
<td>&lt;50</td>
</tr>
<tr>
<td>pH</td>
<td>6–9</td>
</tr>
<tr>
<td>Oil and grease</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Coliform bacteria</td>
<td>400 MPN/100 ml&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

MPN = most probable number
<sup>*</sup> Meat and dairy sectors

Better levels of BOD<sub>5</sub> and COD can be obtained. It is not always possible or cost effective to achieve the total nitrogen and phosphorus levels shown, in view of local conditions.

Table: Typical FDM waste water quality after treatment [140, World Bank (IBRD), et al., 1998]

Typical performance data of some anaerobic techniques are shown in Table.

<table>
<thead>
<tr>
<th>Process</th>
<th>Input COD (mg/l)</th>
<th>Hydraulic retention time (h)</th>
<th>Organic loading (kg COD/m&lt;sup&gt;3&lt;/sup&gt; per-day)</th>
<th>COD removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic lagoons</td>
<td>-</td>
<td>-</td>
<td>0.6–1</td>
<td>-</td>
</tr>
<tr>
<td>Anaerobic contact process</td>
<td>1 500–5 000</td>
<td>2–14</td>
<td>0.5–5.3</td>
<td>75–90</td>
</tr>
<tr>
<td>Fixed bed</td>
<td>10 000–70 000</td>
<td>24–48</td>
<td>1–15</td>
<td>75–85</td>
</tr>
<tr>
<td>UASB</td>
<td>5 000–15 000</td>
<td>4–12</td>
<td>2–12</td>
<td>75–85</td>
</tr>
<tr>
<td>Expanded bed reactor</td>
<td>5 000–10 000</td>
<td>5–14</td>
<td>5–30</td>
<td>80–85</td>
</tr>
<tr>
<td>Fluidised bed reactor</td>
<td>-</td>
<td>-</td>
<td>40–60</td>
<td>-</td>
</tr>
<tr>
<td>Internal circulation (IC) reactor</td>
<td>-</td>
<td>-</td>
<td>31</td>
<td>-</td>
</tr>
</tbody>
</table>

Table: Typical process and performance data of anaerobic waste water treatment processes [78, Metcalf & Eddy, 1981] [88, CIAA, CEFAS, 2003]
Loss of materials

Exceed weight/volume specification

Loss of products by overfilling occurs even with the most accurate filling equipment. Operating to average filling weight legislation, the packaged product will unavoidably contain marginally more than the nominal package contents. Because of its economic significance, overfill is normally very closely monitored by check weighing on a continuous or sampling basis. Such loss of material is normally of no environmental significance. It is, however, very important when conducting a mass balance, to accurately quantify the amount of overfill, so that this can be allowed for in the mass balance equation.

Spillage

Spillage of the product, e.g., onto the floor, results in the product being unfit for human consumption and is defined as loss and waste, if not properly recovered. Routinely occurring spillage indicates poor equipment design, poor maintenance or poor operation, e.g., of a packaging line. This often causes a considerable loss of product and packaging material. When spillage occurs during manual handling, the working procedures may be at fault.

Leakage/overflow

Leakage of liquid product from pipe joints and overflow from tanks may be an important source of loss of material and waste, if not properly recovered. These problems can be caused, e.g., by obsolete gaskets or faulty high level alarm switches.

Product defects/returned product

Products not meeting the required specification, whether identified prior to dispatch or returned by customers, can be a major source of loss of materials and waste, although some may be recovered. This group also includes over-produced fresh products, e.g., in cases where order fluctuations result in too much product being produced which cannot then all be sold in time due to shelf-life considerations.

Inherent loss

Some process equipment, even with the most appropriate technique, can cause a loss of materials and waste which is unavoidable by design. An example of inherent loss is the self-desludging centrifugal separator, where solids from the bowl, and inevitably some product, are flushed to waste during desludging.

A similar situation exists where the product is purged through the equipment with water at the end of production or at product changeover, e.g., in CIP systems. Inevitably the interface between the product and the water will not be sharp and depending on what measures are taken to minimise this, a greater or lesser quantity of a mixture of the two is produced.

Retained material

Retained material occurs when liquid products or ingredients cannot freely drain to the next stage in the process. This can, e.g., be caused by dips in supposedly continuously falling pipelines, which trap the product and prevent it from draining either way. Another example is where the product rises in the pipelines and any trapped product will then not drain away, thus
leading to a loss of material. If the product cannot drain, then it is purged with gas, water or a pigging system.

Also, with very viscous products, e.g. yoghurt, adhesion to the pipeline and tank walls is a significant source of retained material. Unless mechanically removed, e.g. by pigging, prolonged pre-rinsing is likely to be required.

**Heat-deposited waste**

Whenever liquid products are heated, there is a likelihood of deposition of the product onto the heat-exchange surface. Deposits on the plates or tubes in heat-exchangers, and on batch kettles may not rinse off and when removed with detergents is lost in the waste water. In many sectors, these sources of loss are contained and recycled or recovered back into the process.
2.3 Techniques to consider in the determination of BAT across the FDM sector

This section describes techniques (or combinations thereof), and associated monitoring, considered to have the potential for achieving a high level of environmental protection in the activities within the scope of this document. The techniques described will include both the technology used and the way in which the installations are designed, built, maintained, operated and decommissioned.

It covers environmental management systems, process-integrated techniques and end-of-pipe measures. Waste prevention and management, including waste minimisation and recycling procedures are also considered, as well as techniques that reduce the consumption of raw materials, water and energy by optimising use and reuse. The techniques described also cover measures used to prevent or to limit the environmental consequences of accidents and incidents, as well as site remediation measures. They also cover measures taken to prevent or reduce emissions under other than normal operating conditions (such as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and the definitive cessation of operations).

Annex III to the Directive lists a number of criteria for determining BAT, and the information within this chapter will address these considerations. As far as possible, the standard structure in Table 2.34 is used to outline the information on each technique, to enable a comparison of techniques and the assessment against the definition of BAT in the Directive.

This chapter does not necessarily provide an exhaustive list of techniques which could be applied in the sector. Other techniques may exist, or may be developed, which could be considered in the determination of BAT for an individual installation.

Table 2.34: Information for each technique

<table>
<thead>
<tr>
<th>Heading within the sections</th>
<th>Type of information included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>A brief description of the technique with a view to being used in the BAT conclusions.</td>
</tr>
<tr>
<td>Technical description</td>
<td>A more detailed and yet concise Technical description using, as appropriate, chemical or other equations, pictures, diagrams and flow charts.</td>
</tr>
<tr>
<td>Achieved environmental benefits</td>
<td>The main potential environmental benefits to be gained through implementing the technique (including reduced consumption of energy; reduced emissions to water, air and land; raw material savings; as well as production yield increases, reduced waste, etc.).</td>
</tr>
<tr>
<td>Environmental performance and operational data</td>
<td>Actual and installation-specific performance data (including emission levels, consumption levels–of raw materials, water, energy–and amounts of residues/wastes generated) from well-performing installations (with respect to the environment taken as a whole) applying the technique accompanied by the relevant contextual information.</td>
</tr>
</tbody>
</table>

Any other useful information on the following items:

- how to design, operate, maintain, control and decommission the technique;
- emission monitoring issues related to the use of the technique;
- sensitivity and durability of the technique;
- issues regarding accident prevention.
Links between inputs (e.g. nature and quantity of raw material and fuel, energy, water) and outputs (emissions, residues/wastes, products) are highlighted, in particular where relevant to enhancing an understanding of different environmental impacts and their interaction, for example where trade-offs have been made between different outputs such that certain environmental performance levels cannot be achieved at the same time.

Emission and consumption data are qualified as far as possible with details of relevant operating conditions (e.g. percentage of full capacity, fuel composition, bypassing of the (abatement) technique, inclusion or exclusion of other than normal operating conditions, reference conditions), sampling and analytical methods, and statistical presentation (e.g. short- and long-term averages, maxima, ranges and distributions).

Information on conditions/circumstances hampering the use of the (abatement) technique at full capacity and/or necessitating full or partial bypassing of the (abatement) technique and measures taken to restore full (abatement) capacity.

Cross-media effects
Relevant negative effects on the environment due to implementing the technique, allowing comparison between techniques in order to assess the impact on the environment as a whole. This may include issues such as:

- consumption and nature of raw materials and water;
- energy consumption and contribution to climate change;
- stratospheric ozone depletion potential;
- photochemical ozone creation potential;
- acidification resulting from emissions to air;
- presence of particulate matter in ambient air (including microparticles and metals);
- eutrophication of land and water resulting from emissions to air or water;
- oxygen depletion potential in water;
- persistent/toxic/bioaccumulable components (including metals);
- generation of residues/waste;
- limitation of the ability to reuse or recycle residues/waste;
- generation of noise and/or odour;
- increased risk of accidents.

The Reference Document on Economics and Cross-media Effects (ECM) should be taken into account.

Technical considerations relevant to applicability
It is indicated whether the technique can be applied throughout the sector. Otherwise, the main general technical restrictions on the use of the technique within the sector are indicated. These may be:

- an indication of the type of installations or processes within the sector to which the technique cannot be applied;
- constraints to implementation in certain generic cases, considering, e.g.:
  - whether it concerns a new or an existing installation, taking into account factors involved in retrofitting (e.g. space availability) and interactions with techniques already installed,
### Chapter 2

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation size, capacity or load factor</td>
<td>o installation size, capacity or load factor, o quantity, type or quality of product manufactured, o type of fuel or raw material used, o animal welfare, o climatic conditions. These restrictions are indicated together with the reasons for them.</td>
</tr>
<tr>
<td>Quantity, type or quality of product manufactured</td>
<td>These restrictions are not meant to be a list of the possible local conditions that could affect the applicability of the technique for an individual installation.</td>
</tr>
<tr>
<td>Type of fuel or raw material used</td>
<td></td>
</tr>
<tr>
<td>Animal welfare</td>
<td></td>
</tr>
<tr>
<td>Climatic conditions</td>
<td></td>
</tr>
<tr>
<td>Economics</td>
<td>Information on the costs (capital/investment, operating and maintenance including details on how these costs have been calculated/estimated) and any possible savings (e.g. reduced raw material or energy consumption, waste charges, reduced payback time compared to other techniques), or revenues or other benefits including details on how these have been calculated/estimated. Cost data are preferably given in euro (EUR). If a conversion is made from another currency, the data in the original currency and the year when the data were collected is indicated. The price/cost of the equipment or service is accompanied by the year it was purchased. Information on the market for the sector in order to put costs of techniques into context. Information relevant to both newly built, retrofitted and existing installations. This should allow assessment, where possible, of the economic viability of the technique for the sector concerned. Information on the cost-effectiveness of the technique (e.g. in EUR per mass of pollutant abated) and related assumptions for their calculation can be reported. The Reference Document on Economics and Cross-media Effects (ECM) and the Reference Document on the General Principles of Monitoring (MON) are taken into account with regard to economic aspects and monitoring costs, respectively.</td>
</tr>
<tr>
<td>Driving force for implementation</td>
<td>Where applicable, specific local conditions, requirements (e.g. legislation, safety measures) or non-environmental triggers (e.g. increased yield, improved product quality, economic incentives—e.g. subsidies, tax breaks) which have driven or stimulated the implementation of the technique to date. This subsection should be very short using bullet point lists.</td>
</tr>
<tr>
<td>Example plants</td>
<td>Reference to an installation/plant(s) where the technique has been implemented and from which information has been collected and used in writing the section. An indication of the degree to which the technique is in use in the EU or worldwide.</td>
</tr>
<tr>
<td>Reference literature</td>
<td>Literature or other reference material (e.g. books, reports, studies) that was used in writing the section and that contains more detailed information on the technique. When the reference material consists of a large number of pages, reference will be made to the relevant page(s) or section(s).</td>
</tr>
</tbody>
</table>
In this document, some end-of-pipe techniques have been included in this chapter, whether or not they are considered in the determination of BAT.

The techniques described show that prevention can be achieved in many ways, such as using production techniques that pollute less than others; reducing material inputs; re-engineering the processes to reuse products, which, e.g. have not met the customer’s specification; improving management practices and substituting substances with less hazardous ones. This chapter provides information on some both general and specific pollution prevention and control techniques that have been implemented on an industrial scale.

The Emissions from Storage BREF [167, COM 2006] covers general storage and handling techniques so these are generally not included in this document, unless they are related to FDM-specific issues such a food safety and shelf-life.

The FDM sector is so diverse that it is impractical to describe every technique that can be considered in the determination of BAT for every activity and under every circumstance. It is, however, evident that there are various good techniques used in one part of the sector that are also applicable in others. Care has been taken to ensure that the techniques described do not conflict with the requirements of relevant food safety legislation.

2.3.1 General environmental performance

2.3.1.1 Environmental management systems tools

Description
A formal system to demonstrate compliance with environmental objectives.

Technical description
The Directive defines ‘techniques’ (under the definition of best available techniques) as ‘both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned’.

In this respect, an environmental management system (EMS) is a technique allowing operators of installations to address environmental issues in a systematic and demonstrable way. EMSs are most effective and efficient where they form an inherent part of the overall management and operation of an installation.

An EMS focuses the attention of the operator on the environmental performance of the installation; in particular through the application of clear operating procedures for both normal and other than normal operating conditions, and by setting out the associated lines of responsibility.

All effective EMSs incorporate the concept of continuous improvement, meaning that environmental management is an ongoing process, not a project which eventually comes to an end. There are various process designs, but most EMSs are based on the plan-do-check-act cycle (which is widely used in other company management contexts). The cycle is an iterative dynamic model, where the completion of one cycle flows into the beginning of the next (see Figure 2.7).
Figure 2.7: Continuous improvement in an EMS model

An EMS can take the form of a standardised or non-standardised (or customised) system. Implementation and adherence to an internationally accepted standardised system, such as EN ISO 14001:2015, can give higher credibility to the EMS especially when subjected to a properly performed external verification. EMAS provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can, in principle, be equally effective provided that they are properly designed and implemented.

While both standardised systems (EN ISO 14001:2015 or EMAS) and non-standardised systems apply in principle to organisations, this document takes a narrower approach, not including all activities of an organisation, e.g. with regard to their products and services, due to the fact that the Directive only regulates installations.

An EMS can contain the following components:

1. commitment of management, including senior management;
2. definition, by the management, of an environmental policy that includes the continuous improvement of the installation;
3. planning and establishing the necessary procedures, objectives and targets, in conjunction with financial planning and investment;
4. implementation of procedures paying particular attention to:
   1. structure and responsibility
   2. training, awareness and competence
   3. communication
   4. employee involvement
   5. documentation
   6. efficient process control
   7. maintenance programmes
   8. emergency preparedness and response
   9. safeguarding compliance with environmental legislation;
5. checking performance and taking corrective action paying particular attention to:
(a) monitoring and measurement (see also the JRC Reference Report on Monitoring of Emissions to Air and Water from IED-installations (ROM REF)) [170, COM 2015],
(b) corrective and preventive action,
(c) maintenance of records,
(d) independent (where practicable) internal and external auditing in order to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;

6. review of the EMS and its continuing suitability, adequacy and effectiveness by senior management;
7. preparation of a regular environmental statement;
8. validation by a certification body or an external EMS verifier;
9. following the development of cleaner technologies;
10. consideration for the environmental impacts from the eventual decommissioning of the installation at the stage of designing a new plant, and throughout its operating life;
11. application of sectoral benchmarking on a regular basis.

Achieved environmental benefits
An EMS promotes and supports the continuous improvement of the environmental performance of the installation. If the installation already has a good overall environmental performance, an EMS helps the operator to maintain the high performance level.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
None reported. The systematic analysis of the initial environmental impacts and scope for improvements in the context of the EMS sets the basis for assessing the best solutions for all environmental media.

Technical considerations relevant to applicability
The components described above can typically be applied to all installations within the scope of this document. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

Economics
It is difficult to determine accurately the costs and economic benefits of introducing and maintaining a good EMS. There are also economic benefits that are the result of using an EMS and these vary widely from sector to sector.

External costs relating to verification of the system can be estimated from guidance issued by the International Accreditation Forum [171, IAF 2010].

Driving forces for implementation
The driving forces for the implementation of an EMS include:

- improved environmental performance;
- improved insight into the environmental aspects of the company which can be used to fulfill the environmental requirements of customers, regulatory authorities, banks, insurance companies or other stakeholders (e.g. people living or working in the vicinity of the installation);
- improved basis for decision-making;
- improved motivation of personnel (e.g. managers can have confidence that environmental impacts are controlled and employees can feel that they are working for an environmentally responsible company);
- additional opportunities for operational cost reduction and product quality improvement
• improved company image;
• reduced liability, insurance and non-compliance costs.

Example plants
EMSs are applied in a high number of installations throughout the EU. The FDM sector is one of the industrial sectors with the most EMAS-registered organisations [179, European Commission 2015].

Reference literature
[172, EC 2009], [173, DG Environment 2010], [174, ISO 2004], [175, ISO 2010], [179, European Commission 2015]

2.3.1.2 Integrated monitoring system

Description
Integrated monitoring system, formed by a large amount of measuring equipment and permitting the tracking of the energy, gas and water consumption from input to points of consumption.

Technical description
An integrated monitoring system is formed by a large amount of measuring equipment and it permits the tracking of the energy, gas and water consumption from input to points of consumption. The system can obtain data from measuring equipment, such as calorimeters, electric watt-hour meters, gas meters and CO\textsubscript{2} meters.

This technique could also include a system of hardware and software for the automatic detection of electric energy and water consumption. It allows the constant monitoring of installation energy consumption (process consumption and utilities such as air compressors, air treatment units, refrigeration unit and lighting), the detection of deviations and the estimation of the consumption reduction.

Achieved environmental benefits
Benefits include the control and measurement of water and energy consumption in an integrated way. This permits the main points of consumption and potential points of savings to be identified, consumption levels to be controlled, points of losses or incorrect functioning to be identified, and achieved savings to be measured.

Environmental performance and operational data
An example of monitoring is to control temperature, by dedicated measurement and correction.

Technical considerations relevant to applicability
The technique can be implemented in the overall operation of a FDM installation.

Economics
Low investment and operating costs.

Driving force for implementation
The implementation of this technique is stimulated by the potential economic savings, rise in yield and efficiency, and improvement of operating conditions.

Example plants
A dairy installation (#189) [193, TWG 2015].

Reference literature
[193, TWG 2015]
2.3.1.3 Control temperature, by dedicated measurement and correction

Description
Raw material waste and waste water generation can be reduced by controlling the temperature, e.g. in storage vessels, processing vessels and transfer lines.

Technical description
Raw material waste and waste water generation can be reduced by controlling the temperature, e.g. in storage vessels, processing vessels and transfer lines. Possible benefits from this include reduced deterioration of materials, reduced out-of-specification products and less biological contamination. The application of temperature sensors can sometimes be optimised by using them for dual purposes, e.g. for monitoring both product and cleaning temperatures.

Achieved environmental benefits
Reduced energy consumption and reduced waste generation. Potentially reduces water consumption, if water or steam are used for heating.

Environmental performance and operational data
It has been reported that in dairies, the temperature of the milk can be maintained during heat treatment by controlling the flow of steam or hot water.

In confectionery manufacture, temperature sensors can be used to minimise the temperature drop during product transfer, thereby minimising product deterioration.

In meat processing, the temperature of thawing baths for frozen meat can be maintained by controlling the water flow.

In an example meat processing company, installing thermocouples to provide temperature control allowed it to reduce its water supply costs by up to 10%. Thermocouples on the water inlet and outlet to a chilling and washing system, feed into an automated control valve which optimises the flow rate. The control system has reduced water use, energy use and waste water generation significantly, while maintaining sufficient flow rate to meet the process’s hygiene requirements.

A company fermenting molasses to produce alcohol installed an improved temperature control in a fermentation vessel, which was regularly exceeding the required temperature by 5 °C. The result was increased production yields and a 15% reduction in waste.

Technical considerations relevant to applicability
Applicable in installations where heat processes are applied and/or materials are stored or transferred at critical temperatures, or within critical temperature ranges.

Economics
In the example where thermocouples were used, the company reported savings of GBP 13 000/year for an initial investment of GBP 3 000, giving a payback period of 12 weeks (2000). Savings can be achieved due to increased production yields and reduced waste generation.

Driving force for implementation
Minimisation of product deterioration, increased production yields and reduced water consumption.

Example plants
Applied in dairies, confectionery manufacture, at least one meat processing installation in the UK and at least one molasses fermentation installation in the UK.

Reference literature
[ 10, Envirowise (UK) & Entec UK Ltd 1999 ]
2.3.1.4 Level measurement

**Description**
Application of level-detecting sensors and level-measurement sensors.

**Technical description**
The two main categories of level sensors are level-detecting sensors and level measurement sensors. Level-detecting sensors indicate whether or not a fluid is present at a specific point in a vessel (usually a high or low point). Most applications are connected to a visual indicator, a visual or audible alarm, or on-off control of flows in or out of the vessel. Level-measurement sensors allow continuous monitoring of actual fluid levels, with associated variable controls, e.g. increasing or slowing pumping rates.

**Achieved environmental benefits**
Reduced consumption of cleaning materials and water; reduced generation of waste water and reduced risk of contamination of soil, surface and groundwater.

**Environmental performance and operational data**
At an example brewery, a capacitance level switch is used to detect the interface between yeast and beer. The beer was then run off to storage. Yeast can be recovered and used as animal feed.

In beer making, every 1% of wort going to drain adds about 5% to the waste water COD, this can be avoided by using level sensors to prevent overfilling of process vessels with very high COD emission levels.

An example large vegetable processing company made savings through reduced water costs, waste water charges and operator time by installing level controls on the water supply tanks to the flume system that transported the vegetables. Previously, an operator adjusted the water supply controls manually, which led to excessive water overflow from the tanks when the operator was occupied elsewhere. A simple float valve was identified as offering a low cost solution. The valve now controls the water flow to the tanks, freeing the operator to work elsewhere.

**Technical considerations relevant to applicability**
Widely applicable in the FDM sector, e.g. where liquids are stored or reacted in tanks or vessels, either during manufacturing or cleaning processes. Table 2.35 shows some examples of how level sensors can be used to reduce material waste and waste water generation.

<table>
<thead>
<tr>
<th>Installation</th>
<th>Reason for control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage or reaction tanks</td>
<td>Prevent overflow and waste of material or water</td>
</tr>
<tr>
<td>Storage vessels</td>
<td>Provide information for stock control. Minimise waste from out-of-date stock or production losses due to material not being available</td>
</tr>
<tr>
<td>Vessels with automatic transfer controls</td>
<td>Minimise waste from transfer losses or inaccurate batch recipes</td>
</tr>
<tr>
<td>Liquid food materials</td>
<td>To monitor the level in storage tanks to avoid overfilling and loss to drain</td>
</tr>
<tr>
<td>CIP/disinfection-in-place</td>
<td>As a level switch in vessel cleaning to optimise the amount of water/detergent used and to protect against overspill</td>
</tr>
</tbody>
</table>

*Source: [192, COM 2006]*

**Cross-media effects**
There are no cross-media effects associated with this technique.
Economics
In the example brewery, the process modifications cost GBP 9,500 (1999), but the associated reduction in beer losses and waste water charges worth GBP 800,000/year, meant the payback period was 5 days.

The example vegetable processing company saved over GBP 15,000/year through reduced water costs, waste water charges and operator time. The payback period was a few months.

Driving force for implementation
Expensive loss of product.

Example plants
Widely applicable in the FDM sector.

Reference literature

2.3.1.5 Conductivity measurement

Description
Measurement of the conductivity of water.

Technical description
Conductivity measurements are used to determine the purity of water or the concentration of acid or alkali, i.e. by determining the sum of the ionic components of the water. Electrode cells and inductive sensors are two types of sensors used to measure conductivity.

Electrode cells are contact-type sensors, which operate by passing the process fluid between two electrode plates. They are reported to be very accurate. Applications include monitoring process water for reuse, thereby minimising waste water generation and monitoring boiler water to minimise the build-up of deposits on hot surfaces.

Conductivity can also be measured using inductive sensors. These non-contact sensors use two electromagnetic coils around the process fluid and are suitable for hygienic applications. Inductive sensors have a greater range than electrode cells.

The conductivity of rinsing water from CIP (see Section 2.3.3.2.7) is used to determine when flushing is sufficient and CIP can be stopped (instead of using a timer). Rinsing water is collected for reuse to pre-rinse in CIP. By measuring the conductivity of rinsing water, CIP is stopped at the exact moment when flushing is sufficient. This causes consumption of water for rinsing to be reduced.

Achieved environmental benefits
Reduced water and detergent use and reduced quantities of waste water.

Environmental performance and operational data
Although fluid flow is not essential, it provides a self-cleaning effect. Air pockets should be avoided. The equipment should be able to compensate for the change in the conductivity of a fluid with temperature.

At an example dairy (Example A), the CIP cycle comprises a water flush to rinse out residual product; cleaning using acid or caustic detergent for a set period, followed by a water rinse. These stages were previously controlled by individual timers to limit the amount of detergent used. A number of lines and vessels are cleaned by each CIP unit, so the cleaning cycles vary.
The timing of the opening and closing of the drain valve was, therefore, a compromise. This resulted in significant quantities of detergent being discharged as waste water.

Conductivity measurements were introduced to control the addition of acid or caustic cleaning solutions and to determine whether the cleaning solution(s) and/or water could be recovered. This indicated when detergent and/or water could be recovered, and whether the right amount of detergent was being used. All existing CIP units were retrofitted with conductivity probes and they were included in the specification for all new units.

The system works by placing a conductivity probe in the main pipeline from the process equipment, close to the detergent tank inlet. The probe monitors the detergent/water concentration flowing through the line during a cleaning cycle. Detergent cleaning is initiated by a timer and detergent gradually replaces the flush water in the system, which is drained for waste water treatment. Once a set detergent concentration is detected, the conductivity probe signals an actuator to close the drain valve. The flow is then diverted back to the detergent tank and circulated through the system, rather than being discharged. The rinse stage is then initiated by a timer; detergent is recycled back to the detergent tank until dilution has occurred and the set detergent concentration is reached again. At this point, a signal from the conductivity probe opens the drain valve and the rinse-water is drained for waste water treatment until the probe detects clean water again.

The drain valve is then closed and the clean water is diverted to the water tank. The conductivity probe also ensures that the required detergent strength is maintained throughout the cleaning process. Minimal operator attention is required. Each conductivity probe receives some cleaning when the process equipment is cleaned in place. Daily detergent use is monitored by a flow-meter on every CIP unit. If detergent use increases, this indicates that the probe requires further cleaning, i.e. a 10 minute task done by the operators. Additional probe cleaning is usually required every 4 to 6 weeks.

The dairy reports an estimated 15% saving on detergent for each CIP unit; reduced amounts of water and detergent discharged for waste water treatment; reduced downtime of equipment and optimised quantity of detergent used for each cleaning cycle.

In another dairy (Example B), conductivity meters were installed to help reduce detergent use. The conductivity probe detects whether water or detergent is in the line and, if detergent is present, it diverts the flow to a detergent recovery tank. The result was recycling of rinse-water, reduced use of detergent and a consequent reduction in COD in the waste water.

**Technical considerations relevant to applicability**

Widely applicable in the FDM sector in processing and cleaning applications. Examples of the use of conductivity measurement in the FDM sector are shown in Table 2.36. Typical applications of conductivity measurement in the FDM sector are shown in Table 2.37.

**Table 2.36: Examples of the use of conductivity measurement in the FDM sector**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Reason for control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor levels of dissolved salts prior to water reuse</td>
<td>Minimise fresh water use and waste water generation</td>
</tr>
<tr>
<td>Monitor well water</td>
<td>Minimise production of poor quality product (that becomes waste) due to use of unsuitable process water</td>
</tr>
</tbody>
</table>

*Source: [192, COM 2006]*
Table 2.37: Typical applications of conductivity measurement in the FDM sector

<table>
<thead>
<tr>
<th>Sector/activity</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIP</td>
<td>Conductivity monitoring for installation valve control, based on differences between product, e.g. between beer and water or caustic and acid</td>
</tr>
<tr>
<td>Bottling (general)</td>
<td>Conductivity monitoring of caustic use in bottle-cleaning solutions</td>
</tr>
<tr>
<td>Product monitoring (inductive sensors)</td>
<td>Throughout the drinks industries and in dairies</td>
</tr>
</tbody>
</table>

*Source: [192, COM 2006]*

Cross-media effects
There are no cross-media effects associated with this technique.

Economics
The saving on detergent by the Example A dairy, is reported as GBP 13 000/yr. The company report a payback period of 16 months.

The Example B dairy reported savings of GBP 10 000/yr and a payback period of 4 months on the investment.

Driving force for implementation
Reduced detergent use.

Example plants
Numerous installations in the drinks and dairy industries and where CIP is used.

Reference literature
[7, Environment Agency of England and Wales 2000], [10, Envirowise (UK) & Entec UK Ltd 1999], [193, TWG 2015]

2.3.1.6 Turbidity measurement

Description
Measurement of the turbidity of water.

Technical description
Scattered light turbidity devices use a light diffusion method to measure the light scattered through a right angle by the particles or bubbles in the liquid. This method is used for low to average turbidity measurements, including the measurement of turbidity in distilled water. Sampling devices can be used when it is difficult to install the turbidity meter into a process line. This helps to improve hygiene.

Suspended solids turbidity meters work using a light absorption method that measures the amount of light transmitted through matter in the process fluid. They are used for measuring medium to high levels of turbidity.

Achieved environmental benefits
Reduced material loss during processing, increased reuse of water and reduced waste water generation.

Environmental performance and operational data
Turbidity meters should preferably be installed in vertical pipes with an upward flow and the optical unit facing the direction of flow for maximum self-cleaning. To avoid incorrect measurements from floating or settled debris, horizontal pipes should have meters installed at...
the side and not at the bottom or top, to avoid fouling by deposition and floating debris respectively. The fluid velocity should not exceed 2 m/s to avoid spurious readings. To minimise deflection of the beam, gas bubbles and degassing should be avoided.

In a reported food manufacturing process, some product was lost to drain during the separation stages, which resulted in a breach of the company’s water discharge consent. The installation of a hygienic turbidity meter and a flow-meter resulted in reduced product losses to drain, increased product yield and financial savings.

**Cross-media effects**
Low energy consumption associated with the turbidity meter.

**Technical considerations relevant to applicability**
Applicable where product yield can be increased by recovery from process water and for the reuse of cleaning water.

Examples of the use of turbidity measurement in the FDM sector are shown in Table 2.38.

**Table 2.38: Examples of the use of turbidity measurement in the FDM sector**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Reason for control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor quality of process water</td>
<td>Minimise waste water from out-of-specified process water or products</td>
</tr>
<tr>
<td>Monitor CIP systems</td>
<td>Optimise reuse of cleaning water, thus minimising waste water generation</td>
</tr>
</tbody>
</table>

*Source: [192, COM 2006]*

A typical application of turbidity measurement in the FDM sector is the monitoring of process waste streams to determine viability for recovery back into the process.

**Economics**
Reported lower waste water treatment costs and savings of over GBP 100 000/yr Example dairy A and reported cost savings of around GBP 16 000/yr and a payback period of 8 months on combined capital and installation costs.

**Driving force for implementation**
- Reduced product loss.
- To lower the COD content in the waste water and especially the fat content that may cause problems in the waste water pipes.

**Example plants**
At least one cheesemaking dairy and another unspecified food manufacturing installation in the UK.

**Reference literature**
[7, Environment Agency of England and Wales 2000], [10, Envirowise (UK) & Entec UK Ltd 1999], [193, TWG 2015]

**Frequent and prompt cleaning of processing equipment and materials storage areas**

**Description**
Areas where raw materials, by-products, and waste are stored can be cleaned frequently. The cleaning programme can cover all structures, equipment and internal surfaces, material storage containers, drainage, yards and roadways. See also Section 2.3.3.2.1.
Achieved environmental benefits
The adoption of thorough cleaning and good housekeeping as a routine, reduces malodorous emissions and the risk of hygiene and nuisance problems from pests and vermin.

Cross-media effects
Water is consumed during the cleaning process, although the extent depends on the amount of dry cleaning carried out before water is used. There may be opportunities to reuse water from sources within the installation and the WWTP.

Environmental performance and operational data
When ground meat residues, particularly meat mix for salami production or for sausage making, from equipment such as bowl choppers, sausage fillers and from floors, is left standing, it sticks to the surfaces and makes subsequent cleaning difficult. Cleaning such equipment immediately after the end of production minimises the cleaning efforts and the need for water and detergents. The ground meat residues are manually removed to the maximum practical extent, prior to cleaning and sending to the rendering installations.

If raw material containers are emptied and washed frequently, e.g. daily, then decomposing and malodorous materials will not accumulate over long periods of time. Delays in dispatch can provide sufficient time for material to deteriorate and if storage, particularly badly controlled storage, continues on a site, even briefly, odour problems can arise. Even facilities with a quick turnover of clean material can generate odour problems, if good hygiene practices are not observed. For example, sorted fruit and vegetables, peel and cutting residues and organic waste can be emptied daily.

Technical considerations relevant to applicability
Applicable to all FDM installations.

Example plants
Widely applied, e.g. in fruit and vegetable stores.

Reference literature
[20, Nordic Council of Ministers 2001]

Optimise operation by providing training

Technical description
Giving staff at all levels, from management to shop floor, the necessary training and instruction in their duties can help to improve the control of processes and minimise consumption and emission levels and the risk of accidents. This may be undertaken with in-house or external environmental advisers, but they cannot be responsible for the ongoing environmental management of the process. Problems which can arise during routine operations, start up, shut-down, cleaning, maintenance, abnormal conditions and non-routine work should all be covered. Ongoing risk assessment of processes and work areas and the monitoring of compliance with identified standards and operating practices can then be undertaken by managers in partnership with shop floor employees.

Training provision requires an investment of time by all personnel for the provision of information, instruction, training and supervision and the operation of an assessment programme, to identify training needs and the effectiveness of training.

Achieved environmental benefits
Reduced consumption and emission levels and reduced risks of accidents throughout the installation.

Environmental performance and operational data
Numerous examples exist for environmental benefits, including the prevention of accidents, that result from optimised operation through training, e.g.

- avoiding spillage when disconnecting pipes and hoses, e.g. during the bulk delivery of milk, cleaning chemicals, such as caustic and organic solvents, such as hexane for vegetable oil refining
- preventing product losses or spills in warehouses by ensuring workers, e.g. forklift truck drivers, are trained
- ensuring that vessels and hoses are drained before disconnection
- discharging malodorous liquids below the liquid level in a vessel or back venting raw material deliveries into the delivering road tanker are both relatively easy and cost effective to initiate and can control odour emissions
- ensuring that noisy equipment, for which the noise levels cannot be reduced sufficiently at source, is operated for the minimum time necessary and that noise reduction measures to protect the environment, such as closing doors and windows, are always applied. Community provisions on health and safety at the workplace [243, EC, 2003] are also relevant.

Technical considerations relevant to applicability
Applicable to all FDM installations.

Driving force for implementation
 Routinely, considering the environmental impacts can help to focus efforts for achieving lower consumption and emission levels, leading to cost savings and increasing the confidence of the regulatory authority.

Example plants
Many FDM installations.

Reference literature
[205, DoE SO and WO, 1997]

Equipment design and installation design

Design equipment to minimise consumption and emission levels

Description
Careful design of pumping and conveying equipment can prevent solid, liquid and gas emissions. Energy consumption can be minimised by, e.g. energy optimised planning, including reuse of heat and use of insulation. Tanks, pumps, compressor seals and valves and process drains can be major sources of leaks. Examples of effective design considerations include: identifying and marking all valves and equipment settings to reduce the risk that they will be set incorrectly by staff; optimising pipework systems and equipment capacity to minimise product losses, and optimising the extraction and abatement capacity to minimise emissions to air, e.g. during loading and unloading and installing pipes at an angle to promote self-draining.

Designing equipment which is easy to clean makes the recovery of product easier for either its intended use in the process, or for other uses such as animal feed. This dry cleaning can also reduce water consumption and waste water generation.

Designing the equipment to minimise transhipment operations can also reduce the risk of spillage and emissions to air.

Achieved environmental benefits
Reduced consumption of energy, water and substances, and reduced emissions to air, water and land.
Environmental performance and operational data

Examples of ways of minimising emissions to air through design of equipment include fitting tanks with floating roofs, or pumps with double mechanical seals. Refrigeration plants and other equipment, e.g. boilers and cooling towers, can be adequately sized for the maximum expected demand and adequately controlled to always supply the required demand. The use of accurate measurements and often elaborate control mechanisms can sometimes minimise the generation of emissions to air. The control systems in place also require regular and effective maintenance to ensure proper and continued operation.

Conveyors can be completely enclosed and sealed, or fitted with hoods with local exhaust ventilation designed to trap emissions, when enclosure is not feasible. Minimising the length of conveyors and the number of transfer points can reduce emissions. Conveyors can be self-emptying, without dead spaces and provided with drainage to facilitate cleaning.

Noise can be minimised by ensuring, whenever possible, that motors are mechanically isolated from connected ducts or pipes. In addition, for fluid systems, silencers or pulsation dampers can be used to reduce the transmission of fluid-borne noise into the pipe system. For materials handling systems, e.g. chutes and hoppers, the noise generated by impacts between the material and the chute or hopper can be minimised by avoiding abrupt changes in direction and minimising the impact forces, e.g. by maintaining sliding contact of products with chutes and minimising the height of the fall. If impacts cannot be avoided, then noise deadening lining material can be provided.

Maintenance can be taken into consideration at the design stage by, e.g. making water pipework, valves and instrumentation readily accessible for maintenance.

Integrate processing techniques may be possible, to maximise possible product yield and minimise emissions into the environment as a whole.

Technical considerations relevant to applicability
Applicable to all FDM installations.

Driving force for implementation
Reduced consumption and emission levels and their associated costs.

Reference literature

Installation design considerations

Description
There are a number of factors to consider in the initial design of a building to control the generation of emissions to air and noise.

Achieved environmental benefits
Reduced emissions to air and, in many cases, reduced waste.

Environmental performance and operational data
The storage and handling of raw materials is a particular concern for malodorous emissions. For instance, the storage area can be designed to facilitate the operation of a first in first out system. This can be helped by hopper storage which ensures the materials received first are used first, i.e. the hopper is filled at the top and emptied from the bottom. This enables materials to be used fresh, so the use of raw materials is optimised and minimises waste generation.
The risk of product losses or spillages can be reduced in warehouses by ensuring they are designed for easy and safe use, e.g., racking can be designed for efficient use with a forklift truck.

Areas used for loading and unloading can be well designed to facilitate frequent and effective cleaning, by providing smooth surfaces and minimising corners and other places which are difficult to gain access to and to clean.

For extremely polluting materials, the building can be designed so that during abnormal conditions when normal control systems would be sufficient, there are no emissions to air from, e.g., malfunctioning equipment, leaks or during repairs. The number of entry points can be minimised and these can be protected by double doors with an airlock between.

Designing rooms with smooth walls and rounded corners that are easy to clean can also optimise the recovery of materials for use or disposal. This can also reduce water and detergent use for cleaning and consequently also waste water volumes and loads.

**Technical considerations relevant to applicability**

Applicable to all FDM installations.

**Driving force for implementation**

Reduced emissions to air and, in many cases, reduced waste and waste water generation.

**Reference literature**

[34, Willey A R and Williams D A, 2001]

**Maintenance**

**Technical description**

The effective planned preventive maintenance of vessels and equipment can minimise the frequency and size of solid, liquid and gas emissions, as well as water and energy consumption. For example, tanks, pumping and conveying equipment, compressor seals, valves and process drains can be major sources of leaks. Faulty process control equipment can lead to leaks, overflow and loss through drip piping.

The correct operation of the process installation can be regularly reviewed and any deviations or modifications can be assessed in terms of their impact. Simple modifications to a process can often result in considerable reductions in emissions to air.

**Achieved environmental benefits**

Reduced consumption of energy, water and substances, and reduced emissions to air, water and land. Reduced waste, e.g., through co-product/by-product recovery. Reduced noise emissions.

**Environmental performance and operational data**

In general, the maintenance of utility systems receives much lower priority than maintenance that has a direct impact on production or safety. This can be a major contributing factor in excessive water use and unnecessary waste water generation. A well-operated maintenance regime can ensure, e.g., the prompt repair of water leaks and faults which can lead to overflow or spillage to drains. Optimisation of the cooling water systems can avoid excessive blowdown of the cooling tower.

Examples of maintenance practices include:

**General**

- reporting and fixing leaks promptly
- checking that grab edges meet properly to avoid trickling losses, during transhipment of dusty solids.

**Steam**
ensuring that inspection of steam traps is a documented routine activity

repairing steam leaks

ensuring that a documented system for reporting and rectifying steam leaks is in-place

ensuring that the repair of steam leaks is given high priority. Costs can soon mount-up with only a few leaking valve glands.

Compressed air

initiating an effective system for reporting leaks

carrying out an “out of hours” survey, to listen for leaks, locate and tag them

repairing leaks.

Refrigerant

cHECKING THE REFRIGERANT SIGHT GLASS FOR BUBBLES. BUBBLES IN THE SIGHT GLASS USUALLY MEAN A SYSTEM IS LEAKING

finding the leaks and repairing them before the system is recharged with refrigerant

checking that the oil in the compressor sight glass(es) is at the right level. The compressor will be more likely to fail if the oil level is too low, or too high.

Cooling

leakage of materials into a cooling water system or operation of a cooling tower system to cool contaminated process water directly, can greatly increase odour problems.

Fish

maintaining skinning machinery, e.g. by keeping blades sharp, to ensure efficient skinning and to minimise the removal of fish flesh with the skin.

Fruit and vegetables

using sharp cutting heads during fruit and vegetable cutting processes.

Technical considerations relevant to applicability

Applicable to all FDM installations.

Driving force for implementation

Smooth, untroubled production which is not interrupted by breakdowns and accidents. Legislation, e.g. it is illegal to knowingly vent certain refrigerants.

Example plants

Preventive maintenance is widely applied in the whole FDM sector.

Reference literature


Good housekeeping

Technical description

Enforcing a system to maintain the installation in a clean and tidy manner can improve the overall environmental performance. If materials and equipment are kept in their allocated place then it is easier to ensure that use-by dates are respected and less waste is generated. It is also
then easier to clean the installation and reduce the risk of infestation by insects, rodents and birds. Spillages and leaks can be actively minimised and spilled materials can be collected dry immediately.

**Achieved environmental benefits**
Reduced waste generation, reduced contamination of waste water by wet cleaning, reduced odour production and emission and reduced risk of infestation by insects, rodents and birds.

**Technical considerations relevant to applicability**
Applicable to all FDM installations.

**Economics**
Avoids expenditure on odour abatement, waste disposal and waste water treatment.

**Driving force for implementation**
Reduced waste production and safety (prevention of slipping and tripping accidents).

**Methodology for preventing and minimising the consumption of water and energy and the production of waste**
Prevention and minimisation requires the adoption of a systematic approach. A successful methodology usually consists of the steps described in the following sections [1, CIAA, 2002]. These steps are described:

- step 1: obtaining management commitment, organisation and planning
- step 2: analysis of production processes
- step 3: assessment of objectives
- step 4: identifying prevention and minimisation options
- step 5: carrying out an evaluation and feasibility study
- step 6: implementing the prevention and minimisation programme
- step 7: ongoing monitoring by measurement and visual inspection.

The importance of preventing and minimising the consumption of water and energy, and waste production is described below.

**Preventing and minimising water consumption**
The supply of water is not unlimited, so control of its consumption is necessary. This is an important aspect of the conservation of natural resources. In the FDM sector, the required food safety and hygiene standards have to be achieved. This means that cleaning of equipment and installations consumes a major proportion of the water used in the sector. Taking a systematic approach to the management of water use can lead to reduced water consumption. Reduced water consumption also leads to reduced volumes of waste water for treatment. Preventing or, if this is not feasible, minimising water pollution, used in combination with other techniques, can lead to a reduction in water pollution.

Water pollution control can be achieved by:

- reducing the volume of the waste water generated
- reducing the strength of the waste water generated
- eliminating or decreasing the concentration of certain pollutants, particularly the priority pollutants
- recycling or reusing water
- waste water treatment.

**Preventing and minimising energy consumption**
In many of the FDM sectors, energy consumption is an important cost factor. Depending on the nature of the production activities, energy costs may vary from less than 1 % to more than 10 % of the production costs. Taking a systematic approach to reduce energy consumption is an important issue, both from the point of view of the environmental impact, e.g. greenhouse effect, and also due to cost savings.

The concept of energy efficiency is frequently used to measure the energy consumption in an industrial installation. Energy efficiency is often defined as the amount of energy consumed per unit of product. Improving energy efficiency, therefore, means reducing the amount of energy per unit of product. This will result in energy savings at an installation level if the product output remains at a constant level. In improving the energy efficiency, two aspects can be distinguished:

- a reduction of the energy consumption by efficient energy management
- a reduction of the energy consumption by process optimisation and innovation.

Energy management is an approach to controlling and minimising energy consumption and energy costs. It depends, to a large extent, upon placing accountability for consumption on those individuals who are responsible for using it. An essential part of energy management is monitoring and targeting. In several case studies, energy savings of 5–15 % are reported.

A further step in improving energy efficiency can be made by process optimisation and innovation. Sometimes this requires only minor investments. Nevertheless, for innovations that have an important impact both on the process and energy consumption, larger investments may be necessary. Investments in process optimisation and innovation without an efficient system of energy management cannot give a good insight into whether the expected energy savings are actually realised. Furthermore, it is possible that the effect of the energy savings gained by process adaptations can be offset if good housekeeping is not maintained.

An illustration of the relationship between the effects of efficient energy management and implementing energy saving measures, e.g. process optimisation and innovation, is given in Figure.

Figure: Reduction in energy consumption
[1, CIAA, 2002]
Preventing and minimising waste production

Avoidance of waste production is one of the main objectives of the IPPC Directive. Article 3 (c) states “MSs shall take the necessary measures to provide that the competent authorities ensure that installations are operated in such a way that...(c) waste production is avoided in accordance with Council Directive 75/442/EEC of 15 July 1975 on waste; where waste is produced, it is recovered or, where that is technically and economically impossible, it is disposed of while avoiding or reducing any impact on the environment”. Annex IV states “Consideration to be taken into account generally or in specific cases when determining best available techniques, as defined in Article 2(11), bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention: 1. the use of low waste technology; and 3. the furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate;”

Techniques which describe the use, reuse, recovery and recycling of by-products, co-products, residues and materials that can be prevented from becoming waste are described in this chapter. For example, the use of materials originally intended for use in food products, but which do not meet the customers specification but are otherwise fit for consumption, may be suitable for use in animal feed.

The objective of a waste prevention programme is to reduce the environmental impact of manufacturing operations as much as practicably possible, taking into account economics and the environmental benefit, and being consistent with meeting all the regulatory requirements. Minimisation of the wastage of both material and energy achieve legal compliance; reduced financial costs to the producer associated with loss of product and raw material and payment for disposal both on- and off-site. It conserves natural resources.

Hygiene and food safety considerations, using HACCP are paramount in the production of FDM. Waste prevention measures cannot be allowed to endanger the bacteriological quality of the product, e.g. if there is any doubt about meeting quality standards, the product is reprocessed or rejected as waste. Furthermore, thorough cleaning is necessary to meet a required level of cleanliness and hygiene, but this then leads to waste water. Typically, savings can be made in cleaning operations, resulting in less contaminated water and chemicals going to the drain, but without endangering hygiene in the final product.

This methodology provides guidance on management of waste prevention, thereby also allowing reductions to be made in the loss of raw materials, products and auxiliary materials and consequently in costs. Where appropriate, case studies and reported examples are used to demonstrate successful waste minimisation measures. Preventing waste generation from accidental releases is discussed separately in Section.

Information on waste minimisation methodologies can be found in various guides, such as the UK Environment Agency’s (2001): “Waste Minimisation – An Environmental Good Practice Guide For Industry”, [64, Environment Agency of England and Wales, 2001] and in publications of the Environmental Technology Best Practice Programme series such as “Waste Minimisation Pays: Five Business Reasons for Reducing Waste – GG 125” [62, Envirowise (UK), et al., 1998], or “Cutting Costs by Reducing Waste: Running a Workshop to Stimulate Action – GG 106” [63, Envirowise (UK) and William Battle Associates., 1998]. Applying effective techniques in each of the key wastage areas is likely to give significant environmental benefits. An example methodology used in waste prevention and minimisation is shown in Figure.
Step 1: Obtaining management commitment, organisation and planning

Obtaining management commitment
To be successful, the programmes for preventing and minimising water and energy consumption, and waste production require commitment at senior management level. This can ensure that all individuals within the organisation work together in a positive manner to gain maximum benefit from the initiative. One of the best ways of gaining senior management commitment is to convince the managers of the financial benefits that can be achieved.

It is advisable to start by identifying one or two areas where substantial amounts of materials or products are lost, where waste is produced or high water and energy consumption levels are registered and then showing the associated costs for the company. This cost survey includes the cost of wasted raw materials, rework, lost production time, waste treatment costs, wasted labour, loss of materials to the air and to the drain, as well as the excessive use of energy and water.

Sometimes up to 25% of the raw material, or product equivalent, goes to waste or to the drain. Senior management may often be unaware of the scale of losses and highlighting them may provoke full support from senior management for the prevention and minimisation programme.

Organisation (establishing a project team) (see also Section)
It is usually beneficial to appoint a team leader or company champion to co-ordinate and facilitate the programmes. Using project teams and champions can help to increase awareness at all levels and to motivate individuals to take action and participate. The team leader and the project team can be responsible for carrying out assessments and for developing and evaluating proposals and measures [63, Envirowise (UK) and William Battle Associates, 1998].

Planning
Drawing up a detailed project plan together with a time schedule stating when activities need to be carried out can assist the prevention and minimisation programme. This is successful if progress is monitored and individuals with responsibilities to take action are appointed and held to account.

Step 2: Analysis of production processes
An important condition for successful prevention and minimisation of energy and water consumption, and waste production is to have a good overview of the areas and process steps that are relevant to the loss of materials, the generation of waste and the consumption levels.
Such an overview makes it easier to identify measures. This requires a detailed inventory of all of the production processes. In developing this inventory, three levels of measurement can be distinguished.

Collection of quantitative data at the site level
At this level, data on quantities and costs are collected for the total installation, i.e., whole site. Most data should already be available within the company recording systems, e.g., stock records, accounts, purchase receipts, waste disposal receipts and production data. Where information is not available, estimates or direct measurements are required.

The quantities of all raw materials, energy, water and wastes usually cover an annual period. The units need to be consistent. This is essential to allow quantities and activities to be compared in a meaningful way both now and in the future.

Information can be collected in a systematic manner to ensure that the initial assessment is made as complete as possible. Typically, it is useful to keep a paper or electronic database of all the information collected.

Inventory for each process step
The objective of this step is to get an overview of all the production processes and related environmental aspects. Production processes can usefully be represented by a flowchart showing inputs, outputs, and environmental problem areas. Figure shows one example of an input/output worksheet. This may be represented in other formats [60, Environment Agency of England and Wales, 1998].

![Figure: Example worksheet to identify input/output and environmental issues](image-url)

A mass balance can be made to account for the consumption of raw materials and services, and the losses, wastes and emissions that result from the process. A mass balance makes it possible to identify and quantify previously unknown losses, wastes, and emissions, and also provides an indication of their sources and causes. Mass balances are easier, more meaningful, and more accurate when they are undertaken for individual process steps. An overall installation-wide mass balance can then be constructed from these.
Chapter 2

The mass balance can also be used to identify the costs associated with inputs, outputs and identified losses. Environmental performance indicators for the process can be developed from the mass balance data.

Inventory of selected parts

Depending on the inventory at process step level, certain parts of the process/installation may need further analysis for prevention and minimisation options. This requires a more detailed inventory focusing on the most significant aspects or process areas.

Analysis of production processes aimed at the prevention and minimisation of water consumption

First, the water input and water output of the total installation is examined. The use and production of the water is taken into account, including recycled and reused water; water incorporated in the product, e.g. drinks, canned fruits and vegetables, or evaporated water and water used in cleaning. A distinction is usually made between the total and the fresh water used. The overall water consumption and emission levels for an example installation are shown in Figure.

![Figure: Overview of the water input and output of an example installation](image)

Then, a monitoring system needs to be set up. This involves identifying the appropriate measuring points for water consumption and implementing a system for data collection, processing and reporting. The data can sometimes be obtained easily from existing flow measurements, bills for water and waste water discharges and any data provided for a permit. It may also be useful to give an overview of the costs that are related to water input and output, as this will show where financial savings can be made.

On the basis of the information gathered at this stage, benchmarks can be identified. Some examples of benchmarks are:

- specific water consumption \( (m^3/\text{water/tonne of raw material or finished product}) \)
- specific waste water discharge \( (m^3/\text{water/tonne of raw material or finished product}) \)
- ratio of water costs between water input and water output
- water costs per product unit
- water loss as a percentage of water consumption.

Using such benchmarks and, if possible, comparing them with external benchmarks, may give an initial indication of whether or not savings are possible.
Depending on the type of installation, a distinction can be made between departments, types of processes and the main levels in a process. Apart from the production processes, water treatment, waste water treatment and cleaning activities need to be incorporated in the inventory to ensure all potential savings are identified.

Sometimes the water flows for the main processes and departments are already being measured. If not, metering equipment can be installed on the main streams, some even on a temporary basis. Alternatively, the water consumption of the various production processes can be estimated, e.g. on the basis of production volume, however, this gives less reliable results.

On the basis of the information gathered at this stage, it should be possible to select the areas to target for further investigations into water savings. Nevertheless, certain parts of the process may need further analysis for saving options. This requires a more detailed inventory of these parts. The selected parts are split up into logical building blocks, i.e. relevant process parts, unit-operations, equipment and installations. The water input and output are determined for each building block. Furthermore, it may be important to characterise the function of the water in that particular part, e.g. as transport water, washing water, product water, or cooling water.

Frequently, all the data that is needed in this detailed level may not be available. Missing data can be completed by performing additional measurements or by calculation from other data or even by estimation. It depends on how relevant the concerned water flow is in the overall scheme. The level of detail is kept to what is strictly necessary to avoid excessive time consumption and costs for the inventory. Furthermore, the parts of the installation under investigation need to be physically definable and to have logical recognisable names. The use of plans, flowcharts, for each level and process part can assist, as can presenting the data in a uniform way. Flowchart software programs can be used for this.

In each process step, an assessment of the quality requirements of the water used can be made. The most important criteria generally are, depending on the type of process, the presence of organic material from raw materials and products, the presence of auxiliary substances in the water, the microbiological count, pH, chloride content, hardness and the iron and manganese content. It is advisable to group the processing steps requiring the same water quality together and to limit the defined water qualities to a maximum of 5 to 10. The defined quality requirements are such that the water quality should not affect the quality of the finished product.

The qualities of the released flows of each processing step are also established. This information is necessary to judge whether it is possible to reuse water, either with or without intermediate treatment.

Finally, an estimate on the minimum water consumption can sometimes be obtained from external benchmarking. A prerequisite is that data are available for comparable activities. Another approach is to determine the minimum water consumption level based on the specifications, e.g. of the suppliers, and of the various parts of the process lines. Totalling the individual process water requirements throughout the installation leads to a theoretical water consumption design and enables standards or targets to be established.

**Analysis of production processes aimed at the prevention and minimisation of energy consumption**

Information about energy consumption is fundamental to identify where the most effective energy savings and cost effective improvements can be made. Furthermore, it is a basis for demonstrating that the installation is operated in an efficient manner and that energy saving measures are taken in the most appropriate areas.

First, the information needs to be broken down by energy source. As well as purchased electricity, this should also include fuels converted to energy at the site, heat imported directly from external sources and renewable energy sources. Recent values for delivered energy sources
over a recent 12 month period may be used. Conversion to primary energy is advised. Where energy from a CHP installation is used (see Section), the calculated energy used is based on the energy input to the installation, not on the units of energy produced by the installation. An example worksheet for the breakdown of energy consumption can be seen in Table.

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Energy consumption</th>
<th>Delivered</th>
<th>Primary (kWh or MWh)</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>MWh</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>m³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>tonnes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imported steam</td>
<td>tonnes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy from waste/renewable sources</td>
<td>kWh (MJ)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other, specify</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exported steam</td>
<td>tonnes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exported electricity</td>
<td>MWh</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table: Example worksheet for the breakdown of the energy consumption

[1, CIAA, 2002]

Next, an analysis of the energy consumption of the equipment, per department or production line, is made. It is advisable to supplement the energy consumption information with energy balances or flow diagrams to illustrate how energy is used throughout the process. A Sankey diagram can be used to represent situations where energy conversion is highly integrated within the production activities (see an example in Section).

Finally, the specific energy consumption (SEC) is analysed. This means the amount of energy that is consumed per unit of raw material processed or product output.

Analysis of production processes aimed at the prevention and minimisation of waste production

Losses may occur at each stage in the production process, from reception to dispatch. For example, losses associated with poor storage and materials handling may be detected by keeping an accurate inventory of inputs and outputs at all stages of the process from the reception of raw materials to the dispatch of products and end-of-pipe treatments. These losses may be perceived or real losses. Some examples of causes of material losses and some methods of maintaining an accurate inventory are shown in Table.

<table>
<thead>
<tr>
<th>Example causes of real and perceived material losses</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of monitoring of inputs and outputs at all stages of the process from reception of raw materials to dispatch of products and end-of-pipe treatments leading to actual losses and their causes and locations remaining unknown</td>
<td>Carry out a mass balance</td>
</tr>
<tr>
<td>Calculated specific yields showing the quantity of product produced per unit of raw material consumed or the relative yield showing the percentage of raw material converted to product not maintained</td>
<td>Calculate yields, set benchmarks and maintain them</td>
</tr>
<tr>
<td>Perceived or real over- or underfilling leading to spillage of off specification product</td>
<td>Provide, use and regularly calibrate meters</td>
</tr>
<tr>
<td>Over- or underpurchasing leading to deterioration of unused stock</td>
<td>Keep accurate accounts</td>
</tr>
<tr>
<td>Material volume changes due to temperature changes not recognised</td>
<td>Use conversion factors to take account of changes in volume due to temperature</td>
</tr>
</tbody>
</table>

Table: Examples of causes of material losses and some methods of maintaining an accurate inventory

For example, the process flow diagram of a site for liquid milk production can be expanded with specific mass balances, giving an overview of where the main waste milk losses occur, as shown in Figure.

![Figure: Detailed process flow diagram for liquid milk production](image)

The above process flow diagram shows that the overall loss of raw milk from the process is 0.7 to 1.0 % and this is reported to be indicative of industry best practice. The key areas of waste milk generation identified in the diagram are shown in Table.

<table>
<thead>
<tr>
<th>Raw Milk Loss Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw milk CIP and associated installation</td>
<td>0.3 %</td>
</tr>
<tr>
<td>Processing - mainly centrifugal separator discharge</td>
<td>0.1 %</td>
</tr>
<tr>
<td>Finished milk CIP and associated installation</td>
<td>0.3 %</td>
</tr>
<tr>
<td>Overfilling during packaging</td>
<td>0.2 %</td>
</tr>
<tr>
<td>Changeover/spillage during packaging</td>
<td>0.1 %</td>
</tr>
<tr>
<td><strong>Total raw milk loss</strong></td>
<td><strong>1.0 %</strong></td>
</tr>
</tbody>
</table>

*This analysis excludes any reclaimed process milk, which is typically 1.5 % and accounted for in waste reporting systems.*

Table: Key areas of waste milk generation
Chapter 2

Step 3: Assessment of objectives
Based on the analysis made in step 2, the objectives of the prevention and minimisation programme are assessed. The objectives include reduction targets, boundaries and time-scales. The objectives need to be measurable and scheduled into a programme plan so that they can be used to monitor if the programme is proceeding as planned. These objectives can be revised further in the process when implementing the actual prevention and minimisation programme (see step 6).

Step 4: Identifying prevention and minimisation options
Various approaches can be applied to identify measures to prevent and minimise water and energy consumption, and waste production, e.g. brainstorming, internal investigation, external consultancy and pinch technology (see Section).

Identifying prevention and minimisation options depend on the knowledge and creativity of the project team members and other staff, much of which, of course, comes from their own experience. Several options can often be found by carefully analysing the cause of any problem.

Alternatively, people from different parts of the organisation can meet to discuss solutions to specific problems in an open and non-threatening environment, during brainstorming sessions.

Additional ideas may be generated by hiring a consultant with specific expertise and letting him make a walk-through inspection.

For example, in the FDM sector, there are many measures that can be applied to reduce the amount of water used, e.g. elimination of the use of water, optimising process control (see Section), recycling and reuse of water, good housekeeping and maintenance (see Section). Some examples of possible water-saving measures are shown in Table.

<table>
<thead>
<tr>
<th>Water-saving measure</th>
<th>Typical reduction in process use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed circuit water-recycling</td>
<td>up to 90</td>
</tr>
<tr>
<td>CIP (new)</td>
<td>up to 60</td>
</tr>
<tr>
<td>Reuse of wash-water</td>
<td>up to 50</td>
</tr>
<tr>
<td>Countercurrent rinsing, e.g. in CIP</td>
<td>up to 40</td>
</tr>
<tr>
<td>Good housekeeping</td>
<td>up to 30</td>
</tr>
<tr>
<td>Optimisation of CIP</td>
<td>up to 30</td>
</tr>
<tr>
<td>Spray/jet-upgrades</td>
<td>up to 20</td>
</tr>
<tr>
<td>Brushes/squeegees</td>
<td>up to 20</td>
</tr>
<tr>
<td>Automatic shut off</td>
<td>up to 15</td>
</tr>
</tbody>
</table>

Table: Typical achievable reductions in water use
[23, Envirowise (UK) and Dames & Moore Ltd, 1998]

It is reported that in the process of identifying energy efficiency measures, production processes, utilities and buildings need to be considered separately. There is a lot of information on energy efficiency techniques available from various public sources. However, the available techniques are strongly dependent on the particular site and the type of processes applied. Overall, total energy savings are usually the result of small savings in a number of areas. For example, reductions of up to 25 % are possible through improved housekeeping (see Section) and fine-tuning processes. The use of more energy-efficient equipment, heat recovery and applying combined heat and power (CHP) generation (see Section) may also result in additional savings. An example pasta manufacturer indicated that an improvement in the energy efficiency of one of its boilers, from 85 to 90 %, could lead to a 5.56 % reduction in CO₂ emissions (considering a conversion factor of 84.6 kg CO₂/GJ).

Many measures applicable for reducing an environmental impact, e.g. reduction of energy consumption, have no effect on other polluting emissions associated with the installation. Such
measures can be considered as “standalone” and are evaluated according to their individual economic and environmental benefits.

On the other hand, some measures can lead to positive or negative effects on other environmental issues, and in such cases, the wider environmental impacts need to be taken into account. In the case of trade-offs, e.g. between energy consumption and other environmental objectives, an assessment, taking into account the costs and environmental benefits, need to be undertaken to justify the implementation of appropriate measures.

**Pinch technology**

**Description**

The term pinch technology was introduced as a methodology in process design and energy conservation. Nevertheless, it has been developed for use in the areas of water consumption and waste minimisation.

Energy pinch technology is an analysis method that identifies the best use of heat transfer from hot streams, which require cooling, to cold streams, which require heating. A pinch analysis provides a systematic approach to analysing energy networks and improving the energy efficiency of industrial processes. The analysis uses a graphical representation of the energy flows in the process and utility streams to determine the minimum amount of energy and energy system needs to use to satisfy the processing requirements. The technique uses temperature-enthalpy diagrams to characterise the hot and cold streams available for heat transfer. The sum of the hot streams and cold streams in a process can be drawn on a similar diagram from which the pinch temperature can be determined. This information can be used to identify where in the process heat recovery is possible and to what degree. Furthermore, the minimum hot utility requirement and minimum cold utility requirement can be determined. To realise this minimum energy requirement, a heat-exchanger network is installed. The pinch analysis yields the optimum design.

Water pinch technology may be a powerful tool for identifying water reuse, recycling and regeneration opportunities within an installation or process. Water pinch technology uses advanced algorithms to identify and optimise the best water reuse, regeneration and waste water treatment options. The basic concepts are analogous to those for heat recovery. Water flow and the content of water contaminants are taken into consideration, leading to so-called sources and sinks.

**Achieved environmental benefits**

Reduced energy consumption and associated emissions to air. Reduced waste heat released to the air or to water. Maximisation of the reuse of water, taking into account the quality requirements for each application. Minimum fresh water make-up and waste water discharge. Waste minimisation.

**Environmental performance and operational data**

In an example edible oil refinery, pinch technology was applied to analyse whether a new refining method was more energy efficient than its predecessor, which used steam for process heating and river water for cooling. The analysis revealed that the pinch point was 55 ºC and enabled the formulation of a heat recovery strategy. It also revealed that the existing batch processes would lead to a disparity between the timing of heat availability and demand, making it impractical for direct heat exchange between many of the hot and cold process streams. A heat transfer/storage medium was required before any process integration projects could be carried out. A heat recovery network was developed using water for heat transfer and storage. This proved to be highly successful and did not adversely affect production capacity or flexibility. In addition, the use of the utility system, based on three water temperatures, i.e. 30, 55 and 95 ºC, and four thermal tanks, enabled unrelated batch processes to be successfully integrated.
After two years, the edible oil refinery carried out an updated pinch analysis which showed that the pinch point had moved and operational changes were considered. After the pinch analysis, energy consumption was reduced by 35% and CO$_2$ emissions by 16,700 t/yr. There were also reduced quantities of waste heat discharged into the river.

**Technical considerations relevant to applicability**

Pinch analysis is successfully applied in the chemical process industry and refineries. It can also be a useful tool for bigger and more complex FDM installations. For relatively simple operations, it does not result in any more or any better options than those that can be raised by the other methods. Also, the method is difficult to apply for batch processes and it does not take into account electricity consumption.

**Economics**

Table shows the costs and savings reported in an example edible oil refinery when applying pinch technology.

<table>
<thead>
<tr>
<th>Pinch analysis costs (EUR)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Consultancy fees for the pinch analysis</td>
<td>32,000</td>
</tr>
<tr>
<td>In-house staff costs for the pinch analysis</td>
<td>16,000</td>
</tr>
<tr>
<td>Implementation of the pinch analysis recommendations</td>
<td>666,000</td>
</tr>
<tr>
<td>Link to neighbouring installation for export of heat</td>
<td>203,000</td>
</tr>
<tr>
<td>Annual utility water system operating costs</td>
<td>84,000</td>
</tr>
<tr>
<td><strong>Total costs</strong></td>
<td><strong>3,401,000</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pinch analysis savings (EUR)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings reduction in energy costs</td>
<td>1,145,000</td>
</tr>
<tr>
<td>Sale of surplus heat</td>
<td>90,000</td>
</tr>
<tr>
<td><strong>Net savings</strong></td>
<td><strong>1,235,000</strong></td>
</tr>
</tbody>
</table>

**Driving forces for implementation**

Reduction of costs.

**Example plants**

An edible oil refinery in the UK used pinch technology to reduce its energy costs.

**Reference literature**

[1, CIAA, 2002, 237, Caddet, 1999]

**Step 5: Carry out an evaluation and feasibility study**

The objective of the evaluation and feasibility study phase is to evaluate the proposed options and to select those most suitable for implementation. The options are all evaluated according to their technical, economic and environmental merits. The depth of the study depends on the type of the option.

Typically, the quickest and easiest method for evaluating the different options is to form a project team, consisting of staff and management personnel, and to discuss the possible options one by one. This process gives a good indication of which projects are feasible and what further information is needed for more thorough evaluations.

**Technical evaluation**

The potential impacts on products, production processes and health and safety from the proposed options need to be evaluated before actions, which may be complex and costly, can be
decided upon. In addition, laboratory testing or pilot tests may be required when options significantly change existing processes.

**Economic evaluation**

The objective of this step is to evaluate the cost-effectiveness of the proposed options. When performing the economic evaluation, the costs of the change are weighed against the environmental benefits and the financial savings that may result. In reality, economic viability is often the key parameter that determines whether or not an option is implemented.

**Environmental evaluation**

The objective of the environmental evaluation is to determine the positive and negative environmental impacts of the option. In many cases, the environmental advantages are obvious, namely reduced water and energy usage or waste production. In some cases, it may be necessary to evaluate whether, e.g., an increase in electricity consumption would outweigh the environmental advantage of reduced water consumption. An example of a technique with positive and negative environmental impacts, i.e., reducing water consumption and increasing electricity consumption is replacing once-through cooling by a closed-circuit cooling system with refrigeration equipment.

**Step 6: Implementing the prevention and minimisation programme**

Use of an action plan can ensure that the selected options are implemented. The action plan can show the activities to be carried out, the resource requirements, the persons responsible for undertaking those activities and the deadlines for action. It is important to evaluate the effectiveness of the implemented measures and to monitor and review the effects periodically (see Section).

An implementation and action plan needs to be prepared and put in place to implement the options. A step-by-step approach is recommended. The action plan needs to include realistic and achievable consumption and emission reduction targets, which senior management have agreed. Involving all staff when implementing the action plan and providing regular feedback to them, helps to keep the momentum going for the programme and to encourage staff to look for future ideas and initiatives. Review progress against targets periodically.

For example, essential steps in setting targets for energy efficiency measures are as follows:

- recording the energy consumption with regular intervals
- relating the energy consumption to production activities and/or other relevant parameters
- introducing targets for energy consumption
- comparing the real energy consumption with the targets
- reporting
- taking action if the real energy consumption deviates substantially from the target consumption.

As setting realistic targets is not always easy, one approach is to set a figure lower than the average level, e.g., 10% lower. Another approach is to determine the minimum energy consumption level based on the specifications of the various parts of the process lines.

**Step 7: Ongoing monitoring by measurement and visual inspection**

**Description**

It is important to evaluate the effectiveness of measures implemented to minimise consumption and emission levels and to monitor and review their effects periodically. The parameters to be monitored depend on the production processes, raw materials and chemicals used in the installation. The frequency at which the parameter is monitored varies widely according to the needs and risks to the environment and according to the monitoring approach taken. Corrective and preventive action can be carried out if a problem is identified. Furthermore, the introduction
of new products or processes may also have a positive or negative effect on the consumption and/or emission levels and the techniques for minimising these may need to be adapted.

Monitoring may take a number of forms depending on the individual case and may involve the measurement of physical and chemical parameters and visual monitoring. If it is necessary to monitor ongoing waste water emission levels, measurements will be required. Regular and frequent visual monitoring may supplement water consumption measurements. For example, introducing a routine programme for the visual auditing and handling of water and waste water in the installation may form part of a programme of identifying areas of improvement and maintenance requirements.

Further information on monitoring is available in the “Reference Document on the General Principles on Monitoring” [96, EC, 2003].

**Achieved environmental benefits**

By ongoing monitoring, the effectiveness of the chosen measure can be periodically checked to see whether it is meeting the set targets, e.g. consumption and emission performance levels. Under performances can thereby be detected and rectified. Also, monitoring shows trends and can identify priority areas for improvement.

**Environmental performance and operational data**

An example starch manufacturer processes maize into starch, starch derivatives, and glucose, both for food and non-food industries. By carrying out a systematic monitoring and analysis of this process, the company aims to reduce the energy consumption of the installation. The annual savings are equivalent to 3 million m$^3$ of natural gas (95 TJ), i.e. a reduction of approximately 10%.

Previously, the energy consumption in the starch installation was determined from incidental measurements or from data provided by the energy supplier. The energy use of the separate production stages and their respective products was calculated from these data. This only gave an overview of the actual energy consumption and that was not enough to improve the energy efficiency of the installation. Therefore, a monitoring system that measures and registers the specific energy consumption of several process stages was installed at the site. The production process was divided into separate operational units. Each of the units comprises the manufacture of a particular product or group of products. The energy flows in each module are measured in real-time. The measurements allow the determination of both the energy flows at that time and the consumption over a prolonged period of time.

The new system has made it possible to compare the starch installation’s actual and theoretical energy consumption, allowing optimisation of the process in cases of unfavourable differences. Moreover, the system compares the measured energy consumption with that of comparable process units at sister companies and is capable of changing process units according to the most favourable design.

The new monitoring system continuously measures the modules’ water, steam, natural gas, and electricity flows. The collected data are transferred to a central processor and then converted into tables and graphs, which are distributed among the interested parties.

The system, in its present form, only registers and reports the actual energy consumption of the installation. Calculation of the specific energy consumption, related to the production of the installation, is still performed manually. The analysis of the data is based on comparisons with historic data of energy consumption under similar conditions.

An example UK dairy installed a computer-based monitoring and targeting system to help reduce costs and improve profitability. A number of meters were installed in the dairy to measure electricity, oil and water consumption. The meter readings were entered into the system, which presents data to enable the company to pinpoint areas of waste and to take
corrective action. The principle of the system has been well proven in this case, with improvements in energy efficiency constantly being made. Substantial energy and utility savings were achieved. These savings, which were achieved with low capital costs, were partly due to the high motivation of staff at all levels.

**Technical considerations relevant to applicability**
Widely applicable in the FDM sector.

**Economics**
The overall investment costs of the starch example installation amounted to EUR 700000. At a gas price of EUR 0.095/m$^3$, the annual savings are EUR 284000. This equates to a payback period of about 2.5 years.

**Driving forces for implementation**
Reduced costs and improved profitability.

**Example plants**
A starch manufacturer in the Netherlands and a dairy in the UK.

**Reference literature**

**Apply production planning to minimise associated waste production and cleaning frequencies**

**Technical description**
Well planned production schedules which minimise the number of product changeovers and consequently the number “interval cleans”, can minimise waste generation, water consumption and waste water generation. If, instead of making the same product twice or more times it can be made in one batch, the number of changeovers can be minimised. The sequence of production may also influence the number of times cleaning is required and the extent.

If an installation produces several different products or the same product, but with different flavours or colours, they depending on the difference between the product specifications and the risk of cross-contamination, equipment and installation cleaning is required between products. This may be important for food safety reasons, e.g. when changing from using ingredients which people may be allergic to, such as peanuts when making ready meals. Also, for flavour and or colour reasons, e.g. when changing yoghurt flavours from blackberry to peach.

If residues have to be removed from equipment between products, it may be possible to use these in by-products or if not they may be disposed of as waste. If the number of changeovers is minimised, the amount of residue removed can be reduced and the overall proportion of raw material which is used in the final product can be maximised. Likewise the amount of water, energy and chemicals used in “interval cleaning” is minimised.

**Achieved environmental benefits**
Reduced consumption of water, energy and chemicals and generation of waste water and waste.

**Technical considerations relevant to applicability**
Applicable in FDM installations where the same equipment is used for more than one product and mixing between products has to be avoided for legal, food safety or quality reasons.

**Driving force for implementation**
Reduced consumption of water, energy and chemicals and generation of waste water and waste and the costs associated with these.
Receive materials in bulk

Technical description
Many materials, whether for direct use in the process or for auxiliary activities such as cleaning agents, may be supplied in bulk, for storage in silos or returnable containers, or for direct use in returnable instead of non-returnable packaging.

Achieved environmental benefits
Avoids the use of some packaging materials and enables the reuse of those used.

Cross-media effects
If empty containers are returned without cleaning, no cross-media effects apply.

Environmental performance and operational data
Many FDM raw materials are delivered by bulk tanker and stored in silos for direct use in the process. These include, e.g. grain, for milling, brewing and animal feed production; flour, for bread and confectionery manufacturing; semolina, for making pasta; sugar, for confectionery manufacturing and milk for producing milk, milk powder, butter, cheese, yoghurt and other dairy products. Silo storage is designed so that solid materials received first and fed through the top of the silo are used first from the bottom of the silo. Liquids such as milk are used batch wise. Problems with shelf-life can thereby be avoided by managing the control of receipt, storage and use.

In the FDM industry, chemicals used for cleaning, such as caustic, are widely delivered either by tanker and stored in bulk tanks, or delivered and directly used from intermediate bulk containers. This is especially true where these chemicals are used for CIP, such as in dairies and breweries.

When processing ground meat, spices are often used in pre-weighed lots. They are usually stored in plastic bags, which are discarded after emptying. To minimise the use of plastic packaging materials, spices can be dosed automatically from a bulk container.

Technical considerations relevant to applicability
Widely applicable where bulk ingredients or cleaning materials are used.

Economics
Generally, it is cheaper to buy materials and chemicals in bulk than in small quantities.

Driving force for implementation
Prevention and recycling schemes for waste and packaging waste and legislation on health and safety, to minimise exposure to substances hazardous to health and accidents due to manual handling.

Example plants
Widely applied in the FDM sector, e.g. in grain mills, flour mills, bakeries, confectioners, pasta manufacture and dairies.

Reference literature

Minimise storage times for perishable materials

Technical description
Raw materials, intermediate ingredients, by-products, products and waste can all be stored for as short a time as possible. Considering their nature, shelf life, inherent odour characteristics and how rapidly they biodegrade and create an odour nuisance, refrigeration may be used.
Processing products as quickly as possible and thereby minimising storage times can increase the quality and yield and, therefore, the profitability of the process. If stock is minimised to avoid ageing/rotting and materials are processed as quickly as possible, then losses can be minimised. This involves the planning and monitoring of procurement, production and dispatch of materials and finished products, materials destined for downstream users and waste. Rapid use of raw materials or partly processed materials or dispatch can reduce losses due to decomposition and the need for refrigeration. Segregation of waste materials and removal of waste from the installation as quickly as possible can prevent odour problems.

Taking hygiene, food safety, shelf-life and product quality considerations into account, energy can be saved during treatments involving the addition of heat, by removing foods from refrigerated storage in advance of this treatment and allowing their temperature to rise. Likewise, if the temperature of foods destined for cold treatments is not allowed to rise first, energy can be saved during cooling.

**Achieved environmental benefits**
Reduced waste of raw materials, partly processed materials and finished product. Reduced odour emissions and reduced energy consumption for refrigeration.

**Environmental performance and operational data**
To optimise material losses and refrigeration requirements requires cooperation between the suppliers of raw materials and other ingredients, as well as auxiliary materials required for the process, such as packaging. There may be contractual arrangements affecting the price paid to suppliers, depending on the quality of, e.g. raw material provided.

Due to fruit and vegetables being soft edible plant products with a relatively high moisture content, they are perishable in their fresh state. Losses can be prevented by processing them immediately, i.e. avoiding storage.

Fish has a highly perishable nature compared to other food products and generally requires either refrigerated storage or storage in ice from the moment the fish are caught, to avoid decomposition and odour emission and to optimise product quality and yield. Product losses also contribute to the solid and liquid waste loads. Quick processing reduces waste, odour and energy consumption associated with refrigeration and ice production. It also allows fish to be used for products which can be sold for a higher price, e.g. for fresh, cured or smoked fillets.

Due to its high perishability, milk is kept in bulk milk coolers at the farm and quick heat treatment and further processing minimises losses.

If partially processed materials are dispatched as soon as possible from one FDM installation to another where they will be further processed, then refrigeration requirements may be minimised at the producer’s installation and waste may be minimised at the receiver’s installation, by maximising the yield from freshly made ingredients.

**Technical considerations relevant to applicability**
Applicable to FDM installations handling, storing and processing perishable materials.

**Economics**
Usually a large proportion of the manufacturing costs within the FDM sector are related to the raw materials. The economic consequences of waste production are not just limited to the actual costs of waste disposal, but to, e.g. raw material losses, production losses and additional labour costs. Minimising refrigerated storage minimises the associated energy costs.

**Driving force for implementation**
Maximising quality and yield from raw materials, minimisation of waste disposal costs, reduced refrigeration requirements and prevention of odour problems.
Chapter 2

Example plants
Widely applied in the FDM sector.

Reference literature

Transport solid materials dry

Technical description
Many raw materials, co-products, by-products and wastes can be transported without using water. This reduces the entrainment of organic matter into water, which would consequently have to be treated in either an on-site or MWWTP, or sent for landspreading.

Achieved environmental benefits
Reduced water consumption. Reduced waste water production and pollution. Increased potential for the recovery and recycling of substances generated in the process which, in many cases, can be sold for use as animal feed.

Environmental performance and operational data
It is reported that bones and fat from deboning and trimming meat materials can be collected and transported dry. These may or may not be intended for human consumption. For example, some deboning stations use a long trough with a screw conveyor under a wide table to transport away fat and meat and a conveyor belt to transport away bones. The segregated fat may then be sent for, e.g. fat melting and the bones for, e.g. gelatine production.

In the fish sector, it is reported that dry transport systems have been applied in different countries, e.g. Denmark and the UK. For example, water can reportedly be saved if the skin is removed from drums by vacuum instead of water. In addition, fine-mesh conveyor belts are used to collect wastes and separate them from the waste water, thus decreasing the COD. Other dry transport systems used in this sector include the removal of offal by vacuum or by using conveyors after filleting and eviscerating. The use of dry transport systems is also reported in the processing of crustaceans and molluscs for solid waste collection. For further information see Sections 0—.

In the fruit and vegetable sector, dry transport systems are used for the removal of sorted, untreated or partly treated raw materials, peels and cutting residues. Mechanical conveyors can replace water flumes and where the use of flumes cannot be avoided, water volumes may be minimised. Fluming may be advantageous if it is combined with washing. For example, fluming can be combined with the washing of sugar beets and of potatoes used in starch production and, in addition, these processes use water extracted from the raw material. The fluming water is reused after treatment, e.g. remove solid materials such as soil. Fluming may also be necessary for the transport of some fruit and vegetables to avoid mechanical damage during transport, e.g. for tomatoes, peas, artichokes and mushrooms.

Technical considerations relevant to applicability
Applicable in the fish and seafood, meat and fruit and vegetable sectors.

Economics
Reduced water and waste water charges. A higher price can be obtained for the by-product with less water content, e.g. by selling it as animal feed.

Driving force for implementation
Hygiene standards are improved. Reduced water use, reduced need for waste water treatment and lower detergent use and expenditure.

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Example plants
Five Danish herring filleting installations and a fish food company in the UK.

Reference literature

Use a waste management team

Description
Waste generation can be minimised by using raw materials efficiently and in parallel with waste separation to recycle materials that might otherwise be sent to the mixed waste stream. Forming a team dedicated purely to the reduction of waste can ensure that the focus on waste minimisation can be maintained, regardless of other issues in the company. This approach can be more effective if applied in addition to the more usual practice of including waste reduction amongst the shift team responsibilities and the quality team objectives. It also sends out a clear message that it is something that the business takes seriously.

For example, the team can get involved in the design of new equipment, such as production lines. This ensures that, right from the design stage, the engineers are looking at ways of reducing waste.

Daily waste figures can be displayed prominently in the installation, showing how operators are performing against the daily target, what the causes of the waste are and what actions are in place to prevent further waste. A weekly report can be sent to senior management, so that they can show leadership on waste when talking to their teams.

It is reported that in an example installation a simple system was set up whereby any incident that created over 2 tonnes of waste was logged by the operators, an investigation carried out and actions put in place to prevent recurrence.

Having to deal with less waste can also improve the hygiene and safety of the waste disposal area.

Further targets for ongoing improvements can be set.

Achieved environmental benefits
Significant reduction in the amount of solid waste generated and consequently the associated environmental impact associated with its disposal.

Environmental performance and operational data
Use of this technique by an example petfood installation led to a 50% reduction in waste over an 8 month period, which was then maintained. The environmental impact was significantly reduced, together with very significant cost reductions by reducing the loss and waste of raw materials. The waste reduction figures are shown in Figure.
Figure: Waste reduction in petfood production

In an example installation, the company was just about to embark upon a number of significant asset changes. The significant cost reduction potential was recognised as a good incentive to invest money and start the project. The project was set a challenging target of reducing the amount of mixed solid waste fraction by 50%. This target was achieved.

Technical considerations relevant to applicability:
Applicable to all FDM installations.

Economics
Focusing on taking some simple actions delivered significant cost savings in an 8-month period.

Driving forces for implementation
Significant financial savings by increased use of raw materials in the final product and reduced waste disposal costs.

Example plants
At least one petfood manufacturing company in the UK.

Reference literature
[1, CIAA, 2002]
Chapter 2

2.3.2 Techniques to increase energy efficiency

2.3.2.1 General processing techniques

2.3.2.1.1 Heat recovery

Description
Use of heat exchangers and heat pumps to recover heat.

Technical description
The FDM sector has plenty of examples of heat recovery. The most commonly used heat recovery methods are the following:

- direct usage: heat exchangers make use of heat as it is in the surplus stream;
- heat pumps upgrade the heat in relatively cold streams so that it can perform more useful work than could be achieved at its present temperature (i.e. an input of high-quality energy raises the energy quality of the waste/surplus heat).

Heat can be also recovered from the blowdown of a boiler.

Another example of heat recovery is related to air compressor. From 80% to 90% of the mechanical energy that is consumed by compressors in an air compressed system is converted to thermal energy. This causes an increase in air temperature and for this reason a compressor cooling system is required. In this way, this heat can be recovered and reused. The heat output from air compressors can be crossed with water or air to transfer the heat and, then, the heat can be reused. Heating systems, the drying processes and heat feed to the steam boiler or oven burners are the main applications of the heated airstream. The applications of heated water streams are varied [193, TWG 2015].

Achieved environmental benefits
Reduction of energy consumption.

Environmental performance and operational data
There are multiple ways of reusing water reported in the questionnaires of FDM BREF data collection [193, TWG 2015]. Some examples are presented in Table 2.39.
Table 2.39: Various examples of heat recovery in the FDM sector

<table>
<thead>
<tr>
<th>Heat recovery technique</th>
<th>Technical description</th>
<th>Example installations</th>
<th>Economics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Breweries</strong></td>
<td></td>
<td></td>
<td>EUR 1 600 000 as installation cost and EUR 30 000 as annual operating cost (maintenance cost), for a reduction of 4 kWh/hl of heat consumption</td>
</tr>
<tr>
<td>Heat recovery from wort boiling</td>
<td>The simplest way to recover heat from the vapour is to use it to produce hot water for various processes, e.g. for use in production, cleaning operations, flushing brew kettles or for room heating.</td>
<td>#157, #159</td>
<td></td>
</tr>
<tr>
<td><strong>Dairies</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat recovery from the refrigeration plant to pasteurisation</td>
<td>An ammonia-based heat pump is incorporated to use waste heat from the refrigeration cycle to boost pasteurising temperatures.</td>
<td>At least one dairy installation in UK</td>
<td>High investment and operating costs, with a payback period of around 8 years</td>
</tr>
<tr>
<td>Heat recovery from pasteurisation in ice-cream production</td>
<td>The heat released to the water, from the ice-cream mix can preheat the water for various purposes, mainly for cleaning operations.</td>
<td>At least one ice-cream installation in SE</td>
<td></td>
</tr>
<tr>
<td>Heat recovery from warm whey</td>
<td>Utilisation of heat from warm whey for preheating cheese milk</td>
<td>Dairies in DK and in UK (#408)</td>
<td></td>
</tr>
<tr>
<td><strong>Oilseed processing and vegetable oil refining</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat recovery from the hardening of vegetable oils</td>
<td>The hydrogenation reaction that occurs during the hardening of oils to produce fats for cooking, eating and soap-making, is an exothermic process. The heat can be used to heat the product to the desired reaction temperature and to generate steam later in the reaction.</td>
<td>Widely applied in the OI sector.</td>
<td>Additional investment costs are needed. Lower operational costs due to the reduced input of steam generation.</td>
</tr>
<tr>
<td>Heat recovery from the rapeseed dryer</td>
<td>The exhausted vapours from the rotary dryer in the rapeseed processing installation is used to heat water for preheating the seed and reaching an optimum heat recovery.</td>
<td>#86, #466</td>
<td>Investment cost, approximately EUR 100 000 for a heat exchanger with operational air flow rate 20.000 Bm³. Operating cost, approximately EUR 3 900 annually (electricity for circulation pump).</td>
</tr>
<tr>
<td><strong>Starch production</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preheating of potato fruit juice</td>
<td>Preheating of potato fruit juice to about 100 °C is performed by reheating hot fruit juice, from where protein already has been extracted. Spiral exchangers can improve the heating significant compared to plate exchangers.</td>
<td>#149, #150, #151, #152</td>
<td>An investment cost of EUR 1 300 000 (capacity about 100 m³/h in terms of fruit juice) and annual savings of EUR 200 000 (reduction of natural gas consumption) have been reported.</td>
</tr>
</tbody>
</table>

NB: NI= no information provided.
Source: [192, COM 2006], [193, TWG 2015], [227, United Kingdom 2015], [274, NEWPOTATOPRO LIFE project 2007]
For instance, with the application of this technique applied in a NH₃ cooling system, an energy reduction of up to 1.4 MJ/hl of produced beer can be achieved.

**Technical considerations relevant to applicability**

Heat recovery opportunities are present in existing and new FDM installations.

**Economics**

See Table 2.39.

**Driving force for implementation**

In line with the EU Action Plan for the Circular Economy [237, COM 2015], heat recovery aims to improve the resource efficiency of the FDM sector.

**Example plants**

Heat recovery is commonly reported in all FDM sectors.

**Reference literature**

[192, COM 2006], [193, TWG 2015], [227, United Kingdom 2015]

### 2.3.2.1.2 Use of the biogas generated from anaerobic digestion

**Description**

The biogas generated by the anaerobic digester passes through a scrubber (to remove hydrogen sulphide) and then flows through a series of condensate traps before being stored. The stored biogas is preconditioned (dried), analysed and then used as a fuel, e.g. in a gas engine.

**Technical description**

The biogas (methane) produced by the anaerobic digester passes through a scrubber (sodium hydroxide to remove hydrogen sulphide) and then flows through a series of condensate traps before entering a biogas holder. The methane stored in the biogas holder is preconditioned (dried) and then passed through a gas analyser and then on to the gas engine. The gas is combusted in a gas engine which powers a generator producing electricity. Heat is recovered from cooling water and the exhaust is used to heat boiler feed water for example.

CHP plants are most suited to sites where the feed source is readily available and ideally generated at the site as either a waste or by-product such as FDM installations with large amounts of organic wastes which are treated by anaerobic digestion. For general information about CHP see Section 2.1.2.1.1.

**Achieved environmental benefits**

The CHP plant enables the methane gas generated by the anaerobic digester to be converted into a valuable renewable source of energy. Additionally, the CHP plant enables the anaerobic digester to divert waste and instead convert it to a valuable product.

**Environmental performance and operational data**

In a dairy installation (#296), the electricity produced from the generator is converted from low to medium voltage (400 V–10 000 V) and directed to the main switch room for use on site.

A dryer and recuperator were installed on the gas supply line to the CHP. This was necessary to maintain the gas quality, thereby preventing damage to the CHP engine resulting from condensation and other gases. The engine is sensitive to hydrogen sulphide gas and therefore a scrubber system is provided upstream to remove this compound.

**Cross-media effects**

Emissions to air are generated from the combustion.
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Economics
A total cost of around EUR 1 000 000 has been reported (for a CHP plant that generates 600 kWh of electrical and 600 kWh of thermal energy) [193, TWG 2015].

Driving force for implementation
- Reduction of fuel consumption.
- Generation and utilisation of a renewable source of energy and conversion of waste product into a valuable asset.

Example plants
Installation #296.

Reference literature
[193, TWG 2015]

Minimise motor losses

Description
Motor losses can be minimised by:

- specifying higher efficiency motors where feasible;
- when a motor fails, ensuring that proper care and attention is given in the repair process so as to minimise energy losses;
- avoiding the use of greatly oversized motors;
- considering permanent reconnection of the motor electrical supply in star-phase, as a no cost way of reducing losses from lightly loaded motors;
- checking that voltage imbalance, low or high supply voltages, harmonic distortion or a poor power factor is not causing excessive losses.

Achieved environmental benefits
Reduced energy consumption.

Technical considerations relevant to applicability
Applicable where motors are used.

Economics
Reduced energy costs.

Driving force for implementation
Reduced energy costs.

Reference literature

Frequency converters on motors

Technical description
Controlling the speed of the pump motor by frequency converters ensures that the speed of the impeller is exactly adapted to the required output of the pump, as are the power consumption and treatment of the liquid.

Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data
The reduction of the power consumption depends on the capacity and number of pumps and motors. Generally, a 10% reduction in the output of a pump corresponds to a 28% reduction in the power consumption of the pump.

In an example German instant coffee manufacturer, the consistent implementation of frequency converters for all large electrical motors, allowed them to be adjusted in a way that suited the output and electricity peaks during start-up processes were avoided.

In a Danish dairy, 203 motors were equipped with frequency converters. The total power of the motors was 1,216 kW. The estimated cost of the investment was EUR 311,000. The estimated annual saving is EUR 90,000 (1,325,000 kWh).

A whey products company processes whey into several raw materials for use in pharmaceuticals and foods. One of the products is lactose, the production of which involves a refining process, in which “wet” lactose (90% pure) is dissolved in hot water in a circular process. Wet lactose is transported through a shaking tray to a mixing vessel, where it is mixed with hot water. The mixture is pumped into a buffer vessel, where it is stirred, and from which it is returned to the mixing vessel. Thus, the lactose content of the mixture gradually increases. After approximately 1 hour, the mixture is discharged from the mixing unit for further processing. The liquid level in the mixing vessel used to be controlled by regulating the water/lactose flow from the buffer tank. This was achieved by a choke valve on the delivery side of the centrifugal pump used for the transport. This choke system had several disadvantages, e.g. it was inefficient causing unnecessary dissipation of electric energy and it caused unnecessary wear of the pump. The system was replaced with a speed control system on the motor driving the pump. This resulted in energy savings amounting to 12,600 kWh/yr, with a value of NLG 16,38 (1994), a reduction in maintenance costs of NLG 10,257/yr (1994) and a payback period of 0.3 years.

In an example brewery, compressed air (6 bar) is produced by six screw-type and seven piston compressors. One screw type compressor is run as a frequency controlled machine and all compressors are centrally controlled. The advantage of this technology is that the pressure in the supply system does not fluctuate by more than +/- 0.05 bar. The system pressure can be reduced by 0.2 bar. It is reported that an electricity saving of approximately 20% can be achieved by avoiding compressor idle time. Maintenance costs can be reduced by about 15%. It is not possible to quantify the cost benefit resulting from the reduction in system pressure.

Technical considerations relevant to applicability
Frequency converters can be used with standard three-phase motors. They are available for both manual and automatic speed controls. They can be applied in existing and new installations for pumps, ventilation equipment and conveying systems. It is reported that frequency converter driven motors should not exceed 60% of the total energy use of the installation because they can have an adverse effect on the electricity supply and can lead to technical problems.

Economics
The price of a 5.5 kW frequency converter is about EUR 600.

Driving force for implementation
Reduced consumption of electrical power in combination with a more gentle treatment of the product.

Example plants
A dairy in Denmark, a whey manufacturer in the Netherlands, an instant coffee manufacturer in Germany, a brewery in Germany.

Reference literature
[21, Nordic Council of Ministers 2001], [35, Germany 2002], [143, Caddet 1999], [19, German Dairy Association 2001].
Use variable speed drives to reduce the load on motors

Technical description
Motive power in particular can make a significant contribution to energy consumption in industrial processes. The capital cost of a higher efficiency motor is no more than a standard quality motor but the efficiency gain of 2–3% makes significant savings over the motor’s life. In addition, the use of variable speed drives to reduce the load on motors is a much more energy efficient method of regulating flow than throttles, dampers or recirculation systems.

Achieved environmental benefits
Reduced energy consumption.

Technical considerations relevant to applicability
Applicable to all FDM installations where fans and pumps are used.

Driving force for implementation
Reduced energy costs.

Reference literature

Multistage evaporation

Description
The surfaces within the evaporator are heated by steam, which is injected into the top of the evaporator space. This uses fresh steam or exhaust gases from other operations to boil off water vapour from the liquid in the first stage and is an example of energy recovery/reuse.

The evaporated water still has sufficient energy to be the heat source for the next stage, and so on. Vacuum is applied in a multi-effect chain to enable the water to boil off. The liquid being processed is passed through a series of evaporators so that it is subject to multiple stages of evaporation. In this way, one unit of steam injected in the first evaporator might remove three to six units of water from the liquid. The energy savings increase with the number of evaporation stages. Up to seven stages can be operated in series, but three to five is more common. In the final stage, cooling using cooling water may condense the vapour. Some of the vapours can be drawn off the evaporators to be used as heat sources for other process requirements.

In order to achieve further steam efficiency, the vapour leaving each evaporation stage can be compressed (see Section 0) to increase its energy before it is used as the heating medium for the subsequent evaporator.

Achieved environmental benefits
Reduced energy consumption, e.g. by introducing evaporated vapours to the next stage of the evaporator in which the temperature is lower than the previous one.

Environmental performance and operational data
As the heat is used for the next evaporation stage, multistage evaporators save energy. In contrast, single stage evaporation does not enable the heat to be recovered.

Steam requirements for single-stage evaporators are 1.2 to 1.4 t/t of evaporated water. Table shows a comparison of energy consumption data for different numbers of evaporators using TVR (see Section). Further energy savings can be made using MVR (see Section), as can also be seen in the table.
### Chapter 2

#### Table: Comparison of efficiencies of multi-effect evaporators in the dairy industry

<table>
<thead>
<tr>
<th>Type of evaporator</th>
<th>Total energy consumption (kWh/kg water evaporated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVR 3 stages</td>
<td>0.140</td>
</tr>
<tr>
<td>TVR 4 stages</td>
<td>0.110</td>
</tr>
<tr>
<td>TVR 5 stages</td>
<td>0.084</td>
</tr>
<tr>
<td>TVR 6 stages</td>
<td>0.073</td>
</tr>
<tr>
<td>TVR 7 stages</td>
<td>0.060</td>
</tr>
<tr>
<td>MVR single-stage</td>
<td>0.015</td>
</tr>
</tbody>
</table>

It is reported that in the sugar sector, the sugar juice resulting from purification has a 15 % dry matter content and it is necessary to raise this dry matter content to extract the sugar. The evaporation process allows the dry matter content to be increased from 15 to more than 68 %. It is based on the principle of heat-exchange between the sugar juice and the steam produced in a boiler. A multistage evaporator produces the heat-exchange that takes place between the sugar juice and the low-pressure steam. This recycles the steam obtained from the juice after the first exchange. In practice, the low pressure steam from the generator is condensed after undergoing a heat-exchange and returns to supply the boiler. Following the same exchange, part of the water of the sugar juice evaporates and the steam produced in this way heats the second effect, in which a new part of the water evaporates. The effects follow on from each other in this way. The operation can be repeated up to six times in all. A decreasing level of pressure and temperature from one effect to the other allows the operation to be repeated several times with approximately the same amount of energy.

An example large dairy produces dried products, fresh products, semi-hard cheese and butter. The total quantity of milk processed in 2 000 was around 321 000 litres and the total production of milk and whey powder amounted to around 19 000 tonnes. In this dairy, both a single-stage evaporator and a 5 stage falling film evaporator are used. The single-stage evaporator has an input capacity of 30 000 l/h and uses an MVR for preconcentration and a TVR for concentration. The 5 stage evaporator has an input capacity of 22 000 l/h and uses a TVR for preconcentration and concentration. Energy savings were reported using the 5 stage evaporator.

#### Technical considerations relevant to applicability

Applicable in the sugar industry; in starch processing; in tomato, apple and citrus juice concentration; and in the evaporation of milk and whey.

#### Reference literature

[19, German Dairy Association 2001], [31, CEFS 2001], [35, Germany 2002]

#### Mechanical vapour recompression (MVR)

##### Description

**Achieved environmental benefits**

- Reduced odour emissions
- Reduced energy consumption compared to TVR (see Section)
- Reduced cleaning requirements due to less build up of burned product

**Cross-media effects**

- Electricity is needed to power the vapour compressor. MVR generates noise, so sound insulation is required.

**Environmental performance and operational data**

It is reported that the energy consumption of an MVR evaporator is approximately 10 kWh/t of water evaporated, with negligible steam consumption. As all of the vapour is recompressed, rather than just a portion of it, as is the case with TVR evaporators, a higher degree of heat recovery is achieved. Also, a lower evaporation temperature is needed, which means less
product-burnout. Figure shows that higher energy savings can be undertaken using MVR compared to TVR.

An example Japanese dairy upgraded its milk powder process and installed a 4-stage MVR evaporator to replace its existing 4-stage TVR evaporator. When the MVR system was adopted, it was necessary to both maintain the designed evaporation capacity and to prevent milk being scorched and contaminating the surfaces of the heat transfer pipes in the evaporator. A falling film evaporator and an automated control system to control operating parameters, e.g. flowrate, temperature and pressure, were installed. The MVR has operated successfully with an overhaul every 2 years. Savings in the operating costs of up to 75% were achieved, mainly as a result of the reduced steam consumption. Figure illustrates the new 4-stage MVR evaporator.

![Figure: Flowchart of a 4 stage MVR milk evaporator system](image)

In an example Finnish dairy, an MVR system draws all the vapour out of the evaporator and compresses it using mechanical energy before returning it to the evaporator. No thermal energy is supplied, except for the steam required for the start-up. The only electricity required is for the operation of the evaporator. In this installation, the MVR can evaporate 100–125 kg of water using 1 kW of energy.

In an example brewery in Germany, the vapour condensation system draws off the boiling vapours produced by the wort boiling process from the whirlpool pan and compresses them with MVR. The compressed vapours are reused as a heating medium for the boiling process. The advantages of condensing the vapours include reductions in the heat and water losses, improvements in the hot water balance of the operation and reduction in odour emissions. It is reported that approximately 1/3 of the electrical energy consumed by the brewhouse has to be used to drive the vapour compressor system.

**Technical considerations relevant to applicability**

Applicable in sugar manufacturing; starch processing; tomato, apple and citrus juice concentration; brewing and in the evaporation of milk and whey. Most new evaporators are equipped with an MVR system.
Economics

As MVR systems are driven by electricity rather than steam, operating costs are considerably lower compared to TVR. For example, the operating costs of a 3 stage MVR evaporator are approximately half of those of a conventional 7 stage TVR evaporator. The difference in running costs for TVR and MVR increases with the capacity of the evaporator, as illustrated in Figure.

Figure: Comparison of the operating costs of TVR and MVR evaporators

In the example Japanese dairy, the cost of the new MVR evaporator was EUR 1.5 million, compared with EUR 1.3 million for a new TVR evaporator. At an evaporation rate of 30 t/h, the annual operating costs of the MVR evaporator was EUR 175 000, compared with previous annual operating costs of EUR 680 000 for the TVR evaporator, i.e. savings of nearly 75 %.

Example plants
Dairies in Japan and Finland and a large brewery in Germany.

Reference literature
[19, German Dairy Association 2001], [21, Nordic Council of Ministers 2001], [35, Germany 2002], [40, UNEP et al. 2000], [70, CADDET 1992]

Thermal vapour recompression (TVR)

Description
The live steam passes through the injection nozzle and is throttled to the pressure level of the receiving vapour. Vapour is entrained as a result of the difference in speed. Vapour and live steam are mixed in the mixing chamber. Changing the flow aperture in the diffuser determines the pressure at which the mixed steam leaves the steam injection compressor.

Achieved environmental benefits
Reduced odour emissions.

Cross-media effects
Higher energy consumption than MVR.

Environmental performance and operational data
By comparison with MVR, TVR offers advantages of having no moving parts and greater reliability in operation. It is reported that TVR allows for long production cycles and a reduction in cleaning frequency.

Technical considerations relevant to applicability
Applicable in sugar manufacturing; starch processing; tomato, apple and citrus juice concentration; brewing and in the evaporation of milk and whey.

Economics
Lower purchase cost but higher operating costs than MVR.

Reference literature
[19, German Dairy Association 2001], [35, Germany 2002], [70, CADDET 1992]

Switch off equipment when it is not needed

Description
Many simple, no cost and low cost energy saving measures are those that individual employees can take, for example switching off equipment, such as compressors and lighting. Pumps and fans that circulate cold air, chilled water, or an antifreeze solution generate heat, contributing most of the power they consume to the cooling load, so switching them off when not required saves energy. This is also true for lights in a coldstore or cooled room, as they contribute most of the power they consume to the cooling load.

The switching can be timed according to a fixed programme or schedule. Conditions can be monitored to detect, e.g. high or low temperatures, and switch off motors when they are not needed. The load of a motor can be sensed, so that the motor is switched off when idling.

Achieved environmental benefits
Reduced energy consumption.

Technical considerations relevant to applicability
Widely applicable in the FDM sector.

Economics
Reduced energy costs.

Driving force for implementation
Reduced energy costs.

Reference literature

Insulation of pipes, vessels and equipment

Description
Insulation of pipes, vessels and equipment such as ovens and freezers can minimise energy consumption. Insulation can be optimised by selecting effective coating materials with low conductivity values and high thickness and by using pipes, vessels and equipment that are insulated prior to installation. Pre-insulation has the advantage that, e.g. the pipe supports are mounted outside of the insulation coating instead of being directly connected. This reduces the heat loss through the mounts.

Insufficient insulation of pipework can lead to excessive heating of the surrounding process areas as well as the risk of burn injuries.
Achieved environmental benefits
Reduced energy consumption and associated fuel consumption and emissions to air.

Environmental performance and operational data
Insulation of pipes and tanks can reduce the heat/cold loss by 82–86%. Additionally, 25–30% heat can be saved by using pre-insulated pipes instead of traditionally insulated ones.

Hot and cold products are stored and pumped in dairies. In an example new dairy in Denmark, all of the pipes with a temperature difference of at least 10 °C above ambient temperature were fitted with 30 mm insulation. Tanks were coated with 50 mm insulation. Pre-insulated pipes were used with a coating of mineral wool wrapped in a metal sheet. More than 9 km of pipework and 53 tanks were insulated. The calculated savings in energy were 6361 MWh/yr heating energy and 2397 MWh/yr cold energy, i.e. the equivalent of 479 MWh/yr electricity.

In an example Italian pasta installation, the energy dissipated all along pipework was investigated and the insulation was improved. In three cases, the thermal resistance was increased from 0.22 to 0.396, 0.574 and 0.753 m²K/W. This resulted in CO₂ emission reductions of 44.4, 61.6 and 70.7 %, respectively.

Technical considerations relevant to applicability
Applicable to all FDM installations, whether new or existing. Pre-insulated pipes are applicable in new installations and where pipework, vessels and equipment are replaced.

Economics
In the example new Danish dairy, the investment cost was about EUR 1 408 000 with a payback period of 7.6 years.

Driving force for implementation
Reduction in energy costs.

Example plants
Widely applied in the FDM sector and others.

Reference literature
[21, Nordic Council of Ministers 2001]

Reduce the loads on motors
Description
Motors and drives are used to operate many mechanical systems in industrial processes. The load on motors and drives can be reduced by ensuring that regular servicing and basic maintenance steps such as lubrication of machinery are undertaken. If the following points are ticked, the loads on motors can be minimised:

• is the machine that the motor is driving efficient?
• is the system doing a useful and necessary job?
• is the transmission between motor and driven equipment efficient?
• are the maintenance programmes adequate?
• have losses due to, e.g. the pipework, ducting and insulation been minimised?
• is the control system effective?

Achieved environmental benefits
Reduced energy consumption.

Technical considerations relevant to applicability
Applicable where motors are used.
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Economics
Reduced energy costs.

Driving force for implementation
Reduced energy costs.

Reference literature

Minimise heating and cooling times

Technical description
The times for heating and cooling processes can be optimised to minimise the energy consumed. This can be done in a variety of ways, e.g. by using a pretreatment, by stopping the operation as soon as the required effect is required and by selecting equipment which can achieve the required effect with the minimum energy consumption.

Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data
Examples of pretreatments that minimise heating times are soaking vegetable seeds such as lentils (see Section 0) and drying potatoes before frying, in the preparation of potato chips (see Section 8.2.10.1).

Stopping the operation when the required effect is achieved includes not cooking ingredients for longer than is needed, e.g. when baking bread or boiling wort in brewing (see Section) or not cooling foods to colder temperatures than those needed either for processing or storage (see Section 0).

Examples of minimising heating times by equipment selection include direct heating during baking (see Section 0) and using fluidised bed driers (see Section), e.g. for coffee roasting (see Section 0).

Technical considerations relevant to applicability
Applicable where heating and cooling operations are carried out.

Driving force for implementation
Reduced energy consumption and associated costs.

Optimise start-up and shut-down procedures and other special operating situations

Technical description
Start-up and shut-down procedures and other special operating situations can be optimised. For example, by minimising the numbers of start-ups and shut-downs, waste gases from purge vents or preheating equipment can be minimised. The emission peaks associated with start-up and shut-down can be avoided and consequently, the emissions per tonne of feedstock are lower. This also applies to the operation of abatement equipment.

Achieved environmental benefits
Depending on the application reductions in the consumption of energy; waste generation and emissions to air and water can be achieved.

Environmental performance and operational data
In air abatement, e.g. waste gas thermal oxidisers do not operate effectively until they reach the combustion temperatures of the pollutants they are used to destroy, so they need to be started up before they are actually required (see Sections 2.3.7.3.6 and 2.3.7.3.7).
Driving force for implementation
Reduced consumption and emission levels.

Reference literature
[65, Germany, 2002]

Combined heat and power generation (CHP)

Combined heat and power generation (CHP) – European overview
The production of electricity through CHP represented 11% of the EU-15 total electricity production in 1998, leading to energy savings comparable to the annual gross energy consumption of Austria or Greece. A proposal for a Directive aimed at saving energy and combating climate change by promoting CHP was presented by the EC on 23 July 2002 [90, EC, 2002]. The proposed Directive would encourage MSs to promote CHP through a systematic identification and progressive realisation of the national potential for high efficiency CHP. MSs would have to report on the progress achieved towards meeting this potential and on the measures taken in this respect.

Description

Achieved environmental benefits
Reduced energy consumption and emissions to air, e.g. NO\textsubscript{x}, CO\textsubscript{2} and SO\textsubscript{2}.

Environmental performance and operational data

Technical considerations relevant to applicability
Widely applicable. The applicability of CHP very much depends on several technical aspects. Although CHP is a well established and technically mature technique, it is vital that the right design decisions are made. The main factors to consider are the consumption pattern of electricity and heat in the installation and the ratio between electricity and heat consumption. Additional important factors are whether the installation is running continuously and whether large variations in processes occur. A simple rule of thumb is that the site needs to have a simultaneous demand for heat and electricity for at least 4000 hours a year.

Economics
A decision on whether to implement CHP based on investigation of the economic aspects will take account of the price of gas and electricity. A balance of relatively expensive gas or other fuels and cheap electricity mitigates against the selection of CHP. For example, if electricity prices fall or gas prices rise, the financial return from CHP will decrease. This is possible in a free energy market. One option, which is sometimes applied, is to design the CHP installation on the basis of heat consumption with excess electricity being sold to the public grid. Whether this is an attractive option very much depends on the price obtained for the excess electricity that is sold.

With regard to financing of the CHP installation, the tendency is for companies to not finance it themselves. Sometimes joint ventures with energy suppliers are formed and sometimes third parties completely finance the CHP installation. A contract for delivery of electricity and heat by the CHP installation normally runs for 10 to 15 years.

In the UK, it has been found that CHP can now reduce the total energy bills of an installation by 20%. In the example brewery, the savings in energy costs were 16.2%.

Example plants
Applied in sugar manufacturing installations, dairies, breweries and distilleries.

Reference literature
[53, COM 2002]
Improving the efficiency of a heat generator

Description
Efficiency is defined as the ratio of energy output to energy input of a process. The efficiency of a heat generator can be described as the ratio between the energy taken up by the fluid which carries the heat and the incoming energy of the fuel, estimated on the lower calorific power. The typical method for calculating the efficiency of the heat generator is the so-called “indirect method”. This method is based on the conventional evaluation of losses through perceivable heat in fumes, incomplete combustion and dispersions from the heat generator walls.

For the evaluation of losses to the chimney and of losses as a result of incomplete combustion, the recourse is generally to measure two of the following parameters, i.e. $O_2$, $CO_2$ and $CO$, and to use these to work out percentage losses by means of an Ostwald combustion diagram.

Losses due to dispersions through the heat generator walls are generally constant with the variation in load and may be evaluated by means of diagrams supplied by boiler manufacturers.

The controls to be carried out to monitor efficiency are the following:
- analyses of fumes and $O_2$
- use of the fuel and of the air combustion
- pressure, temperature and capacity of the heat carrying medium in the heater, e.g. diathermic oil, and the thermal carrier fluids to the users, e.g. steam or superheated water.

The indirect method of measuring the efficiency of a heat generator has shown the optimal values for the fume analysis of a methane-fired diathermic oil heater installed in a pasta installation, which produces more than 300 t/d. These are shown in Table.

Table: Optimal values for the fume analysis in a pasta installation

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$O_2$ (percentage by volume in dry fumes)</td>
<td>3 %</td>
</tr>
<tr>
<td>$CO$</td>
<td>$\leq 70 \text{ mg/Nm}^3$</td>
</tr>
<tr>
<td>Gaseous $NO_x$</td>
<td>$\leq 250 \text{ mg/Nm}^3$</td>
</tr>
</tbody>
</table>

The efficiency of a heat generator may be improved by reducing losses or by increasing the efficiency of the transfer of heat by the heat carrying medium. To reduce losses in the fumes, the temperature of the fumes to the chimney can be lowered, so reducing losses in the form of perceivable heat. Also, the excess air can be regulated to prevent incomplete combustion.

Achieved environmental benefits
Reduced energy consumption and emissions to air.

Environmental performance and operational data
In an example pasta installation, to reduce heat losses through the chimney, i.e. which represented about 50 % of the total losses, the temperature of the fumes to the chimney was lowered. The excess air was regulated to prevent incomplete combustion.

In existing installations, efficiencies could rise from 85 to 90 % with a reduction in $CO_2$ emission levels from 5.5 to 6.5 %. In new installations, the efficiencies could be higher than 91 % with a reduction in $CO_2$ emission levels greater than 7.6 %.

In addition, by preheating the combustion air by means of fume recovery, a 2 % increase in efficiency per every 50 °C decrease in the temperature of the fumes was achieved. The temperature of preheated air generally varies between 170 and 200 °C.
For existing heaters with correct combustion, efficiencies of 90% can be achieved. For new heaters using diathermic oil with fume recovery that preheats the combustion air, efficiency values of 92% under conditions of economic load and 91% under conditions of maximum load, can be achieved.

**Technical considerations relevant to applicability**
Applicable to both new and existing FDM installations.

**Economics**
The cost of implementation is low for existing installations, but high for new installations.

**Example plants**
A pasta industry in Italy.

**Reference literature**
[82, Unione Industriale Pastai Italiani 2002]

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**Heat pumps for heat recovery**

**Description**

**Achieved environmental benefits**
Reduced energy consumption, e.g. heat recovery

**Cross-media effects**
Heat pumps require electricity.

**Environmental performance and operational data**
It is reported that in 1997 there were more than 16 food companies in Australia using over 30 heat pump driers for LTD of food materials. The heat pump drier consists of a conventional drying chamber with an air circulation system and the usual components of an air conditioning refrigeration system. The drying air is dehumidified by an evaporator, which is the cooling section of the refrigeration cycle, and reheated by the condenser of the heat pump. The energy efficiency expressed by a specific moisture extraction rate, i.e. kg water removed/kWh energy used, is between 1–4, with an average of 2.5 kg/kWh. FBDs are not suitable for sticky materials or if the shape is irregular. The two driers can be used in series. Dehumidified air from the heat pump is directed first to the fluidised bed with the semi-dried product. The airflow then passes through the cabinet drier. It is reported that using this combination, energy efficiency can be improved by up to 80%.

**Technical considerations relevant to applicability**
A good heat source is needed in combination with a simultaneous need for heat near the source.

**Economics**
The economic feasibility depends on the price of fuel related to that of electrical power.

**Driving force for implementation**
Reduced costs for energy and water.

**Example plants**
Several food companies in Australia.

**Reference literature**
[21, Nordic Council of Ministers 2001], [41, CADDET UK National team 1997]
2.3.2.2 Techniques related to cooling/freezing

Further information on general techniques for cooling is available in the Industrial Cooling Systems BREF [162, COM 2001].

The major energy savings can be achieved in cooling and freezing. Savings are possible by correct adjustment of the working parameters, such as the evaporator temperature, conveyor belt speed and blower power in the freezing tunnel. These depend on the product being processed and the throughput. The consumption of energy in electrical systems in the freezing tunnel can be kept as low as possible by opting for frequency converters on the blowers, on the distributor conveyor and by installing high efficiency low energy lighting.

2.3.2.2.1 Using a plate heat exchanger for Precooling of ice-water with ammonia

Description
Precooling of the returning ice-water (e.g. with a plate heat exchanger), prior to final cooling in an accumulating ice-water tank with a coil evaporator.

Technical description
Ice-water is used as a cooling medium, e.g. for cooling milk and vegetables. The amount of energy consumed for the production of ice-water can be reduced by installing a plate heat exchanger to precool the returning ice-water with ammonia, prior to a final cooling in an accumulating ice-water tank with a coil evaporator. This is based on the fact that the evaporation temperature of ammonia is higher in a plate cooler than when evaporator coils are used, i.e. -1.5 °C instead of -11.5 °C.

Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data
It is reported that the capacity of an existing ice-water system can be increased without the need to increase the compressor capacity by installing a plate cooler for precooling the returning ice-water.

In an example dairy, the precooling system saved almost 20 % of electricity when installed in an existing ice-water system [21, Nordic Council of Ministers 2001].

In an example dairy (#124), heat pumps are used for heat recovery from the cooling system. This equipment moves the energy content in the lukewarm ice-water to the ‘cold’ hot water in the production. The equipment makes it thus possible to produce part of the ice-water used in the production (and with no excess heat outlet / emissions to environment) and to heat water without using heat from a boiler (and without emissions to air). In the system, 10 °C ice-water (lukewarm water) from the production is cooled to 1.5 °C in a plate heat exchanger by use of ammonia. The heat is transferred as a gas through a low-pressure compressor to a high-pressure compressor. In the high-pressure compressor the gas is compressed. The compressed gas is let through a plate heat exchanger where it condenses as it meets warm water (65 °C) from the production. The condensed gas heats the 65 °C water to 90 °C. The 90 °C water is used in the production to pasteurise milk. The ammonia is recirculated in the system.

Cross-media effects
Using ammonia involves safety risks. Leakages can be prevented by proper design, operation and maintenance.

Technical considerations relevant to applicability
This cooling system is commonly applied in new installations, but it can also be applied in existing installations.
**Economics**

The price depends on the existing ice-water system and capacity. [21, Nordic Council of Ministers 2001] In an example dairy, the investment costs were estimated to be approximately EUR 50 000, including a plate cooler, a pump, valves, regulators, pipework and installation. In another dairy, with a permitted milk production capacity > 600 tonnes/day, an installation cost of EUR 135 000 was reported. [193, TWG 2015]

**Driving force for implementation**

Reduced consumption of electrical energy and/or increased cooling capacity, without the need for an investment in a new ice-water tank.

**Example plants**

A dairy in Sweden and dairies in Denmark (#124, #133). [193, TWG 2015]

**Reference literature**

[21, Nordic Council of Ministers 2001], [193, TWG 2015]

**Operating without automatic defrosting during short production stops**

**Description**

When freezing food, there are regularly problems with the supply to the freezer in a processing step or when switching from one product to another. During these periods, it is nevertheless important to keep the empty freezing tunnel at a sufficiently low internal temperature. To reduce energy consumption during these stops, the automatic defrosting of the evaporators can be switched off as, in an empty freezing tunnel, there is little or no transport of moisture or water, e.g. water is only transported with the food entrance and exit. This avoids re-cooling the evaporator after defrosting.

**Achieved environmental benefits**

Reduced energy consumption.

**Environmental performance and operational data**

An example evaporator weighs approximately 2 tonnes and is made of steel. To cool this mass again from 15 to -35 °C takes about 13.33 kWh (48 MJ) of refrigeration. Thus, switching off the automatic defrosting during short production stops yields a saving in the compressor consumption, i.e. savings of 5 to 9 kWh can be made per evaporator that is not defrosted.

**Technical considerations relevant to applicability**

Applied in the deep freezing of packaged and unpackaged food products.

**Reference literature**

[14, VITO et al. 2001], [15, Van Bael J. 1998]

**Heat recovery from cooling systems**

**Description**

**Achieved environmental benefits**

Reduced energy consumption, e.g. heat recovery.

**Environmental performance and operational data**

It is reported that recovered heat can be used for heating tap water or ventilation air, thawing deep frozen goods, or preheating the cleaning liquids or the product.
The installation of a heat recovery system in the cooling unit of a Nordic dairy, which included both screw and piston compressors with a cooling capacity of 3,200 kW, resulted in energy savings of about 1,200,000 kWh/yr.

Technical considerations relevant to applicability
Widely applicable in new installations. The lack of space can be an obstacle for existing installations. The technique is economically feasible in installations with deep freeze storage, as normal cold storage does not produce sufficient quantities of heat during winter time.

Economics
Reduced energy costs. The investment cost in the Nordic dairy example above was about EUR 160,000 with a payback period of 6.3 years.

Example plants
A dairy in a Nordic Country.

Reference literature
[21, Nordic Council of Ministers 2001]

Lowering condensation pressure

Description
The efficiency or the (COP) of the freezer unit is mainly determined by the evaporator pressure and the condensation pressure. The reduction of condensation pressure raises the COP and lowers the electricity consumption. The condensation pressure is kept as low as possible by providing sufficient condenser units.

Achieved environmental benefits
Reduced energy consumption.

Technical considerations relevant to applicability
Applied in the deep freezing and refrigeration of packaged and unpackaged food products.

Reference literature
[14, VITO et al. 2001], [15, Van Bael J. 1998]

Lowering condensation temperature

Description
The reduction of condensation temperature raises the COP and lowers the electricity consumption. This reduction can be achieved by fitting an adequate capacity of condenser batteries so that, even in summer, which is high season for the vegetable sector, sufficiently low condensation temperatures can be achieved.

Low temperatures can also be achieved by keeping the condensers clean and replacing badly corroded ones. Blocked condensers cause the condensing temperature to increase and the cooling capacity also drops, so the required temperature may not be achieved.

Ensuring that air entering the condensers is as cold as possible also contributes to lowering the condensation temperature. The warmer the air entering the condenser then the higher the condensing temperature is. This can be minimised by shading the condensers if necessary, ensuring that warm air is not recirculated, removing anything which obstructs the airflow and freezing at night.

Achieved environmental benefits
Reduced energy consumption.
Environmental performance and operational data
Lowering the condensation temperature by 1 ºC raises the COP by 2%. Lowering the condensation temperature by 5 ºC causes the electricity consumption to fall by 10%.

Technical considerations relevant to applicability
Applied in the deep freezing and refrigeration of packaged and unpackaged food products.

Reference literature

Raising evaporation temperature
Description
Raising the evaporation temperature improves energy performance. To do this, a simultaneous optimisation of various freezing tunnels can be carried out, as shown in. This optimisation needs to be undertaken again after a tunnel is shut down, a different product is processed and another flowrate is set.

Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data
It is reported that if the evaporator temperature is raised by 1 ºC, the COP rises by 4% and the refrigeration capacity rises by 6%.

A Flemish study on energy consumption during the freezing of vegetables in a freezing tunnel, showed that the greatest savings can be achieved by adjusting the evaporator temperature, the residence time of the vegetables in the freezing tunnel, the airflowrates relative to the vegetable flowrate and the type of vegetables. This study shows that it is not always necessary to set the evaporator temperature at the lowest level, i.e. -40 ºC, for good freezing quality. Furthermore, it is very important to monitor the temperature of the product after it has gone through the freezing tunnel. Low temperatures, i.e. < -18 ºC, are not necessary as the vegetables will ultimately be stored in a confined space at -18 ºC. High temperatures, i.e. > -16 ºC, lead to lower freezing qualities. In a worst case scenario, the whole mass can freeze together during storage in crates. The conclusions of the study are summarised in Figure.
Chapter 2

With reference to Figure:

1) The evaporator temperature of the freezing unit is set to the lowest position, e.g. -40 ºC.
2) The fans are set to the maximum airflowrate permissible without product loss. If the air regulating valves are fully opened or the rotation speed adjustment is set at maximum frequency, product is blasted out of the bed. Then, the valves are closed more or the frequency is lowered.
3) In adjusting the speed of the conveyor belt, inversely proportional to the residence time on the belt, care is taken to ensure that the layer thickness is not too low. This always leads to the formation of preferential air channels in the vegetable bed, which means that the rest of the bed receives little airflow. The layer thickness is not set too high either, since this leads to block freezing of the lower layers. As the pressure drop over the vegetable bed rises, the air speeds fall with lower heat removal.
4) The product temperature in each freezing tunnel is measured. To take the measurement, an insulated container is filled with product. The reading is taken as soon as the temperature stabilises. Immediately after freezing, the outer temperature has a lower temperature than the centre.
5) If all product temperatures are lower than -18 ºC then increase the evaporator temperature until the product temperature of one tunnel is equal to -18 ºC.
6) Lower the airflowrates in the other tunnels until a product temperature of -18 ºC is achieved after passing through the tunnel.

Technical considerations relevant to applicability
Applicable to the deep freezing of packaged and unpackaged food products.

Reference literature
[14, VITO et al. 2001], [15, Van Bael J. 1998]
Using high efficiency motors for driving fans

Description

Achieved environmental benefits
Reduced energy consumption.

Technical considerations relevant to applicability
Applied in the deep freezing of packaged and unpackaged food products.

Reference literature
[14, VITO et al. 2001], [15, Van Bael J. 1998]

Reducing the fan output during short production stops

Description
When freezing food, there are regularly problems with the supply to the freezer in a processing step or when switching from one product to another. During these periods, it is nevertheless important to keep the empty freezing tunnel at a sufficiently low internal temperature. For this to occur, the fans need to be kept running, but the airflow rates can be reduced. To do this, motors with regulated rotation speeds can be switched to the lowest possible frequency. In addition, a number of fans can be switched off. This reduces the energy consumption of the fans and of the refrigeration unit.

Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data
Any reduction in the fan power by 1 kW results in a total saving of 1.4–1.6 kW.

Technical considerations relevant to applicability
Applied in the deep freezing of packaged and unpackaged food products.

Reference literature
[14, VITO et al. 2001], [15, Van Bael J. 1998]

Using cold water from a river or lake for precooling ice-water

Description
Ice-water is used as a cooling medium, e.g. for cooling milk and vegetables. Cold water from a river or lake can be used for precooling ice-water.

Achieved environmental benefits
The electrical energy consumption is reduced to some extent, depending on the temperature of the river water.

Cross-media effects
Energy is needed for pumping the water to the cooling tower. The river water returns unpolluted but with a slightly increased temperature.

Environmental performance and operational data
In an example dairy, cold river water is pumped into a cooling tower, where the warm water of a closed ice-water system is pre-cooled prior to final cooling in an ice-water tank. The river water is then led back into the river. The system saves cooling energy corresponding to a temperature decrease of 7–10 °C.
Technical considerations relevant to applicability
Applicable when the installation is located near a river with cold water.

Economics
The system requires pipelines from the river and back, as well as an efficient pumping system and a storage tank. An example dairy reports investment costs of approximately EUR 230000 and annual savings of approximately EUR 23000.

Driving force for implementation
Reduced energy costs.

Example plants
A dairy in Sweden.

Reference literature
[42, Nordic Council of Ministers, et al., 2001]

Optimising air conditioning and cold storage temperatures

Technical description
Not cooling air conditioned rooms and coldstores to a temperature below that necessary reduces energy consumption without compromising food quality. Coldstores are often held at lower temperatures than necessary because of worries about failure. Having a coldstore at a lower temperature than necessary makes it more likely that failure will occur.

It is reported that keeping controls simple and getting settings right can be a big step towards making a refrigeration plant operate as efficiently as possible by, e.g., setting the thermostat to achieve the best energy efficiency for the installation without compromising reliability. Marking the normal readings on gauges helps the early detection of equipment malfunction. Automatic controls can be used to switch off the refrigeration plant and/or lights when they are not required. Lights and motors in cooled spaces not only use electricity, but because they generate heat they contribute to the energy required to decrease the temperature to that required. If they can be removed where unnecessary and switched off when not required, energy can be saved.

Achieved environmental benefits
Reduced energy consumption.

Technical considerations relevant to applicability
Applicable in all FDM installations which have air conditioned spaces and refrigeration equipment.

Driving force for implementation
Reduced energy costs.

Reference literature

Minimising transmission and ventilation losses from cooled rooms, coldstores and freezing tunnels

Description
To reduce transmission and ventilation losses in the freezer unit, the following measures can be undertaken:

• keep doors and windows closed as much as possible
• fit fast-closing and effectively insulating doors between areas with different temperatures
• limit door size to the minimum necessary for safe access
• maintain good sealing around doorways. Build-up of ice around openings indicates poor sealing
• do not load materials in the doorway
• cool the area in front of the cooling room
• if a door has to be used regularly, fit a strip curtain
• restrict ventilation by fitting the passage between the loading/unloading space of the vehicle and the storage area with an effective seal
• limit air movements when doors and hatches are opened
• apply adequate thermal insulation and screening of freezing tunnels from their surroundings
• refrigerate at night, when the ambient temperature is lowest.

Achieved environmental benefits
Reduced energy consumption. In some cases, there may also be reduced odour and noise emissions.

Technical considerations relevant to applicability
Applied in the deep freezing of packaged and unpackaged food products and air conditioned rooms.

Economics
In 2001, it was reported that an open door cost GBP 6/h for a freezer store and GBP 3/h for a chill store.

Reference literature

Regularly defrosting the entire system

Technical description
Evaporators that operate below 0 °C should be completely defrosted before ice starts to cover the fins. This may be every few hours or every few days. When the evaporator is iced-up, the evaporating temperature drops, increasing energy consumption. The capacity also drops and the required temperature may not be reached. If the defrost elements are not working properly, then the frost build-up on the evaporator will worsen. For this reason, it is also important to check that the evaporators defrost properly. Section 0 describes the automatic defrosting of cooling evaporators.

Achieved environmental benefits
Reduced energy consumption.

Environmental-performance and operational data
A 1 °C drop in the evaporating temperature can increase the running costs by 2–4 %. A defrost-on-demand system, which initiates a defrost when needed rather than by a timer, has reportedly reduced power consumption by 30 % in some applications.

Technical considerations relevant to applicability
Applied in the deep freezing and refrigeration of packaged and unpackaged food products.

Reference literature
[ 14, VITO et al. 2001 ], [ 15, Van Bael J. 1998 ]
Optimisation of the defrosting cycle

Technical description
To optimise the defrosting cycle of the evaporators, the time between defrosting cycles can be adjusted. If the time between two defrosting cycles is too long, the efficiency of the evaporator falls and the pressure drops via the evaporator. If the time is too short, considerable heat is generated unnecessarily in the storage area.

Achieved environmental benefits
Reduced energy consumption.

Technical considerations relevant to applicability
Applied in the deep freezing of packaged and unpackaged food products.

Reference literature
[14, VITO et al. 2001], [15, Van Bael J. 1998]

Automatic defrosting of cooling evaporators in cold storage

Description
The layer of frost formed on the surface of evaporators reduces their heat-exchange efficiency. Warm gas from compressors can be used for defrosting and to remove this layer. Energy savings depend on the capacity/number of the evaporators and the operating time of the frosted evaporators.

Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data
In an ice cream installation, five evaporators running for 3,000 hours per year with an ice layer of 0.87 mm were equipped with an automatic defrosting system. As a result, approximately 100,000 kWh/yr energy could be saved. The estimated investment cost was EUR 15,000, with a payback of 2.2 years.

Technical considerations relevant to applicability
Widely used in new installations and can easily be applied to existing operations.

Economics
Reduced energy costs. Short payback periods.

Example plants
An ice cream installation in a Nordic Country.

Reference literature
[21, Nordic Council of Ministers 2001]

Use of binary ice as a cooling fluid (secondary refrigerant)

Description
Binary ice can be used as a refrigerant fluid. Binary ice may be described as “liquid ice”. It comprises ice crystals of 10–100 µm, in suspension in water, containing antifreeze. The antifreeze is either ethanol based containing an anti-corrosion substance, or if the binary ice is for the immersion of food, common salt (sodium chloride).
Two technologies are described for the production of binary ice. The first, which is shown in Figure, is for small and medium capacity binary ice, i.e. 100–1000 kW. The numbers in the following text refer to. The binary ice is generated with a special evaporator, called a binary ice generator (1), which is supplied with fluid by a pump (2), from a binary ice storage vessel (3). A conventional refrigeration plant (4), with a small refrigerant charge, is connected to the binary ice generator. “Natural” refrigerants such as water (not for freezing), air, carbon dioxide (still under development), ammonia and hydrocarbons can be used, as alternatives to chlorofluorohydrocarbons. A secondary pump (5) supplies binary ice at a given ice concentration into the main feed pipe (6), where pumps (7) (optional), supply binary ice to the cooling loads (8). In the case of “zero load”, but on standby, the binary ice is kept circulating in the secondary loop (6) and (10) but is passed over valve (9), which opens as soon as the cooling loads are disengaged. The return pipe (10) transports the binary ice fluid, (with or without ice crystals) back to the storage vessel (3).

Binary ice system with a conventional refrigeration plant

Medium and large capacities of binary ice, i.e. 1000 kW–1 MW, can also be produced with a refrigeration process with “water as refrigerant”. The technology is very similar to that shown in, with the exception that the conventional refrigeration plant (4) is not necessary. A water vapour compressor and suitable vacuum conditions, for binary ice typically 500 Pa (5 mbar), cause the water to evaporate in an empty vessel (evaporator) and the compressor removes the water vapour, which is eventually condensed.

Achieved environmental benefits

Under comparable conditions, the coefficient of performance for binary ice is normally better than for conventional chilling and freezing plants, i.e. less power is consumed. Smaller refrigeration units are required, so fewer materials are needed and reportedly, because they do not have to be so chemically resistant, they can be simpler and better suited for recycling. As the entire installation is not filled with potentially harmful refrigerants, the probability and severity of an accidental release is reduced. Unlike other refrigerants, binary ice made from water and alcohol can normally be released to the WWTP, with the permission of the regulator. The properties of an ice crystal’s rapid phase change reportedly ensure excellent heat transfer. The surface can, therefore, either be reduced or the binary ice can be “warmer”, which results in lower energy demand and less surface freezing. The product weight loss is consequently less and defrost may even be unnecessary for air chillers. Fluid coolers can reportedly also be 20 to 50% smaller.

Environmental performance and operational data
Chapter 2

compares the volumes of the refrigerants brine and binary ice required to achieve a 3 ºC decrease in temperature.

Comparison between the volumes of binary ice and brine required to achieve a 3 ºC decrease in temperature

<table>
<thead>
<tr>
<th>Cooling process</th>
<th>Refrigerant</th>
<th>Comparable cooling ability for a given mass, to achieve a 3 ºC decrease in temperature</th>
<th>Energy available for cooling (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Chilling</td>
<td>Brine</td>
<td>1.0</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Binary ice of 10 % ice crystals</td>
<td>1.0</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Binary ice of 20 % ice crystals</td>
<td>6.0</td>
<td>66</td>
</tr>
<tr>
<td>Freezing</td>
<td>Brine</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Binary ice of 10 % ice crystals</td>
<td>2.7</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Binary ice of 20 % ice crystals</td>
<td>7.3</td>
<td>66</td>
</tr>
</tbody>
</table>

For example, four to seven times more refrigerant has to be circulated if brine is used as a refrigerant, compared to binary ice. It has been reported that pipe diameters can be approximately 50 % smaller and the pumping power 70 % lower, for binary ice compared to brine. It is also reported that binary ice plants commonly run throughout 24 h/d, so only a small ice making machine and storage volume is required.

In an example slaughterhouse and meat processing installation, the slaughtered cattle and pig carcases were chilled, prior to further processing. The following binary ice plant, with a total installed capacity of 424 kW, was installed and provides the cooling requirements shown in Table.

Cooling requirements of a binary ice plant

<table>
<thead>
<tr>
<th></th>
<th>3,800 m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total area used</td>
<td>40</td>
</tr>
<tr>
<td>Number of employees</td>
<td></td>
</tr>
<tr>
<td>Production per week</td>
<td>500 cattle and 2,000 pigs</td>
</tr>
<tr>
<td>Refrigerant</td>
<td>Ammonia</td>
</tr>
<tr>
<td>Binary ice system</td>
<td>Trade name</td>
</tr>
<tr>
<td>Number of independent refrigeration plants</td>
<td>2</td>
</tr>
<tr>
<td>Compressors</td>
<td>Gram (reciprocating)</td>
</tr>
<tr>
<td>Additional features</td>
<td>Heat-recovery</td>
</tr>
<tr>
<td>Cooling work per day</td>
<td>5,500 kWh/d</td>
</tr>
<tr>
<td>Full load operating hours (maximum)</td>
<td>13 h/d</td>
</tr>
<tr>
<td>Installed refrigerating capacity (icemakers)</td>
<td>230 kW</td>
</tr>
<tr>
<td>Operating hours of the binary ice plant (hottest summer day)</td>
<td>24 h/d</td>
</tr>
<tr>
<td>Binary ice storage work</td>
<td>1,600 kWh</td>
</tr>
<tr>
<td>Binary ice storage volume</td>
<td>34 m³</td>
</tr>
<tr>
<td>Binary ice fluid corrosion-inhibitor</td>
<td>Trade name</td>
</tr>
<tr>
<td>Maximum binary ice concentration of ice in storage</td>
<td>&gt;50 %</td>
</tr>
<tr>
<td>Binary ice concentration in the pipework</td>
<td>12 %</td>
</tr>
</tbody>
</table>

Technical considerations relevant to applicability

Applicable to all FDM installations.

Economics

For the slaughterhouse and meat processing example referred to above, the service life was 15 years. With an interest rate of 7 % and a depreciation time of 10 years, the additional direct investment costs could reportedly be recovered in 2.2 years and the annual operating costs of the binary ice plant, including depreciation, immediately recoverable. It is estimated that the payback time would be 10 to 15 years for typical Danish slaughterhouses.
It is reported that binary ice plants normally run at off-peak tariff or during times when there is a low overall electrical loading.

**Driving force for implementation**
The phase out of ozone-depleting chlorofluorohydrocarbons under the “Montreal protocol” and the expected pressure to reduce the use of hydrochlorofluorohydrocarbons by the “Kyoto protocol”.

**Example plants**
Applied in meat processing, fish processing, brewing and cold storage in Germany.

**Reference literature**
[94, Germany 2003]

**Techniques in relation to compressed air generation and use**

**Optimise pressure settings**

**Description**

**Achieved environmental benefits**
Reduced energy consumption and reduced noise, if large compressors run for shorter periods.

**Technical considerations relevant to applicability**
Applicable where there is more than one use for compressed air in an installation.

**Driving force for implementation**
Reduced energy consumption and associated costs.

**Example plants**
Widely applied.

**Reference literature**

**Optimise the air inlet temperature**

**Description**

**Achieved environmental benefits**
Reduced energy consumption.

**Driving force for implementation**
Reduced energy consumption and associated costs.

**Reference literature**

**Techniques related to steam systems**

**Avoid losses of flash steam from condensate return**

**Description**

**Achieved environmental benefits**
Reduced energy and water consumption.
Environmental performance and operational data
The flash steam typically contains about 40% of the energy in the original pressurised condensate.

Technical considerations relevant to applicability
Applicable where flash steam is produced and can be reused.

Driving force for implementation
Reduced energy consumption and associated costs.

Reference literature

Isolate unused/infrequently used pipework

Description
There may be branches of the steam distribution system that are no longer used and can be removed from the system. Also, pipework that supplies steam to infrequently used equipment can be isolated using valves or slip-plates. Unused and infrequently used pipework causes energy to be consumed unnecessarily and is likely to receive less maintenance attention. Removal of pipework may leave the remaining pipework inadequately supported, so additional support may be required.

Achieved environmental benefits
Reduced energy and water consumption.

Technical considerations relevant to applicability
Fully applicable.

Driving force for implementation
Reduced energy consumption and associated costs.

Reference literature

Minimising the blowdown of a boiler

Description

Achieved environmental benefits
Reduced energy consumption. Reduced waste water generation.

Environmental performance and operational data
Table shows the potential fuel savings by reducing the blowdown as a function of steam pressure in the deep freezing of vegetables. At a steam pressure of 10 bar, a fuel saving of 2.1% can be achieved if the blowdown volume is reduced by 10%.

<table>
<thead>
<tr>
<th>Effective boiler pressure (bar)</th>
<th>Fuel saving per blowdown reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0.19</td>
</tr>
<tr>
<td>10</td>
<td>0.21</td>
</tr>
<tr>
<td>12</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Technical considerations relevant to applicability
Applicable where a boiler is used.
Integrated bottling installation

Technical description
An example installation produces distilled wines, neutral alcohol, grain spirit, essences and distilled rum and whisky. The annual production volume is 70 million standard 0.7 litre bottles. A new bottling line was installed to reduce the energy consumption.

Currently, incoming raw materials are checked for compliance with quality limits. Before the raw materials enter the production process, the liquid raw materials are stored in large steel tanks and non-liquid raw materials are stacked in the pallet store. The mixing department blends the basic materials in accordance with defined recipes. This is done in special mixing tanks. The metering of all basic materials, including the conditioned product water, is controlled by “weight dosage” and a computer system. To remove TSS, the mixed batches are then filtered using bed filters. Different filter beds with different separation efficiencies are used for each individual type of spirit. After a quality check is made by the analytical laboratory, the final mixed and filtered product goes to the bottling line. A flow diagram of this process is shown in Figure.

Figure: Flow diagram of the processing of spirits

The bottling line is shown in Figure.
During the first stage, stacker systems are used to supply individual units with the pallets of empty bottles and the cartons. These are also used for the closures and labels required for bottling and packaging. The empty bottle pallets are placed on conveyor belts and the protective plastic film is then removed manually. The pallet enters the slider unit, where the empty bottles are slid off one layer at a time and are then arranged in a single file on the bottle conveyors. Then they are fed to the bottling units. The protective plastic film is collected, pressed into bales and sent to a recycling company.

The empty bottles are filled on the rotary bottling unit and then capped. The first bottle filled is always tested. Bottling starts after clearance has been given by the laboratory. Control systems on the filling units monitor the bottles for the correct filling level and correct closure. Short or unsealed bottles are automatically removed. The filled bottles then go to a labelling unit. Self-adhesive plastic film labels are used as well as traditional paper labels. Ink-jet printers add the prescribed batch identification information.

The filled bottles are then packed. There are two types of packing machines, the ones that work based on the wraparound principle and the ones that work based on the folding box principle. The wraparound principle performs four operations in a single process. It erects the carton, inserts the contents, closes it and feeds it on. One machine is needed instead of four.

The full cases may be labelled and then passed via a carton weigher to the palletising systems. The carton weigher detects any deviation from the target weight for the carton and removes such cartons from the production process as rejects. After weighing, the cartons are automatically palletised on “euro pallets”. The pallets, loaded with cases of full bottles, are then wrapped in a stretch film to ensure a better load security during transport.

As the installation does not have an internal store for finished products on the site, its entire production is taken by shuttle vehicles to an external logistics store. Two shuttle vehicles at a time can dock at the loading stations and be loaded with 30 pallets each within three minutes. No fork lift trucks are used in this process.

**Achieved environmental benefits**  
Significant reduction in energy consumption. Reduced noise pollution.

**Cross-media effects**
Waste water is produced, e.g. from processing, cleaning and rinsing. Waste is produced, e.g. PET film, residual packaging material and broken glass.

**Environmental performance and operational data**

The new bottling line consumes an average of 1.0 to 1.5 kWh less energy per 1,000 standard bottles than the older technology (not described). The shuttle conveyor saved 15,600 litres of diesel fuel, compared to loading full pallets with forklift trucks. Table shows consumption and emission levels of the bottling line in the year 2000. Table and Table show production, energy consumption and waste water data from 1999 to 2001.

### Table: Consumption and emission figures of the bottling line (2000)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water consumption</td>
<td>m³</td>
<td>38.8/10</td>
</tr>
<tr>
<td>Built in product</td>
<td>m³</td>
<td>25.5/00</td>
</tr>
<tr>
<td>Energy consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>MWh</td>
<td>1.9/23.9</td>
</tr>
<tr>
<td>Electricity</td>
<td>MWh</td>
<td>3.3/16.6</td>
</tr>
<tr>
<td>Specific energy consumption</td>
<td>kWh/10³ bottles</td>
<td>9.4</td>
</tr>
<tr>
<td>Production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vinasse</td>
<td>tonnes</td>
<td>3530</td>
</tr>
<tr>
<td>Vinasse potash</td>
<td>tonnes</td>
<td>754</td>
</tr>
<tr>
<td>Waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardboard/paper</td>
<td>tonnes</td>
<td>258</td>
</tr>
<tr>
<td>Scrap metal</td>
<td>tonnes</td>
<td>10</td>
</tr>
<tr>
<td>Broken glass</td>
<td>tonnes</td>
<td>157</td>
</tr>
<tr>
<td>PET film</td>
<td>tonnes</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>kg/10³ bottles</td>
<td>4.0–1.2</td>
</tr>
<tr>
<td>Waste water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>m³</td>
<td>13.2/30</td>
</tr>
<tr>
<td></td>
<td>m³/10³ bottles</td>
<td>0.199</td>
</tr>
<tr>
<td>COD content</td>
<td>mg/l</td>
<td>1,000–5,400</td>
</tr>
<tr>
<td>BOD₅ content</td>
<td>mg/l</td>
<td>1,200–3,000</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>7.7–8</td>
</tr>
</tbody>
</table>

### Table: Production, energy consumption and waste water generation figures for a spirits installation from 1999 to 2001

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>1999</th>
<th>2000</th>
<th>2001 (until Nov.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total production</td>
<td>10³ bottles</td>
<td>60,636</td>
<td>66,465</td>
<td>62,083</td>
</tr>
<tr>
<td>Production of new technology</td>
<td>10⁴ bottles</td>
<td>47,256</td>
<td>48,072</td>
<td>47,189</td>
</tr>
<tr>
<td>Total electricity</td>
<td>kWh</td>
<td>2,282,840</td>
<td>2,316,640</td>
<td>2,097,560</td>
</tr>
<tr>
<td>Electricity of new technology</td>
<td>kWh</td>
<td>462,928</td>
<td>469,503</td>
<td>442,830</td>
</tr>
<tr>
<td>Total electricity</td>
<td>kWh/10³ bottles</td>
<td>32.8</td>
<td>34.8</td>
<td>33.8</td>
</tr>
<tr>
<td>Electricity of new technology</td>
<td>kWh/10³ bottles</td>
<td>9.8</td>
<td>9.8</td>
<td>9.4</td>
</tr>
</tbody>
</table>
There is also a reduction in noise pollution due to the smoother action of the new mechanical systems.

Technical considerations relevant to applicability
Applicable in bottling installations.

Economics
The fully automated shuttle system saves the high running costs and operating resource requirements of the forklift truck technology. In addition to reducing resource consumption, the technological modernisation had a substantial economic effect as a result of the increased hourly output. This is one reason for the 10% reduction in production costs per standard bottle and the 7.5% increase in productivity, when comparing 1999 to 2001.

Example plants
A spirits production installation in Germany.

Reference literature
[35, Germany 2002]

2.3.2.3 Techniques related to cooking

2.3.2.3.1 Avoidance of precooking step if possible

Description
Avoidance of the precooking step if the food can be cooked subsequently during the sterilisation step.

Description
Before preservation in cans, bottles and jars, the food can be cooked before it is placed into the packaging container. Water bath, shower, steam, hot air and microwave ovens are used for such precooking. Precooking can be avoided if the food can be cooked subsequently, during sterilisation.

Achieved environmental benefits
Reduced water and energy consumption. Reduced waste water generation and pollution.
Environmental performance and operational data
In the fish sector, medium-sized and large fish are cooked, e.g. before canning. Small fish such as sardines are canned whole and are then cooked in the cans during sterilisation. The circumstances which enable precooking to be avoided and cooking to take place during the sterilisation step depend on factors such as the size of the food pieces; the size of the cans, bottles or jars; the recipe; ensuring the quality of the product and the length of the sterilisation time.

Technical considerations relevant to applicability
Widely applicable in the FDM sector, for foods that are intended to be preserved and cooked.

Reference literature
[71, AWARENET 2002]

Hot air oven

Description
Hot air ovens include a recirculation system for hot air, which is obtained by passage through heat exchangers, and a steam inlet to control food surface humidity. Hot air ovens distribute heat more evenly than other ovens, so cooking time and cooking temperatures can be reduced, thereby cutting energy consumption.

Achieved environmental benefits
Reduced water and energy consumption.

Technical considerations relevant to applicability
Widely applicable in the FDM sector, e.g. for meat, fish and vegetables.

Reference literature
[71, AWARENET 2002]

Microwave oven

Description
In a microwave oven, the food is heated by passing microwaves through it. The resulting generation of heat inside the food facilitates rapid cooking.

Achieved environmental benefits
Reduced water and energy consumption.

Technical considerations relevant to applicability
Widely applicable in the FDM sector, e.g. for meat, fish, shellfish and vegetables.

Reference literature
[71, AWARENET 2002], [137, Oxford University Press 2002]

2.3.3 Techniques to reduce water consumption

2.3.3.1 General processing techniques

The benefits of improved process control include an increase in saleable product, improved quality and reduced waste.
Chapter 2

Improving the process control of inputs, process operating conditions, handling, storage and waste water generation can minimise waste by reducing off-specification product, spoilage, loss to drain, overfilling of vessels, water use and other losses.

To improve process control, it is important to identify at which stage in the process waste is generated, what is the cause of that waste and what improvements can be made to reduce the waste. For example, fitting a level switch, float valve, or flow-meter can eliminate waste caused by overflows. The degree of maintenance cleaning and calibration of all such devices will vary depending on their design and the frequency and conditions of their use.

It is vital that the process monitoring and control equipment is designed, installed and operated so that it does not interfere with hygiene conditions in the production process, and does not, in itself, lead to product loss and waste. Further information about monitoring is available in the “Reference document on the general principles of monitoring” [96, EC, 2003].

2.3.3.1.1 Water recycling

Description
Recycling or reuse of water streams (preceded or not by water treatment), e.g. for cleaning, washing, cooling or for the process itself. The degree to which the water can be recycled or reused is limited by the purity requirements and the water demand of the process.

Technical description
Recycling of water can be carried out either preceded or not preceded by water treatment. The Examples are given for both options under Environmental performance and operational data below.

Achieved environmental benefits
- Reduction of water consumption (e.g. water of drinking water quality) by using water sources of a different quality.
- Reduction of emissions to water.
- The technique can also enable heat to be recovered.

Environmental performance and operational data
There are multiple ways of reusing water reported in the questionnaires of the FDM BREF data collection [193, TWG 2015]. Some examples are as follows.

- Cooling water is recycled as cleaning water. This is the case for installation #036.
- Hot water generated from cooling systems is recycled in the process. This is the case for installation #048 (used in the mashing in beer production).
- Water generated from beet sugar processing is recycled, e.g. as cooling and cleaning/washing water. This is the case for installations #027, #087, #111, #125, #285.
- Washing water is reused several times for the same or different washing. This is the case for installations #181, #279, #283.
- Cooling water is reused several times for cooling again (closed-circuit cooling, see also Section 2.3.3.3.1). This is the case for installations #228, #291.
- Cooling water is recycled as boiler feed water. This is the case for installation #463.
- Water generated from RO filtration of raw materials (e.g. condensate of whey) is recycled. This is the case for installations #124, #130, #134, #232, #303.
- Waste water after being biologically treated is recycled as cleaning or cooling water. This is the case for installations #035, #114, #305.
Condensates generated in evaporation and drying operations after being filtrated with RO is recycled. This is the case for installations #051, #124, #292, #296.

Waste water after being biologically treated and filtrated by using ultrafiltration followed by reverse osmosis is recycled. This is the case for installations #035, #310.

Rinsing water after cleaning is reused for pre-rinsing. This is the case for installation #058.

Rinsing water after cleaning is recycled for the pasteuriser. This is the case for installation #247.

Rinsing water after cleaning is recycled for auxiliary services. This is the case for installation #183.

Rinsing water after cleaning is recycled for cooling. This is the case for installation #279.

The condensate from vapour generation is partly recycled as process water after energetic usage. This is the case for installation #087.

Waste water after physico-chemical treatment is recycled in a biofilter and bioscrubber. This is the case for installation #466.

Waste water is evaporated and reused in the process. This is the case for installation #086.

Rainwater is recycled. This is the case for installation #035.

Recovered condensate can be recycled as feed to the boiler, heated water, or heated water for cleaning equipment and other installations (see also Section 2.3.3.5.1).

Waste water is recycled from the lauter turn in breweries (see also Section 4.4.2.2).

Scaling waste water is filtered and recirculated for preliminary fish rinsing in fish and shellfish processing (see also Section 7.4.2.1.2).

Water that arises from peeling, sorting and canning is recycled.

Countercurrent water is reused in starch washing (see also Section 14.4.2.1).

Flume water used for transporting beet is reused through the initial stages of the process. Retained water from the previous year’s campaign is reused to start the new campaign. Condensates from the evaporation and crystallisation stages are reused as process water in several stages, including beet washing (see also Section 15.4.2.1).

Optimising the CIP systems can, for example, minimise the quantity of the cleaning and disinfection agents used, by recirculating cleaning solutions (containing e.g. caustic soda).

In fruit and vegetable processing, recycling of water is common practice, sometimes with some treatment, such as filtration, during the unit operations prior to blanching.

Cross-media effects
Increase in recycling/reuse of water can result in an increase in energy and chemical consumption for treatment of water before recycling.

Technical considerations relevant to applicability
Water recycling opportunities are present in existing and new FDM installations.

Economics
TWG, please provide information.

Driving force for implementation
- Reduced consumption of drinking quality water in regions with water shortages.
- In line with the EU Action Plan for the Circular Economy [237, COM 2015], reuse of process and waste water aims to improve the resource efficiency of the FDM sector.

Example plants
Water recycling is commonly reported in all FDM sectors.

Reference literature
[226, EDA 2016], [193, TWG 2015]
2.3.3.1.2 Use of control devices to optimise water flow

Description
Use of various control devices, e.g. photocells, flow valves, thermostatic valves, to adjust the water flow.

Technical description
Flow measurement and control techniques can reduce material waste and waste water generation in FDM processing. Applying flow measurement and control in transfer lines allows the accurate addition of materials to storage and processing vessels and filling packaging, thereby minimising the excessive use of materials and the formation of out-of-specification products.

Sensors such as photocells can be fitted to detect the presence of materials and to supply water only when it is required. Water supplies can be turned off automatically between products and during all production stoppages.

Valves are the most common control device and they are extensively used with both manual and automatic control systems. Valves are often used to modify a flowrate to control a different process parameter, e.g. the temperature of chocolate can be measured and, if necessary, adjusted by controlling the flowrates of heating and cooling water. Examples include flow regulators and solenoid valves; others are available.

Flow regulators are used to provide a constant flow at a predetermined rate. The flow through the regulator can be adjusted within a limited range, but these devices are designed with the intention that adjustments are infrequent.

Solenoid valves are two position devices where a solenoid is used to open or close a valve on receipt of a control signal.

Examples of the general applicability of flow measurement and control are shown in Table 2.40.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Condition/activity</th>
<th>Reason for control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer lines</td>
<td>Accurate addition of materials to reaction vessels</td>
<td>Minimise excessive use of materials and formation of out-of-specification products</td>
</tr>
<tr>
<td>Steam supplies</td>
<td>Maintaining correct operating temperatures</td>
<td>Minimise waste from underheated or overheated materials and products</td>
</tr>
<tr>
<td>Cleaning systems</td>
<td>Water use</td>
<td>Optimise use and minimise waste water generation</td>
</tr>
</tbody>
</table>

*Source: [192, COM 2006]*

Some typical applications of flow measurements are shown in Table 2.41.

<table>
<thead>
<tr>
<th>Product/activity</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft drinks</td>
<td>Flow measurement and feedback control for raw material addition</td>
</tr>
<tr>
<td>Bulk solids</td>
<td>For example, determining the flow of potato crisps to a flavour drum to ensure the correct ratio of flavouring</td>
</tr>
<tr>
<td>Milk powder</td>
<td>Flow measurement for accurate batching of ingredients into the process as specified in recipes</td>
</tr>
<tr>
<td>CIP</td>
<td>Flow measurement to ensure a fixed volume of water issued for each cleaning stage</td>
</tr>
</tbody>
</table>

*Source: [192, COM 2006]*
Achieved environmental benefits
Reduced water consumption and associated energy use.

Environmental performance and operational data
An example food manufacturing company identified that excessive water consumption by its vacuum pumps was due to a higher flow than necessary for the seal water. Although the maximum flow for the service liquid should have been 2.7 m$^3$/h, the actual flow was almost 11.5 m$^3$/h, i.e. over four times the design requirement. Installing constant flow valves to ensure the correct flowrate to each of the water ring vacuum pumps reduced water use by approximately 60 000 m$^3$/year, corresponding to 7.5 % of the site’s mains water consumption. Water and waste water costs fell and there was reduced energy consumption and wear of the vacuum pumps.

At an example chicken processing company, excessive water consumption was identified. Flow regulators were installed to fix the water supply to particular processes at the rate required by the process, thereby saving on water consumption.

An example fish processing company installed a solenoid system on the water supply to a pre-wash system. Water had previously flowed continuously, causing overflowing and entrainment of debris into the waste water. The solenoid enabled the water supply to be shut off when the conveyor belt was not in use. Water used by the process fell by 40 %.

In a brewery installation (#160), a vacuum is applied in bottles just before filling by a vacuum pump. Water flow is led into the pump to produce a venturi effect to take air out of the filler and also refrigerate the pump. There is a relationship between the vacuum generated by the pump and its working temperature, which is controlled by the cooling water. Using a thermostatic valve to adjust the raw water supply, it is possible to control the vacuum and save water. Water savings close to 0.1 hl/hl of product have been achieved. [193, TWG 2015]

Cross-media effects
There are no cross-media effects associated with this technique.

Technical considerations relevant to applicability
Flow regulators are widely applicable, where a constant flow is required at a set rate.

The use of solenoid valves is applicable throughout the FDM sector and they are frequently used to control water supply.

Economics
The introduction of constant flow valves in the food manufacturing installation referred to resulted in costs falling by GBP 70 000/yr, giving a payback on the investment of less than one month.

At the chicken processing installation, the introduction of flow regulators cost less than GBP 1000 and resulted in water savings worth over GBP 10 000/yr.

At the fish processing installation, the 40 % reduction in water use saved GBP 2 500/yr and gave a payback period of 5 weeks.

Driving force for implementation
Reduced water consumption and associated costs.

Example plants
Widely applied in the FDM sector.

Reference literature
[7, Environment Agency of England and Wales 2000], [10, Envirowise (UK) & Entec UK Ltd 1999], [193, TWG 2015]
2.3.3.1.3 Optimisation of water nozzles

Description
Use of correct number and position of nozzles; adjustment of water pressure and flow.

Technical description
Water nozzles are widely used in the FDM sector, e.g. for washing and sometimes for thawing the product, and cleaning the equipment during processing. Water consumption and waste water pollution minimisation can be carried out by correctly positioning and directing the nozzles. The use of presence-activated sensors and most importantly, only installing them where required, can ensure that water is only consumed where necessary. Removing nozzles where water is used to direct food and replacing them with mechanical devices can reduce water consumption, and the entrainment of food particles in water which would then have to be treated in a WWTP.

In addition, water consumption can be optimised by monitoring and maintaining the water pressure of the water nozzles. Water pressure can be adjusted according to the unit operation requiring the highest pressure, and a suitable pressure regulator can be installed at each of the other unit operations which require water.

Achieved environmental benefits
Reduced water consumption and waste water generation. Reduced waste water pollution, e.g. due to the reduction of the contact time between the food and water.

Environmental performance and operational data
When processing Vienna sausages, cooling is required after smoking. This is normally carried out by showering the sausages in the smoking cabinet or in a specially designated area. A large quantity of water is often used for this purpose if irrigation pipes are used. Water consumption is commonly around 3.5 m$^3$/t. Instead of irrigation pipes, water saving nozzles and a timer control are reportedly used. To avoid unnecessary waste, the nozzles have to be correctly positioned and directed so that all the water hits the sausages. When cooling is carried out in cabinets specially designed for the purpose, the sausages can be sprayed with finely atomised water, the water supply is then stopped and air is pulled through the cabinet. This causes the water on the surface of the sausages to evaporate. As the surface dries out, a new cycle of water spraying and drying is started. The method results in substantial water savings.

Nozzles are also used when sausages are vacuum packed. A vacuum packing machine uses cooling water, approximately 0.2 m$^3$/t of sausages. Setting the water quantity and fixing and locking the position of the nozzles minimises water consumption. Another possible alternative is to collect and reuse the cooling water.

In the fish sector, a reduction in water consumption of about 0.13 to 0.2 m$^3$/t raw material has been reported.

In white fish filleting, water consumption can be reduced by up to 90 % by installing nozzles and sprinkling the water in one or two seconds out of every three. In the sorting of herring and mackerel, a 50–65 % reduction in water consumption can be achieved by regulating the nozzle sizes so that they only supply the necessary amount of water.

It is reported that in fish skinning and cutting, reducing both the number and size of spray nozzles can lead to water savings of about 75 %. In fish filleting, a reported reduction of 60 % to 75 % in water consumption is obtained by using the following means which combine a planned use of nozzles and other techniques:

- removing unnecessary water nozzles;
- using water nozzles instead of water pipes for washing the product;
- using mechanical devices instead of water nozzles to move the fish from the tail cut;
• replacing the nozzles for washing the driving wheels on the filleting part with mechanical scrapers;
• replacing existing nozzles by nozzles with a lower water consumption;
• using pulsating water nozzles, i.e. alternating the opening and closing of the water supply with an automatic valve;
• replacing the waste drain by mesh conveyors and closing the nozzles in the waste drain. The waste will be separated from the process water directly near the filleting machine, resulting in shorter contact time and less entrainment of, e.g. fat;
• using presence-activated sensors to control when the nozzles operate;
• using dry transport of viscera and fat;
• removing skin and fat from the skinner drum by vacuum.

The frame can be cut from fish fillets by two sets of rotating knives. The knives may need to be cooled with water from nozzles, which can also clean off fish meat and scale, although it may be possible to do this mechanically.

Cross-media effects
There are no cross-media effects associated with this technique.

Technical considerations relevant to applicability
Applicable to all the FDM sectors. In the fish sector, nozzles are used in scaling, skinning, cutting, eviscerating, and filleting. In the meat sector, they are used in the processing of sausages. In brewing, they are used for cask and bottle cleaning.

Example plants
Widely applied in the FDM sector. Used in the Danish herring industry.

Reference literature
[ 13, Nordic Council of Ministers 1997 ], [ 20, Nordic Council of Ministers 2001 ], [ 71, AWARENET 2002 ]

2.3.3.1.4 Segregation of water streams to optimise reuse and treatment

Description
Waste water that does not need treatment (e.g. uncontaminated cooling water or uncontaminated rainwater) is segregated from waste water that has to undergo treatment, thus reducing the hydraulic load on the drainage and treatment system and enabling water recycling as well as material recycling.

Technical description
A detailed technical description of a waste water collection and segregation system can be found in the CWW BREF [ 242, COM 2016 ].

There are generally four types of water streams present in an FDM installation, i.e. water directly associated with use in the process, domestic/sanitary waste water, uncontaminated water and surface water. A water segregation system can be designed to collect these water streams and separate them according to their characteristics, e.g. their contaminant load.

When it is feasible to do so, and it will not affect food safety, the uncontaminated water streams can be reused for specific process applications, e.g. washing, cleaning, make-up for utilities, for sequential reuse, and exceptionally, for the process itself. Uncontaminated water for which there is no reuse opportunity available can generally be discharged without treatment and doing so prevents an unnecessary burden being imposed on the WWTP.

Contaminated waste water may be segregated to receive appropriate treatment according to its characteristics. It may then be possible for the high volume, low polluted streams to be either
recycled following suitable treatment or discharged directly to the WWTP without treatment or be mixed with treated waste water prior to discharge. In some cases, materials can be recovered from process water for use in the process or for other uses such as animal feed.

Uncontaminated water for which there is no reuse opportunity available should be discharged without treatment provided that the requirement on the recipient quality can be met. If that is not possible, it should be considered whether treatment of the specific water stream is an option, thus preventing an unnecessary load on the WWTP.

**Achieved environmental benefits**
The main benefits of the technique include lowering the volume of waste water requiring treatment and increasing the load of pollutants thus enabling more efficient treatment (including reduced energy consumption) as well as allowing water and material recycling/reuse.

Reduced water contamination, by keeping clean water separate from dirty water and consequently also reduced energy consumption associated with the waste water treatment because not all of the waste water is subjected to every treatment. The reuse of water reduces water consumption and consequently also generally results in a reduction of emissions. It can also enable heat to be recovered.

**Environmental performance and operational data**
Separate discharge is recommended to avoid a dilution effect of the treated waste water. The more concentrated the effluents that result from separation, the more generally effective their downstream treatment is.

**Cross-media effects**
There are no cross-media effects associated with this technique.

**Technical considerations relevant to applicability**
For existing installations, there might be technical and economic difficulties associated with the installation of a waste water separation/segregation system (see Economics below).

Segregation of waste water is applicable in new and substantially altered existing FDM installations. For new installations, the waste water segregation system can be designed so that different types of waste water are separated. For existing installations, this may not be possible due to the costs involved and the physical or engineering constraints at specific sites.

**Economics**
Segregation of waste water can involve a high capital cost at existing installations. However, this may be offset by the reduced running costs due to the lower requirement for waste water treatment (e.g. water-holding capacity, energy consumption), whether on site, at a MWWTP or a combination of both. Waste water separation/segregation systems can be installed efficiently at new installations. It may not be economical to segregate small, isolated streams. Reduced costs associated with water consumption and in some cases with reduced energy consumption.

**Driving force for implementation**
- Reduction of long-term expenses for treating waste water.
- Enabling of water and material recovery. Moreover, by segregating low strength streams, a treatment facility can be reduced in size. Reduced water and energy consumption.
- In some countries, the mixing of uncontaminated rainwater with other effluents is not permitted.

**Example plants**
Widely used in the FDM sector and any other industrial activity with waste water generation.
Used in the fruit and vegetable; dairy; sugar; drinks and brewing sectors. The technique is also used in at least one snack food installation in the UK (see Section 0).

Reference literature
[226, EDA 2016], [242, COM 2016]


**Only pump up water that is required**

**Description**

By only pumping up the quantities of water that are actually required in the production process, the impact on groundwater levels is minimised and energy is saved. Water can be extracted on demand to avoid excessive storage and the risk of water being wasted, either through contamination or leakage.

**Achieved environmental benefits**

Reduced water and energy consumption.

**Technical considerations relevant to applicability**

Applicable in areas where groundwater is extracted.

**Driving force for implementation**

Local shortages of groundwater.

**Example plants**

Fruit and vegetable installations in Belgium.

**Reference literature**

[31, VITO, et al., 2001]

**Use automated water start/stop controls**

**Achieved environmental benefits**

Reduced water consumption, reduced volumes of water requiring treatment and if the pressure is regulated, reduced entrainment of biological matter and contamination.

**Environmental performance and operational data**

Care taken during the selection, installation and maintenance of the photocells can make certain that they are reliable and their correct position ensures that products are washed to the extent required and no more.

Use of the technique pre-supposes that water needs to be applied to each product detected and the technique does not distinguish between clean and dirty products.

**Technical considerations relevant to applicability**

Applicable where a water supply is required intermittently.

**Driving force for implementation**

Reduced water costs.

**Reference literature**

[1, CIAA 2002]

**Flow measurement and control**
Technical description

Flow-meters with no internal measuring element, e.g. electromagnetic meters, are particularly suited to hygienic applications. To reduce contamination, flow-meters need to be robust and easy to clean. In processes where fluids may solidify at low temperatures, heat tracing may be required to ensure that the fluid does not solidify in or around the equipment. There are various types of flow-meters available, e.g. rotameters, positive displacement meters, electromagnetic flow-meters, ultrasonic transit time meters and vortex shedding meters. Each type has particular installation requirements to ensure that they measure accurately.

In CIP systems, flow measurement can control and optimise the water use, thereby minimising waste water generation.

The control of clean and purge interfaces is important, because it can contribute to significant losses. By using flow or conductivity controls, e.g. water/milk interfaces are accurately detected to minimise the amount of raw milk lost to drain. Pigging can also be used to control interfaces (see Section 2.3.3.2.6).

Achieved environmental benefits

Reduced waste of materials, products and water and less waste water generation.

Environmental performance and operational data

When processing ground meat, the water flow to sausage fillers and similar equipment can be minimised. The water flow is stopped automatically when the equipment is not used at breaks or production stops.

In an example dairy processing 3,000 m³ of raw milk a week, 0.2% of waste milk was saved by optimising the water/milk interface through flow-meters and conductivity probes. The final site waste water COD reduced from 3,100 to 2,500 mg/l.

In a vegetable processing company, manual flow control valves were installed on the water supply to the conveying system. This allowed the operators to make sensitive adjustments to the water flow. In addition, a particular valve setting and water flowrate could easily be repeated.

A confectionery manufacturer found that there was considerable variation in the weight of chocolate coating on its products. A number of measures were implemented to improve the control of chocolate addition. These included installation of an electromagnetic flow-meter and a control valve to control the chocolate feed rate accurately. Consumption was reduced by 10 t/yr.

A company manufacturing ready-made meals installed a positive displacement meter to increase its understanding of water use in the equipment cleaning bay. After several weeks of monitoring, it became clear that water consumption varied significantly and that it was not related to production levels. Following discussions with the operators in the area, improved cleaning procedures were introduced. The result was an immediate reduction in water use of 80 m³/week.

It is reported that in drinks manufacturing, the volume of liquid can be metered to containers, instead of filling them to their full capacity.

Technical considerations relevant to applicability

Widely applicable in the FDM sector.

Economics

In the example dairy, raw milk and waste water savings were GBP 88,640/year.
In the vegetable processing example quoted above, with the valves set for the optimum flow rate, the company saved about GBP 18,000/yr in water and waste water costs. The payback period was 3 months.

In the confectionery company, the modifications cost GBP 7,500 to implement, but the reduction in chocolate consumption was worth GBP 15,000/yr, giving a payback period of 6 months.

The improved management of water use in the ready-made meals company resulted in savings of GBP 3,000/yr in water and waste water costs, giving a payback of 10 weeks on the GBP 600 that was paid to install the meter.

Driving force for implementation
Reduced waste of materials and water and the associated cost savings. Reduced extra quantities provided and associated cost savings.

Example plants
Flow measurement and control is widely applied in the FDM sector.

Reference literature
[7, Environment Agency of England and Wales 2000], [10, Envirowise (UK) & Entec UK Ltd 1999], [20, Nordic Council of Ministers 2001]

2.3.3.2 Techniques related to cleaning

Processing equipment and production facilities are cleaned and disinfected periodically, with the frequency varying according to the products and processes. The aim of cleaning and disinfection is to remove product remnants from the foregoing process run, other contaminants and microorganisms in order to guarantee product quality, food safety, line capacity, heat transfer and optimum operation of the equipment. It can be carried out manually, e.g. using pressure cleaning or automatically, e.g. using CIP. Manual cleaning generally requires the dismantling of the equipment to be cleaned.

2.3.3.2.1 Dry cleaning

Description
Removal of as much residual material as possible from raw materials, vessels, equipment and installations before they are cleaned with liquids, e.g. by using compressed air, vacuum system, catchpots with a mesh cover.

Technical description
As much residual material as possible can be removed from vessels, equipment and installations, before they are wet cleaned. This can be applied both during and at the end of the working period. All spillages can be cleaned up, by, e.g. shovelling or vacuuming spilt material or by using a squeegee, prior to wet cleaning, rather than hosing them down the drain. This reduces the entrainment of material into water, which would consequently have to be treated in a WWTP. This is enhanced further by transporting materials such as ingredients, by-products and waste from processing as dry as possible.

Dry cleaning is facilitated by, e.g. providing and using catchpots with a mesh cover, making sure suitable, dry clean-up equipment is always readily available and providing convenient, secure receptacles for the collected waste. Catchpots may be locked in place to ensure that they are in place during cleaning. As well as manual dry cleaning of equipment and installations, other measures can be used, such as letting materials drain naturally, by gravity, into suitably located receptacles and by using pigging (see Section 2.3.3.2.6).
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The cleaning procedure can be managed to ensure that wet cleaning is minimised and that the necessary hygiene standards are maintained. For example, the use of hoses can be prohibited until after dry clean-up.

Achieved environmental benefits
Reduced water consumption and volume of waste water. Reduced entrainment of materials in waste water and, therefore, reduced emission levels of, e.g. COD and BOD. Increased potential for the recovery and recycling of substances generated in the process. Reduced use of energy needed to heat water for cleaning. Reduced use of detergents.

Cross-media effects
Increased solid waste.

Environmental performance and operational data
It is common practice for the staff involved in cleaning to remove floor drain grates and hose raw materials and product directly down the drain, perhaps believing that a subsequent screen or catchpot will trap all solids. However, when these materials enter the waste water stream they are subjected to turbulence, pumping and mechanical screening. This results in the breakdown and release of soluble BOD, along with colloidal and possibly suspended grease solids. Subsequent removal of this soluble, colloidal and suspended organic matter can be far more complicated and expensive than the use of simple catchpots with mesh covers.

Applied examples of this technique are:

- in sausage making, ground meat residues from equipment such as bowl choppers, sausage fillers and from floors can be manually removed, to the maximum practical extent prior to cleaning and sent, e.g. to a rendering installation, instead of being washed into the WWTP.
- in fish processing, dry cleaning of belts can be undertaken and result in less waste and water pollution being produced.
- in fruit and vegetable processing, product losses throughout the process, can be shovelled up and sent for use as animal feed;
- the residues from wine processing, e.g. grape stems, pomace, marcs and lees can be collected separately before cleaning the equipment with water;
- catchpots over floor drains can be used to keep residues, e.g. grain and fruit skins, out of the drainage system;
- grain dust can be collected by vacuum systems in, e.g. flour mills, animal feed mills, breweries and distilleries;
- floors and open equipment can be pre-soaked to loosen dirt before cleaning;
- residual materials from pipework can be removed using compressed air, before cleaning or product changeover.

When cleaning dusty materials, it is important to consider the risks associated with fire and explosion and with occupational health. Immediate removal may be necessary to safeguard hygiene and prevent microbiological risks.

When cleaning equipment, it is important to consider the risks associated with access to hazardous moving parts and to sharp edges.

Technical considerations relevant to applicability
Applicable to all FDM installations.

Driving force for implementation
Reduced energy and water use, reduced need for waste water treatment and lower detergent use and expenditure.

Example plants
Many installations apply some dry cleaning prior to wet cleaning.
2.3.3.2.2  Fit cleaning hoses with hand operated triggers

**Technical description**
Trigger control shut-offs can be fitted to cleaning hoses with no other modification, if a water heater is used to provide hot water. If a steam and water blending valve is used to provide hot water, it is necessary to install check valves to prevent steam or water from entering the wrong line. Automatic shut-off valves are often sold with nozzles attached. Nozzles increase the water impact and decrease the water flowrate.

**Achieved environmental benefits**
Reduced water and energy consumption.

**Environmental performance and operational data**
In an example installation, the energy saved was calculated for running a hose that had been fitted with an automatic shut-off valve and nozzle, using water at a temperature of 71 °C. The flowrate before installation was 76 l/min and after installation was 57 l/min. The time the hose was running was 8 h/d before installation and 4 h/d afterwards. For a water cost of USD 21/m³, an annual water cost saving of USD 4,987 (costs in 2000) was calculated. An annual energy saving of 919 GJ has also been calculated.

**Technical considerations relevant to applicability**
Applicable to all FDM installations.

**Economics**
If nozzles are installed without automatic shut-offs, the equipment costs are less than USD 10. An automatic trigger controlled shut-off with a nozzle costs approximately USD 90. (Costs in 2000). The payback is reported to be immediate.

**Driving force for implementation**
Reduced water and energy costs.

**Example plants**
Widely applied.

**Reference literature**
[1, CIAA 2002], [8, Environment Agency of England and Wales 2000], [14, VITO et al. 2001], [20, Nordic Council of Ministers 2001], [71, AWARENET 2002]

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2.3.3.2.3  High-pressure cleaning using a centralised water ring main

**Description**
Water is sprayed onto the surface to be cleaned at pressures ranging from 15 bar to 150 bar.

**Technical description**
In high-pressure cleaning, water is sprayed onto the surface to be cleaned at pressures ranging from 15 bar, which is considered to be low pressure, up to 150 bar, which is considered to be high pressure. A pressure of about 40 to 65 bar has also been described as high.

Mobile pressure cleaning machines require longer downtimes than those supplied from a ring main. Diesel operated pressure cleaners emit fumes, which make them unsuitable for use inside FDM installations. Electrically operated pressure cleaners require additional operator safety precautions, including residual current devices and high maintenance. Mobile machines reportedly also use more water.
Cleaning agents are injected in the water, at moderate temperatures of up to 60 °C. An important part of the cleaning action is due to mechanical effects. Pressure cleaning reduces water and chemical consumption compared with mains hoses. It is important, however, that a pressure that is both safe and efficient is used. There is concern in the food industry about the hygiene implications of over-splash and aerosols associated with the use of high pressure hoses.

High and medium pressure cleaners have the following advantages compared with low pressure cleaners, i.e. water use is lower due to the mechanical cleaning action of the water jet; chemical use is lower because heavy soiling is removed by the action of the water jet and the reduction in water volume means that there is less of a breeding ground for bacteria. However, there can be concerns about the increased aerosol risks with higher water pressures.

Research has shown that even low pressure systems can cause a significant level of aerosol above the height of 1 metre and should not, therefore, be used during production periods in hygiene sensitive areas. Dry clean-as-you-go systems can be used and these not only reduce water consumption and optimise waste disposal, but reduce the risks of slipping accidents. Outside of production periods, both high and low pressure systems can be used safely, but because of its better efficiency, a high pressure system is more cost effective. High pressure cleaning is reported to be fast, easy to use, efficient and cost effective.

Achieved environmental benefits
Reduced water and chemical consumption, compared to traditional hoses and to low pressure high volume pressure cleaning.

Environmental performance and operational data
Ring mains have the advantage that they are always available for use. When using high pressure cleaning, it is important that the correct balance is achieved between the pressure; water volume where the water is sprayed; the water temperature and chemical dosing for each particular application. Inadequate pressure may result in poor cleaning and excessive pressure will increase the risk of damage to surfaces and equipment and even of injury to people.

Technical considerations relevant to applicability
Widely applicable in the FDM sector.

Economics
The cost savings in steam, water and waste water, of high pressure/low volume systems compared with low pressure/high volume systems are reported to be around of 85 %. Reduced costs associated with reduced consumption of chemicals.

Example plants
Widely applied.

Reference literature
[ 9, Envirowise (UK) 1998 ]

2.3.3.2.4 Low-pressure foam and/or gel cleaning

Description
Use of low-pressure foam and/or gel instead of water to clean walls, floors and/or equipment surfaces.

Technical description
Low pressure foam cleaning can be used instead of traditional manual cleaning with water hoses, brushes and manually dosed detergents. It can be used to clean walls, floors and equipment surfaces. A foam cleaner, such as an alkaline solution, is sprayed on the surface to be
cleaned. The foam adheres to the surface. It is left for about 10–20 minutes and is then rinsed away with water.

Low pressure foam cleaning can either use a centralised ring main or decentralised individual units. Centralised systems supply pre-mixed cleaning solutions and pressurised water from a central unit and during cleaning they automatically change between foam spreading and rinsing. Mobile pressure cleaning machines require longer downtimes than those supplied from a ring main. Diesel operated pressure cleaners emit fumes, which make them unsuitable for use inside FDM installations. Electrically operated pressure cleaners require additional operator safety precautions, including residual current devices and high maintenance. Mobile machines reportedly also use more water.

**Achieved environmental benefits**
Reduced water, chemical and energy consumption compared to the use of traditional water hoses, brushes and manually dosed detergents.

**Environmental performance and operational data**
A dairy in Denmark, producing 25 000 tonnes of cheese per year, has a centralised system consisting of about 50 satellite units, located in the different process areas. The water consumption has been calculated to be 40% of the corresponding consumption for traditional manual cleaning. The foam cleaning system reportedly uses cold water at 10 °C, whereas manual cleaning with water hoses requires water of at least 40 °C. The calculated savings in this case are 19 800 m³ water/yr and 1 160 MWh/yr.

Reported advantages of using foams include increased contact time with soiled surfaces, which allows improved cleaning results to be achieved, even though less aggressive chemicals are used. The chemical constituents soften soiling, resulting in improved rinsing efficiency and cleaning. It is easy to see where foams have been applied and they are very easy to rinse, so less water is used. Labour costs are also reduced because, compared with traditional methods, cleaning takes less time. Due to less aggressive chemicals being used, there is reduced wear and tear on machinery and reduced risk to the operator. A potential disadvantage of using foams is that their bulky nature can cause them to shear from surfaces under their own weight, so reducing the contact time.

Cleaning with gels provides a longer contact time than foams, between the soiling and active detergent, because of the tenacious nature of gels with surfaces and there is greater accessibility to crevices as access is not inhibited by air bubbles. However, gels are transparent and difficult to see and may be inconsistent at high temperatures.

Reported advantages of using gels include increased contact time with soiled surfaces, which allows improved cleaning results to be achieved, even though less aggressive chemicals are used. The chemical constituents soften soiling, resulting in improved rinsing efficiency and cleaning. As gels are very easy to rinse, less water is used. Labour costs are also reduced because, compared with traditional methods, cleaning takes less time. Due to less aggressive chemicals being used, there is reduced wear and tear on machinery and reduced risk to the operator.

Gels are typically used for cleaning walls, ceilings, floors, equipment and containers. The chemical is sprayed onto the surface to be cleaned.

**Technical considerations relevant to applicability**
Applicable in new and existing installations, for cleaning floors, walls, vessels, containers, open equipment and conveyors.
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Economics
The investment cost of the foam cleaning system in an example cheese installation in Denmark (reported in 2000) was about EUR 188 000, with a payback time of 3.2 years.

Driving force for implementation
Better cleaning and the elimination of problems associated with high pressure cleaning, e.g. spreading of aerosols containing dirt particles and bacteria.

Example plant
At least one cheese installation in Denmark.

Reference literature
[9, Envirowise (UK) 1998], [21, Nordic Council of Ministers 2001]

2.3.3.2.5 Optimised design and construction to facilitate cleaning

Description
This can be achieved by spillage collection devices, reduction of pipelines, closed loops, better design of nozzle system, etc.

Technical description
The hygienic design is a set of design and construction criteria that improve the cleanability of equipment and facilities, by avoiding critical points and dead-zones where the product may be retained and cannot be removed properly using standard sanitation (cleaning and/or disinfection). The prefix 'eco' refers to additional design criteria intended to reduce the environmental impact during sanitation (i.e. spillage collection, reduction of pipelines, reuse of cleaning water in closed loops, etc.)

The main goal of hygienic design of equipment and facilities is hygiene, but it is also related to the reduction of the environmental impact of cleaning and disinfecting operations, requiring a lower input of water, energy and chemicals, to achieve the same level of hygiene. In other words, from the hygienic point of view, equipment and premises are hygienically designed and constructed if they minimise the risk of contamination of food being processed.

From the environmental point of view, equipment and premises hygienically designed and constructed reduce the environmental impact of their sanitation. Eco-hygienic design of equipment and installations is presented as a preventive technique to reduce the environmental impact of sanitation of food production equipment while maintaining the hygienic results of sanitation.

At the global level, there are two recognised groups working on hygienic design criteria and standards:

1) The European Hygienic Engineering & Design Group (EHEDG) has published several guidelines for hygienic design criteria that have become a reference for both equipment manufacturers and the food industry. These guidelines are online and are regularly updated and complemented by new documents in various languages.
2) 3-A SSI is an independent US corporation dedicated to education and the mission to promote food safety through hygienic equipment design in the food, beverage, and pharmaceutical industries (http://www.techstreet.com/3a).

Achieved environmental benefits
Reduction in consumption of water, energy and chemicals.
Environmental performance and operational data
The data presented in this section come from the demonstration trials developed in the ECODHYBAT project in two Spanish companies: Calidad Pascual (dairy products) and Pescanova (sea product processing).

Table 2.42 shows the values of reduction of water and energy consumed during sanitation of hygienically designed equipment compared to the consumption levels during sanitation of conventional equipment.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Calidad Pascual (dairy products)</th>
<th>Pescanova (sea product processing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction of direct water consumption</td>
<td>41 %</td>
<td>33 %</td>
</tr>
<tr>
<td>in sanitation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction of direct energy consumption</td>
<td>14 %</td>
<td>33 %</td>
</tr>
<tr>
<td>in sanitation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: [273, ANIA 2016]

The sanitation of 14 pieces of food industry equipment designed according to eco-hygienic design criteria were compared one by one to the sanitation of equivalent conventional equipment. The results on water savings in these demonstration trials is shown in Table 2.43.

The industrial equipment to be evaluated was artificially soiled using a soiling solution composed of a mixture of whole milk, fluorescein, ethanol and gluing additive. The performance of the sanitation in both hygienic designed and conventional designed equipment was determined by measuring the fluorescein concentration. The evolution of the fluorescein concentration over time allowed to measure the moment when the equipment was cleaned, and the comparison of the consumption of water and energy between hygienic designed and conventional designed equipment.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Range of water savings (%)</th>
<th>Water savings average (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calidad Pascual (dairy products)</td>
<td>9–75</td>
<td>41</td>
</tr>
<tr>
<td>Pescanova (sea product processing)</td>
<td>0–96</td>
<td>33</td>
</tr>
</tbody>
</table>

Source: [273, ANIA 2016]

Cross-media effects
The construction phase of some eco-hygienic designed equipment could potentially entail an increase in material, energy or water use compared to construction of conventional equipment (i.e. extra polishing in order to reduce the roughness of the surface). However, any extra consumption required would be clearly negligible in comparison to the consumption of the near daily sanitation over the total life cycle of food processing equipment (lifetime 10–20 years).

Technical considerations relevant to applicability
Eco-hygienic design should not modify the technical performance of the productive equipment with respect to the conventional designed models.
Economics

In the majority of the cases, the increase in the market price of eco-hygienic certified equipment (with EHEDG certification) compared to their conventional equivalents is below < 5% (data from a survey of machinery production companies carried out by the ECODHYBAT project). Related information is shown in Table 2.44.

Table 2.44: Market price of eco-hygienic certified equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Price, conventional (EUR)</th>
<th>Price, eco-hygienic certified (EUR)</th>
<th>Price increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump HCP 40-150</td>
<td>1670</td>
<td>1690</td>
<td>1.20</td>
</tr>
<tr>
<td>Ball valve DN 2”</td>
<td>198</td>
<td>208</td>
<td>5.05</td>
</tr>
<tr>
<td>Throttle valve - casting GGG40 + PTFE 2”</td>
<td>4.75–241.91</td>
<td>10–300</td>
<td>24–110</td>
</tr>
<tr>
<td>Single-seated valve–Aseptic version</td>
<td>511–1902</td>
<td>530–1930</td>
<td>1.5–3.9</td>
</tr>
<tr>
<td>Flexible tube (EUR/m)</td>
<td>7–27</td>
<td>11–35</td>
<td>30–57</td>
</tr>
<tr>
<td>2” metal connection with clamp</td>
<td>5</td>
<td>14</td>
<td>180</td>
</tr>
<tr>
<td>Sensor VEGABAR 64</td>
<td>1580</td>
<td>1619</td>
<td>2.5</td>
</tr>
<tr>
<td>Electromagnetic flow meter</td>
<td>670–775</td>
<td>69–785</td>
<td>1.3–3.1</td>
</tr>
</tbody>
</table>

Source: [273, ANIA 2016]

Driving force for implementation

Reduction of costs associated with savings in water and energy consumption.

Example plants

Calidad Pascual (dairy products) and Pescanova (sea product processing) in Spain.

Reference literature

[273, ANIA 2016]

2.3.3.2.6 Pigging system for pipes

Description

Use of a system made of launchers, catchers, compressed air equipment, and a projectile (also referred to as a 'pig', e.g. made of plastic or ice slurry) to clean out pipes. In-line valves are in place to allow the pig to pass through the pipeline system and to separate the product and the rinsing water.

Technical description

Pigging can be used to recover valuable products from pipelines and to reduce water and waste water costs.

Pigging is a system which is built into the existing pipe system (see Figure 2.8). This makes it possible to put a 'pig' into the pipes to separate product and rinsing water between different batches of product. The end product can thus be collected and used in the production of the same or a similar product.
Figure 2.8: Pigging system

The system comprises launchers, catchers, compressed air equipment and in-line valves to allow the pig to pass through the system. One-piece, food grade rubber pigs, are propelled along from a launcher using compressed air and stopped at the other end of the pipe by a bar that allows product, but not the pig, to pass. The pig is returned to the launcher by using a valve to switch the direction of the compressed air. A window at either end of the pipe allows the pig to be seen by the operator. The pig is used between each batch, with additional system rinses being carried out when colour or flavour cross-contamination can occur. Occasional CIP cleans, e.g. using caustic, are used for hygiene reasons.

An innovative method using ice slurry has recently been rolled out with significant environmental and productivity benefits. This method involves using crushed pumpable ice as a semi-solid object to clean pipes. Rather than flushing food pipes and tanks with liquid water (prior to the use of detergents such as caustic soda), the ice slurry is driven through the system which is far more efficient in mechanically recovering residual product [275, COM 2015].

Achieved environmental benefits
Reduced product losses during batch changeovers and cleaning; reduced water consumption for cleaning and a lower quantity of waste water that is also less contaminated.

Environmental performance and operational data
With the application of this technique in an example juice installation (#153), significant reductions in water consumption for cleaning and subsequent waste water production have been achieved.

An example jam manufacturer installed a new pigging system. Installation and operator training were carried out on site with assistance from the supplier. Regular checks made in the company’s laboratory show that the new system did not compromise hygiene standards or affect product quality.

An example jam installation normally makes jam for bulk sale in 2.5 tonne batches [27, Envirowise (UK) 2000]. The cooked jam is held in two high temperature kettles, before being pumped to holding tanks next to the loading bay, where the batch can be kept warm. Then it is pumped into a bulk tanker, or cooled for transfer into intermediate bulk containers. In addition to cleaning for hygiene reasons, the pipes and vessels are cleaned between batches when colours change. For the bulk production process, the cleaning sequence was a water rinse of the whole system, CIP vessel clean, sometimes with caustic and a final water rinse of the whole system.
Before the pigging system was introduced, the whole system rinse involved sucking cleaning water, under vacuum, through the pipes between the pulping and evaporator vessels and the kettles, and then using the jam pump to pump the cleaning water through the pipe run to the tanker bay. As the jam pump was not designed to pump water, each flushing took some time. A large amount of water (5.4 m$^3$/clean) was also used, typically twice a day. Saleable product left in the pipe was pushed out by the flush water to drain. The site waste water thus had high TSS and COD emission levels.

Jam used to be wasted between batches on the bulk line. Following installation of the pigging system, there was an increased batch yield of jam. This resulted in some 173 tonnes of saleable product being recovered annually. The amount of mains water used to flush the bulk pipeline fell from 2020 m$^3$/yr to 310 m$^3$/yr. Waste water volumes from the bulk line decreased by the same amount. The reduction in average COD emission levels for the site waste water fell from around a peak of 25 000 mg/l to around 5 000 mg/l, meaning that unit costs fell by over 76 %, from EUR 12/m$^3$ to EUR 2.83/m$^3$. Further economic information is given in Table 2.45.

Although pigging is the most significant reason for the reduction in COD emission levels, the example company believes that there is also a significant contribution from the vacuum cleaning of sumps, gulleys and food traps. The pigging system required virtually no maintenance during the first year and no new pigs were needed. Due to wear and tear of the pigs, the company expect to replace a maximum of two each year. Energy consumption fell by around 680 kWh/yr because the compressed air mechanism required less energy than the old pumping arrangements.

The company recently installed three further pigging systems on other non-bulk manufacturing lines. Substantial cost savings are expected, together with a further reduction in waste water COD emission levels.

Line cleaning takes slightly less time with the pigging system than with the old system.

Technical considerations relevant to applicability
Applicable where viscous materials are transferred by pipeline, e.g. juices, or during the production of sweet and savoury preserves and the manufacturing of dairy products such as yoghurt.

Economics
An investment cost of EUR 130 000 was reported, with annual savings of EUR 66 000 (due to less waste being produced) [193, TWG 2015].

The annual costs and savings associated with the use of pigging in the example jam making installation are shown in Table 2.45.

<table>
<thead>
<tr>
<th>Item</th>
<th>Savings</th>
<th>Annual savings (EUR)</th>
<th>Annual costs (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced waste water COD and volume</td>
<td>76 %</td>
<td>167 000</td>
<td>-</td>
</tr>
<tr>
<td>Recovered product</td>
<td>173 t/yr</td>
<td>217 000</td>
<td>-</td>
</tr>
<tr>
<td>Reduced water use</td>
<td>1 710 2,020 m$^3$/yr</td>
<td>2 000</td>
<td>-</td>
</tr>
<tr>
<td>Reduced energy consumption</td>
<td>-</td>
<td>48</td>
<td>-</td>
</tr>
<tr>
<td>Gulley cleaning, etc.</td>
<td>-</td>
<td>-</td>
<td>6 200</td>
</tr>
<tr>
<td>Replacement pigs (2/yr)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>386 048</td>
<td>6 380</td>
</tr>
<tr>
<td>Net cost savings</td>
<td>-</td>
<td>-</td>
<td>379 668</td>
</tr>
<tr>
<td>Total capital cost</td>
<td>-</td>
<td>-</td>
<td>30 800</td>
</tr>
<tr>
<td>Payback period</td>
<td>-</td>
<td>4.2 weeks</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: [27, Envirowise (UK) 2000]
Driving forces for implementation
Recovery of valuable product and reduced water and waste water treatment costs.

Example plants
Widely used in the FDM sector [193, TWG 2015]. At least one jam making installation in the UK.

Reference literature
[1, CIAA 2002], [27, Envirowise (UK) 2000], [193, TWG 2015], [275, COM 2015]

2.3.3.2.7 Optimisation of CIP (cleaning-in-place)

Description
Ensuring that CIP is optimised, e.g. by:
- measuring turbidity, conductivity, temperature or pH to dose water and chemicals in optimised quantities;
- reuse of water and chemicals.

Technical description
CIP systems are cleaning systems that are incorporated into equipment and can be calibrated and set to use only the required quantities of detergents and water at the correct temperature (and sometimes pressure) conditions. CIP systems can also be optimised by incorporating the internal recycling of water and chemicals; carefully setting operating programmes, which coincide with the real cleaning requirements of the process; using water efficient spray devices and by removing product and gross soiling prior to cleaning. Equipment correctly designed for CIP cleaning should have spray balls located so that there are no “blind spots” in the cleaning process. CIP systems can be much more efficient than manual cleaning, but they need to be designed and used to optimise their potential advantages.

Design and operational features which increase the efficiency of the CIP system include:
- using a turbidity or conductivity detector to optimise both the recovery of material/product from water and the reuse of cleaning water, during pre-rinsing (see Sections 2.3.1.5 and 2.3.1.6);
- measuring pH to optimise chemical consumption.

Additional features to optimise CIP include:
- dry product removal before the start of the wet cleaning cycle by, e.g. gravity draining, pigging (see Section 2.3.3.2.6) or using compressed air;
- pre-rinsing using small quantities of water, which, in some circumstances, may be combined with either returning the pre-rinse-water to the process for reuse or recovering it for disposal;
- optimising the CIP programme for the size of plant/vessel and type of soiling, with respect to chemical dosing, water consumption, temperature, pressure and cleaning and rinsing times;
- internal recycling of water and chemicals;
- reusing of intermediate/final water for pre-rising;
- recycle control based on conductivity (see Section 2.3.1.5) rather than time;
- water efficient spray devices;
- correct selection of CIP detergents;
- collection and reuse of CIP detergents: instead of discharging to waste water after each CIP, the detergents are collected in tanks to be reused; new detergent is fed continuously until the correct concentration is reached.
regeneration of caustic soda used in CIP. The pipes and tanks are flushed through with hot alkali as a first step resulting in a liquid very high in organic matter. The used caustic soda is then passed through a process in which a clay-based reagent is used to separate the alkali from the solids which forms a sludge.

It is common practice for the final rinse-water to be reused, either for pre-rinsing, intermediate rinsing or the preparation of cleaning solutions. The aim of the final rinse is to remove the last traces of cleaning solutions from the cleaned equipment. Clean water is used and the rinsing water, which returns to the central CIP unit, is clean enough to be reused, instead of being discharged to the drain. The recovery of the final rinsing water requires a connection from the CIP return pipe to the pre-rinsing tank. A conductivity transmitter is used to divert the water, e.g. to the pre-rinsing tank.

Secondary water from, e.g. RO and/or condensate may be suitable for direct use in pre-rinsing in CIP, or for other uses after treatment. The use of such water for pre-rinsing may depend on whether it is possible to recover materials for reuse in the process. If this is the case, then drinking water quality water is required.

The chemicals used in CIP are normally an alkaline solution, based on caustic, to detach and remove fat and protein layers and an acid solution, e.g. based on HNO$_3$, to detach and remove mineral layers. In many cases, the acid step is not required. Cleaning using only the caustic step, is sometimes called single-phase cleaning. Chelating agents, normally based on EDTA, are sometimes added to the alkaline solution to both prevent the precipitation that normally occurs when alkaline concentrates are diluted and to dissolve calcifications and deposits. The chelating agents and other additives can be harmful to the environment. Section 2.1.3.2.1 contains further information about the use of chelating agents, including EDTA. Some advantages of single-phase cleaning are, that it reduces water and energy consumption and increases the speed of cleaning. Using both acid and alkali cleaning solutions requires two cleaning solution tanks with additional pipework, intermediate flushing and consequently use more water and energy and take longer.

The choice of the cleaning agents used depends on a number of factors and cannot be determined in general. The simple basic materials such as caustic and HNO$_3$, as well as specially blended, ready-made cleaning agents are available for particular applications. Care should be taken to ensure that chemicals which are not really required are not used, e.g. chelating agents like detergents containing EDTA are not required for the cleaning of milk tankers and raw milk storage tanks.

An example of a CIP system is shown in Figure 2.9.
It is reported that parallel or serial cleaning of tanks and parallel cleaning of pipe systems need to be avoided. Both parallel and serial cleaning of tanks results in excessive mixing of pre-rinse and cleaning solution, and cleaning solution and final rinse. This limits the reuse of cleaning solution and energy. In a parallel configuration it can be difficult to achieve the required distribution of the flow through more than one tank and the CIP return from the tanks needs a different residence time. When switching from pre-rinse to cleaning solution or from cleaning solution to final rinse this results in a long mixing zone. In a serial configuration the content of the piping between tank I and II will result in a long mixing zone as well if the content is not drained. When the cleaning solution arrives in tank I (drained), the pre-rinse content of the piping may become mixed with cleaning solution in tank II (drained before).
Achieved environmental benefits
A reduction in the consumption of water, cleaning agents and the energy needed to heat the water are achievable because it is possible to set the consumption levels, specifying the use of only that required for the surface area to be cleaned. It is possible to maximise product recovery and reuse water and chemicals within the system. There is a subsequent reduction in the amount of waste water generated.

Environmental performance and operational data
Optimising the CIP systems can, e.g. minimise the quantity of the cleaning and disinfection agents used, by recirculating cleaning solutions. Some losses will still occur with contaminated water and solutions, therefore, still need to be recharged. For example, when the particulate content of cleaning solution reaches a specific level it will need to be disposed of. An additional effect of recirculating the solutions is that a partial recuperation of the thermal energy is possible.

In an example installation in Germany, the cleaning solution, i.e. 2 % caustic soda, is reused during the five or six working days of the week. The solution can be used for longer, e.g. weeks, if a storage tank is installed.

Figure 2.10 shows the CIP system for a bottling process in a brewery.

![CIP system for bottling process](image)

Figure 2.10: Use of a CIP system for the bottling process in a brewery

Turbidity meters can be used in CIP for phase changes between product and water. The conductivity of milk products and cream is very similar to that of water. It is easier to separate milk products and water and thus to control phase changes between milk products and water with turbidity meters. Therefore it is easier to control what should go to water milk and what should go to waste water. This will reduce the amount of product residues in the waste water.
Conductivity meters are used to control the phase changes between lye and water and between acid and water. Therefore it is easier to control what should go back to the cleaning solution tanks, what should go to waste water and what should be reused as rinsing water. In this way, the amount of water and the amount of cleaning solution discharged as waste water are reduced.

The use of flow meters in combination with preset volumes also reduces the amount of water needed.

Finally, frequency converters on cleaning pressure pumps can reduce the amount of energy needed.

Within a six-year implementation of CIP optimisation (collection and reuse of detergents) in a dairy installation (#127), consumption of water decreased to 55% and consumption of detergents decreased to 34%. In a brewery installation (#400), the application of one phase of CIP has resulted in a 30% reduction of water consumption for cleaning [193, TWG 2015].

Cross-media effects
Possible energy use associated with pumping the water and cleaning agents.

Technical considerations relevant to applicability
Applicable to closed/sealed equipment through which liquids can be circulated, including, e.g. pipes and vessels. Incorporation of a CIP system can be considered at the equipment design stage and installed by the manufacturer. Retrofitting a CIP system may be possible, but is potentially more difficult and expensive.

For large installations with highly branched pipework, a centralised CIP system may not be appropriate. Often, the distances are too long and this leads to considerable losses of heat, detergents and water, as well as excessive pumping capacities. In such cases, several small CIP systems can be used. These can be supplied with the necessary cleaning solutions from the centralised CIP system, via a closed pipeline.

For some applications, such as some small or rarely used installations or where the cleaning solution becomes highly polluted, such as UHT installations, membrane separation plants, and the preliminary cleaning of evaporators and spray dryers, single-use systems are used. In these systems, cleaning agents are not reused, because they may impede the cleaning effect in other installations.

Economics
The capital cost can be high but annual savings due to reduced water and chemical consumption are achieved.

Driving force for implementation
- Reduced costs of water, energy and chemicals.
- Automation and ease of operation. Reduced requirement to dismantle and reassemble equipment.

Example plants
CIP is widely used in the FDM sector. For example, an online detection of transition points between the product and the water phases is implemented for the recovery of product from CIP in a dairy installation (#341) [193, TWG 2015].

CIP is used in many dairies and breweries and in the manufacture of instant coffee. It is also used to clean the equipment used for the stabilisation of wine.

Reference literature
[1, CIAA 2002], [5, German Dairy Association 1999], [21, Nordic Council of Ministers 2001], [130, Portugal-FIPA 2003], [134, German Dairy Association 1997], [144, CIAA-EDA 2003], [193, TWG 2015], [275, COM 2015]
2.3.3.2.8 Optimisation of manual cleaning

Description
Ensuring that the water consumption of manual cleaning is reduced. This includes:
- monitoring of water consumption;
- water pressure controls and water-efficient spray nozzles for hoses;
- cleaning as soon as possible after use to prevent wastes hardening.

Technical description
For additional information please consult the Sectoral Reference Document on Best Environmental Management Practices for the food and beverage manufacturing sector [275, COM 2015].

Achieved environmental benefits
Reduced water consumption and waste water pollution.

Technical considerations relevant to applicability
Applicable to all installations where manual cleaning is applied.

Economics
Reduced water consumption and waste water treatment costs.

Example plants
This technique is widely applied in the FDM sector.

Reference literature
[275, COM 2015]

Using metered water dispensers and/or high pressure low volume sprays for cleaning trucks

Technical description
Using metered water dispensers and/or high pressure low volume sprays for cleaning trucks can reduce water consumption and waste water pollution.

Achieved environmental benefits
Reduced water consumption and waste water pollution.

Environmental performance and operational data
Grape containers are reportedly cleaned using this technique. The cleaning water is drained.

Technical considerations relevant to applicability
Applicable to FDM installations where materials are delivered in trucks.

Economics
Reduced water and waste water treatment costs.

Example plants
Used in wine processing installations.

Reference literature
[71, AWARENET 2002]

Pre-soak floors and open equipment to loosen dirt before cleaning

Technical description
Floors and open equipment can be pre-soaked before being wet cleaned. This can loosen the dirt and, therefore, make subsequent cleaning easier. E.g. less water, at high pressure and/or high temperature, may be required to dislodge hardened or burnt-on dirt and the use of chemical cleaning substances, such as caustic, may be minimised.

**Achieved environmental benefits**
Depending on the circumstances, the consumption of water and energy for heating water may be reduced. The consumption of chemicals may be reduced.

**Technical considerations relevant to applicability**
Applicable where hardened or burnt-on dirt needs to be removed during cleaning.

**Reference literature**
[1, CIAA 2002]

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**Removal of residual materials from pipework, using compressed air, before cleaning or product changeover**

**Technical description**
Food quality compressed air can be used as a dry cleaning technique to remove residual materials from pipework, taking care not to raise dust emission levels in the workplace. Some advantages of the technique include that it can be used to gain access to parts of equipment where pigs (see Section 2.3.3.2.6) cannot physically pass and any risk of contamination from introducing cleaning tools or equipment can be avoided.

**Achieved environmental benefits**
Reduced product losses during batch changeovers and cleaning; reduced water consumption for cleaning and a lower quantity of waste water that is also less contaminated.

**Cross-media effects**
Energy is consumed to produce compressed air.

**Environmental performance and operational data**
To minimise the amount of residual butter in the pipework of butter-making equipment, compressed air can be used to push a block of cooled butter through the pipework and valves at the end of production, before the cleaning. This works in a very similar way to pigging, but is possible in parts of the equipment inaccessible to pigs.

**Technical considerations relevant to applicability**
Applicable in installations where powders and other solids are transported using compressed air and where hard, but compressible foods can fill a space and physically force materials through that space.

**Driving force for implementation**
Minimisation of product waste.

**Example plants**
Butter-making dairies in Germany.

**Reference literature**
[35, Germany 2002]

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**Management of water, energy and detergents used**

**Description**
Chapter 2

If the consumption of water and detergents, and the cleanliness is recorded on a daily basis, it is possible to detect deviations from normal operation and then to monitor and plan ongoing efforts to reduce the future consumption of both water and detergents without jeopardising hygiene. This applies to all cleaning, whether it is manual, e.g. using pressure cleaning, or automated, e.g. using CIP.

Trials can also be undertaken, e.g. using less or no detergents; using water at different temperatures; using mechanical treatment, i.e. the use of “force” both in the water pressure, and from using tools such as scouring sponges and brushes.

Monitoring and controlling the cleaning temperatures can enable the required cleaning standard of equipment and installations to be achieved without the excessive use of cleaning agents.

An important part of preventing the overuse of water and detergents on an ongoing basis is ensuring that staff are trained in the handling, and making up of solutions and their application. For example, they should not make cleaning solution concentrations too high, either by pouring too much during manual dosing or by setting automatic dosing systems too high. This can happen easily, through lack of training and supervision, particularly during manual dosing.

Achieved environmental benefits
Potential reduced consumption of water and detergent and of the energy required to heat the water. The reduction potential depends on the cleaning requirements at each part of the installation or equipment to be cleaned.

Environmental performance and operational data
Inadequate hygiene controls cause food safety problems, which can result in product rejection or a shortened shelf life. Improvements in cleaning techniques can be achieved by, e.g. using flow restrictions on the water supply and regulating the water pressure from high pressure to medium and low pressure for night and day cleaning, respectively. The frequency of wet cleaning can also be assessed with the objective of reducing the number of full wet cleans. In some installations, one full wet clean per day may be sufficient to maintain the required hygiene level.

The planning of equipment cleaning frequency and duration can take into account its size and complexity and the type and degree of soiling.

Technical considerations relevant to applicability
Applicable to all FDM installation.

Economics
The technique can result in reduced water, energy and detergent costs.

Driving force for implementation
Reduced water, energy and detergent costs.

Reference literature
[1, CIAA 2002], [8, Environment Agency of England and Wales 2000]

Supply of pressure-controlled water and via nozzles

Technical description
Pressure cleaning is used for cleaning floors, walls, vessels, containers, open equipment and conveyors and as a rinsing stage following cleaning and the application of chemicals. Both cold and hot water can be used, depending on the cleaning needs.

Where a supply of water is essential, it can be supplied through nozzles (see Section 2.3.3.1.3) fitted to the equipment for processing or fitted to hoses used for cleaning equipment and/or installations. For cleaning operations, the water may be supplied to the hoses from a ring main.
Nozzles fitted to processing equipment are designed and positioned for each individual cleaning application.

**Achieved environmental benefits**
Reduced water consumption. Where heated water is used, the overall energy consumption can be reduced.

**Environmental performance and operational data**
The water flowrate at each nozzle can be set by the management, depending on the application. Also, the water pressure can be adjusted according to the cleaning operation requiring the highest pressure and a suitable pressure regulator can be installed at each of the other cleaning stations which require water. The water consumption can be optimised by monitoring and maintaining the water pressure and the condition of the water spray nozzles.

**Technical considerations relevant to applicability**
Applicable in all FDM installations, according to in-line, general operational and cleaning needs.

**Driving force for implementation**
Reduced water consumption.

**Reference literature**
[1, CIAA 2002]

### Cleaning with gels

**Technical description**

**Achieved environmental benefits**
Reduced water, chemical and energy consumption compared to the use of traditional water hoses, brushes and manually dosed detergents.

**Environmental performance and operational data**

**Technical considerations relevant to applicability**
Applicable in new and existing installations, for cleaning floors, walls, vessels, containers, open equipment and conveyors.

**Driving force for implementation**
Elimination of problems associated with high pressure cleaning, e.g. spreading of aerosols containing dirt particles and bacteria.

**Reference literature**
[9, Envirowise (UK) 1998]

### 2.3.3.3 Techniques related to cooling/freezing

#### 2.3.3.3.1 Closed-circuit cooling

See also Section 2.3.3.1.1.

**Description**
Recirculation of cooling water via a cooling tower or a cooler connected to a central refrigeration plant.
Chapter 2

Technical description
Water is used to cool, e.g. a pasteuriser or a fermenter. The water is recirculated via a cooling tower or a cooler connected to a central refrigeration plant, i.e. it is re-chilled and returned to the equipment being cooled. If there is a need to prevent algae or bacterial growth, chemicals may be added to the recirculated water. Otherwise, the cooling water can be reused for cleaning purposes.

Achieved environmental benefits
Reduced water consumption and reduced waste water treatment.

Environmental performance and operational data
It is reported that closed-circuit cooling can save 80 % of water consumption, compared to an open system. This may be significant in areas where water is not readily available. Once-through cooling water which does not contact the FDM materials will not entrain contaminants and may be considered for direct discharge to a receiving water body, however, it will carry a thermal load. Passing once-through uncontaminated cooling water through a WWTP both increases energy consumption and causes dilution, without decreasing the overall load, so direct discharge is advantageous.

In an example brewery with a capacity of 500 000 hl/yr, a closed circuit cooling system was introduced in a tunnel pasteurisation unit to replace an open system which cooled using fresh water. The reduction in water consumption was estimated to be 50 000 m³/yr.

For fermenter cooling, closed-circuit cooling using a chiller and a recirculation pump is reported to result in improved cooling.

In sugar production, cooling water is used on site for electricity generating turbines. Typically, cooling water will have been abstracted from a river and will pass around a turbine once before it is discharged back to the river.

Cross-media effects
Energy may be consumed to cool the cooling water. It may be possible to recover some of this heat.

In recirculating cooling tower systems, the cooling water is recycled constantly through a cooling tower. However, running the water over the cooling tower maintains a high dissolved oxygen level which can cause corrosion within the system, and evaporation of water at the tower can cause the build-up of suspended solids. The recirculating water may, therefore, require treatment to prevent corrosion and some of the water needs to be discharged periodically to prevent build-up of excess dissolved solids. Precautions also need to be taken to control the conditions for growth of Legionella bacteria, which may make the spray from cooling towers a possible source of legionnaires’ disease. Closed-circuit systems minimise corrosion and there is no build-up of dissolved solids.

If a large water source, such as a large volume flow river is available, then the cross-media effects associated with closed-circuit cooling may be greater. If the river can provide the volume required and accept the thermal load without significant harm to aquatic life or not interfering with other users of receiving surface water and the water does not become contaminated then once-through cooling may be a better environmental option. Once-through cooling water will also require energy to pump it from its source and out of the installation. If care is not taken to prevent leaks from the system being cooled, then contaminated water may be discharged.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
In a fermenter, the potential cost was reported to be medium, but the payback time short.
In the reported brewery example above, the investment cost of the installation of the cooling tower and other necessary equipment was USD 45 000 (before 1996) and the payback period was approximately a year.

**Driving force for implementation**
Reduced water consumption and subsequently reduced waste water and the associated financial savings.

**Example plants**
Applied in dairies, breweries, soft drinks manufacturing and sugar production from sugar beet.

**Reference literature**

### 2.3.3.3.2 Recirculation of cooling water after electrochemical treatment

See also Section 2.3.3.1.1.

**Description**
Recirculation of water from the cooling tower pond through a vessel containing electrodes made from a combination of metal oxides which act as anode where oxidising ions are generated from water.

**Technical description**
The technique involves recirculation of water from the cooling tower pond through a vessel containing electrodes made from a combination of metal oxides which act as anode where oxidising ions are generated from water. Furthermore, the vessel wall acts as cathode, reaching a pH of 13 in the wall which causes the precipitation of calcium salts on the vessel wall, preventing the concentration of salts in the tower pond and, therefore, preventing the need to purge water from the pond. Periodically, in a programmed way, the salty precipitate on the vessel wall is washed down and drained. By applying direct current voltage to electrodes in the chambers, OH\(^-\) ions are produced by partial electrolysis of the water. The addition of OH\(^-\) ions promotes a scale formation with the excess of Ca\(^{+2}\) and CO\(_3^{+2}\) ions in the chambers.

**Achieved environmental benefits**
Reduced water consumption and avoidance of the use of chemicals.

**Environmental performance and operational data**
In an example brewery (#157), 80 % of the cooling towers’ water consumption is reduced, and also 100 % of the chemical consumption, avoiding continuous chemical treatment. The maintenance and cleaning of equipment takes about half an hour per month.

This technique is generally efficient provided the characteristics of the water supply network do not fluctuate continuously.

**Driving force for implementation**
Limitations on the use of chemicals in operating licences.

**Economics**
An investment cost of EUR 40 000 and annual operating cost of EUR 2 400 have been reported, with annual savings of EUR 28 000 (for nine pieces of equipment for treating ten evaporating condensers).

**Example plants**
At least one brewery installation (#157).
2.3.3.4 Techniques related to bottling

2.3.3.4.1 Dry disinfection

Description
Disinfection of the bottles with gaseous nitrogen peroxide without the use of water.

Technical description
The technology is based on the replacement of the blower and the filler by a single machine. Eliminating the distance between these two machines allows the removal of the air conveyors that were used to carry the empty PET bottles from the blower to the filler.

The bottle disinfection system is also evolving. The classic technique uses water and peracetic acid to rinse and disinfect the bottle. Even if the disinfection solution is reused several times, this technique generates a huge volume of waste water. With the new dry filling machine, nitrogen peroxide is directly injected into the preforms before they are heated, the peroxide then vaporises during the heating and the blowing, producing an aseptic empty bottle. The bottles are directly filled and closed without using water.

Achieved environmental benefits
Reduced energy and water consumption.

Environmental performance and operational data
In a soft drinks installation (#279), the use of the dry bottling technology contributed to an increased in the total water recycled in the installation.

Cross-media effects
Consumption of nitrogen peroxide.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
An investment cost of EUR 6 million has been reported for a soft drink and nectar juice installation with a permitted production capacity of 1 000 tonnes/day.

Example plants
Installation # 279.

Reference literature
[ 193, TWG 2015 ]

2.3.3.5 Techniques related to steam systems

2.3.3.5.1 Maximisation of condensate return

See also Section 2.3.3.1.1.

Description
Recovered condensate can be reused as feed to the boiler, heated water, or heated water for equipment and cleaning other installations.
Technical description
In this technique, water and heat which is contained in discharge condensate is taken advantage of. This recovered condensate can be reused as feed to the boiler, heated water, or heated water for equipment and cleaning other installations. A condensate recovery unit is a vessel which receives condensate from all practical points where condensate is produced. The vessel stores the condensate and mixes it with fresh make-up water prior to it being used as boiler feed water.

If hot condensate is not returned to the boiler it has to be replaced by treated cold make-up water. The additional make-up water also adds to water treatment costs. Instead of routinely discharging condensate to the WWTP because of the risk of contamination, the condensate can be collected in an intermediate tank and analysed to detect the presence of any contaminant. This also leads to savings in the use of chemicals for the treatment of boiler feed-water. Additionally or alternatively, if the condensate cannot be returned to the boiler due to contamination, heat can be recovered from the contaminated condensate before it is used for lower grade cleaning activities, e.g. yard cleaning. Pollution can be detected by different devices (e.g. turbidimeter). In general, the temperature of recovery condensates is about 100 ºC to 180 ºC. Mechanical pumps can be used in all situations in which the condensates generated do not have enough pressure to be returned to the feeding tank.

The energy in any steam used for direct injection to the process may be considered to be fully utilised.

Achieved environmental benefits
Reduced energy and water consumption and reduced waste water generation. Reduced consumption of boiler feed-water treatment chemicals.

Environmental performance and operational data
If hot condensate is not returned to the boiler, it has to be replaced by treated cold make-up water and wastes some 20 % of the energy absorbed in the generation of the steam from which the condensate is derived. This may be the greatest single energy loss in steam use.

In an example dairy installation (#311), high-pressure steam condensation water, drained by condensation traps mounted before every user pressure reduction system, is routed back into the boilers' feed water tank. The total annual water demand is reduced by 3 %. In an example sugar manufacturing installation (#413), condensate generated during the campaign is stored on site and reused during non-operational periods to replace borehole-extracted water, where borehole-extracted water quality is not required [193, TWG 2015].

Technical considerations relevant to applicability
Applicable where steam is produced in a boiler.

Economics
An investment cost of EUR 50 000 (EUR 45 000 for the pipeline return system and EUR 5 000 for the project and design) and payback periods of 1–4 years have been reported.

Driving force for implementation
Reduced energy consumption and associated costs.

Example plants
Used in various FDM sectors [193, TWG 2015].

Reference literature

Multistage bottle cleaning system
Technical description
In an example installation, carbon dioxide neutralisation lowered the pH to 7.5–8. The neutral pH enhances the efficiency of the disinfectants, and considerably reduces the need for chemical agents.

The neutralised water is pumped from the second hot water zone (tank 2) and is added to the closed cooling circuit to cool the spray water. This cools the cleaning water in this zone. The cooled water is then fed back into the second hot water zone (tank 2).

Achieved environmental benefits
Reduced water consumption and consequently waste water volumes. Reduction in waste water contamination loads, due to reduced chemical consumption. Reduced energy consumption. Reduction in transport, storage and handling of chemicals. The pH of the waste water is optimised.

Environmental performance and operational data
The water consumption per bottle cleaned was cut from 530 to 264 ml (51%) in the example installation, with a consequent reduction in the waste water volume. The water consumption will vary depending on the size of the bottles and how dirty they are. Apart from the high water consumption, other disadvantages of the older bottle cleaning machines were, e.g. scale formation in the hot water zones and alkali entrainment; the need for expensive complexing agents and disinfectants and the fact that these chemicals can get into the waste water. These are eliminated with this multistage combination process. Even with a 51% reduction in fresh water input, the return of the cooled water still ensures reliable cooling of the bottles.

Technical considerations relevant to applicability
This system can replace bottle cleaning machines in existing bottling lines. For example, this process can be applied to all older bottle cleaning machines that have a water consumption of more than 400 ml per bottle cleaned, e.g. 80% of the bottle cleaning machines in use in the German soft drinks sector are models of this kind.

It is reported that to ensure adequate cleaning quality, it is not realistic to work on the basis of a target water consumption of less than 200 ml per bottle cleaned. New models need only 150 ml of cleaning water per bottle cleaned. There is thus no potential saving for these machines.

Economics
To achieve an acceptable payback period, a water saving of at least 200 ml per bottle cleaned is needed.

Driving forces for implementation
Reduction in water, cleaning and disinfection agents consumption and costs.

Example plants
At least one soft drinks manufacturer in Germany.

Reference

Reuse of bottle cleaning solutions after sedimentation and filtration

Achieved environmental benefits
Reduced caustic soda and fresh water consumption. Reduced pollution of waste water.

Cross-media effects
Energy consumption, e.g. for pumping.

Environmental performance and operational data
The outputs which are not reused, e.g. waste water and sediment, are neutralised with carbonic acid. Alternatively, sulphuric acid ($H_2SO_4$) can be used. Using hydrochloric acid (HCl) could lead to the production of acidic vapours. If the pH is lower than 10, neutralisation is normally not necessary. If the neutralisation is made using CO$_2$, room ventilation needs to be installed.

**Economics**
Savings in water and caustic soda costs. Reduced waste water treatment costs.

**Driving forces for implementation**
Cost reduction.

**Reference literature**

**Optimisation of water consumption in bottle cleaning**

**Technical description**
In an example brewery in Denmark, the rinsing water flow for bottle cleaning is measured (see Section) and automatic valves are installed to interrupt the water supply in case the line stops (see Section 2.3.3.1.2). Fresh water is used in the last two rows of the rinsing nozzles.

Final rinse water can be reused for the pre-rinse or other stages when cleaning bottles, cans or other containers. Where water ring vacuum pumps are used in the filling operation, contamination of the seal water can be minimised so that it can be reused as rinse water.

**Achieved environmental benefits**
Reduced water consumption and waste water load.

**Environmental performance and operational data**
In the example brewery, water consumption volumes of about 0.5 hl/hl of beer were reported.

**Technical considerations relevant to applicability**
Applicable to all FDM installations where bottles are cleaned for filling, e.g. preserves, soft drinks, wine manufacturing, breweries and dairies.

**Example plants**
At least one brewery in Denmark.

**Reference literature**
[8, Environment Agency of England and Wales 2000], [29, Danbrew Ltd 1996]

**Techniques related to preservation in cans, bottles and jars**

**Batch sterilisation after filling of cans, bottles and jars**

**Technical description**
The filled and sealed cans, bottles and jars are placed in baskets in a steriliser, e.g. a batch wise operated autoclave and heated to a set temperature for a required time to ensure proper sterilisation and preservation of the product. Some foods can also be cooked during this process. After sterilisation, cans, bottles and jars are cooled down to 25–35 °C with chlorinated water.

**Achieved environmental benefits**
Reduced water consumption and waste water generation.

**Cross-media effects**
The waste water may contain some traces of oil, sauces and brines after sterilisation, if the cans have not been cleaned properly first.

Environmental performance and operational data
To minimise water use, autoclaves with water storage facilities are used. In addition, the water is recirculated for cooling the cans and reused in cleaning operations when it can no longer be used in sterilisation.

Technical considerations relevant to applicability
Widely applicable in the FDM sector, e.g. in the preservation of meat, fish, crustaceans, molluscs, vegetables, milk, beer and oil.

Reference literature
[71, AWARENET 2002]

Continuous sterilisation after filling of cans, bottles and jars

Technical description
Continuous sterilisers enable close control over processing conditions and so produce more uniform products. They produce gradual changes in pressure inside the cans, bottles and jars and, therefore, less strain on the seams compared with batch equipment. Continuous sterilisers, e.g. cooker coolers, can vary slightly in design and size and operate continuously. Some models can accommodate up to 25,000 cans, bottles or jars. They carry them on a conveyor through three sections of a tunnel that are maintained at different pressures for preheating, sterilising and cooling. The food can be cooked during preheating and sterilising.

Achieved environmental benefits
Reduced water and energy consumption. Reduced waste water generation.

Cross-media effects
The waste water may contain some traces of oil, sauces and brines after sterilisation, if the cans, bottles or jars have not been cleaned properly first.

Environmental performance and operational data
When using a continuous steriliser, e.g. cooker cooler, the water is reused continuously and water is added, as required, to replace the minimal evaporation loss, thereby controlling the amount of water and energy consumed. The water is reused for cleaning when it can no longer be used in sterilisation.

The main disadvantages of continuous sterilisation include a high in-process stock which would be lost if a breakdown occurred, and in some cases of metal corrosion and contamination by thermophilic bacteria may occur, if adequate preventive measures are not taken.

Technical considerations relevant to applicability
Widely applicable in the FDM sector, e.g. in the preservation of meat, fish, crustaceans, molluscs, vegetables, milk, beer and oil.

Reference literature
[71, AWARENET 2002], [138, Fellows P.J. 2000]

Water bath oven – cooking water

Technical description
Water bath ovens allow the best homogeneity of heating to be obtained. Nevertheless, the immersion into hot water causes weight loss and results in proteins and fat being released into the water. This can be skimmed to recover by-products and to avoid it contaminating the waste water. This also increases the potential for cooking water reuse. Cooking water reuse can also be increased by applying membrane systems to clean the water.
Achieved environmental benefits
Reduced water consumption. Reduced waste water pollution. Recovery of by-products from cooking water.

Cross-media effects
When cooking in a water bath oven, a large amount of water and energy are both needed.

Environmental performance and operational data
It has been reported that after the cooking of fish, approximately 3–4 g oil/kg fatty fish can be released into the water. By-products, e.g. fatty acids and flavours, are recovered from cooking water.

The use of a water bath oven for cooking meat, prior to canning, produces waste water contaminated with fat, protein and fragments of meat.

Technical considerations relevant to applicability
Widely applicable in the FDM sector, e.g. for meat, fish, shellfish and vegetables.

Reference literature
[52, Italy 2001] [71, AWARENET 2002]

Water bath oven—using water instead of brine

Description
Cooking in water instead of brine reduces the salinity of waste water.

Achieved environmental benefits
Reduced salinity of waste water.

Environmental performance and operational data
Cooking in brine may be necessary for some recipes.

Technical considerations relevant to applicability
Widely applicable in the FDM sector, e.g. for meat, fish, shellfish and vegetables.

Reference literature
[71, AWARENET 2002]

Shower oven

Description
Shower ovens allow a good uniformity of heating and use less water and energy than water bath ovens. They operate by the simultaneous heating action of water sent through the showers and from the saturated steam which rises from the heated collecting basin, at the bottom of the oven.

Achieved environmental benefits
Reduced water and energy consumption, compared to water bath ovens.

Cross-media effects
Energy consumption, e.g. for steam production.

Technical considerations relevant to applicability
Widely applicable in the FDM sector, e.g. for meat, fish, shellfish and vegetables.

Reference literature
[71, AWARENET 2002]

Steam oven
Chapter 2

Description
Steam ovens are similar to shower ovens, but they do not have a water shower. Heating is due to the steam produced in the water heated in the collection basin. Cooking by steam reduces water consumption and waste water generation and pollution.

Achieved environmental benefits
Reduced water consumption. Reduced waste water generation and pollution.

Cross-media effects
Energy consumption, e.g. for steam production.

Environmental performance and operational data
The use of a steam oven for cooking meat and fish, prior to canning, produces waste water contaminated with fat, protein and fragments of food.

Technical considerations relevant to applicability
Widely applicable in the FDM sector, e.g. for meat, fish, shellfish and vegetables.

Reference literature
[52, Italy 2001] [71, AWARENET 2002]

2.3.4 Techniques to avoid the use of harmful substances

2.3.4.1 Proper selection and reduction of cleaning chemicals

Description
Avoidance or minimisation of the production of harmful residues:
- use of less harmful cleaning chemicals (e.g. ozone);
- reduction of the use of cleaning chemicals (e.g. EDTA, halogenated biocides, acids).

Technical description
Chemicals such as chlorine, quaternary ammonium compounds, bromine or iodine based products are routinely used to maintain the hygiene of food manufacturing sites. However, these are often potentially hazardous in combination with organic residues. Moreover, to work safely and effectively, such chemicals typically require large volumes of water and often high temperatures. Then, when cleaning is complete, further treatment with significant associated environmental impact is often needed to clean up any effluent.

Avoid or minimise the production of harmful residues can include the following measures:
- use of less harmful cleaning chemicals (e.g. ozone);
- reduce the use of cleaning chemicals (e.g. EDTA, halogenated biocides, acids).

Ozone (O3) in water solution can destroy the cell membrane of pathogens by oxidising the phospholipids and lipoproteins and has the advantage of itself quickly breaking down into harmless oxygen. Ozone is effective against a wide range of microbes including bacteria, yeasts, moulds, viruses and spores. The incorporation of rich-ozone water in CIP - and other cleaning processes - has the advantage over traditional disinfectants that no residues are left and the ozone is applied cold. This reduces the volume of water necessary to rinse detergents from the plant and energy associated with heating the water. Ozone can also be used in dry settings.

Achieved environmental benefits
Reduction in consumption of cleaning agents and detergents.

Technical considerations relevant to applicability
Hygiene requirements may restrict the use of this technique.
Example plants
This technique is implemented in multiple FDM installations [193, TWG 2015].

Reference literature
[193, TWG 2015], [275, COM 2015][275, COM 2015]

2.3.4.2 Optimal use of cleaning-in-place (CIP) by reuse of cleaning chemicals

Please see Section 2.3.3.2.7.

2.3.4.3 Dry cleaning

Please see Section 2.3.3.2.1.

2.3.4.4 Optimised design and construction to facilitate cleaning

Please see Section 2.3.3.2.5.

2.3.4.5 Use of refrigerants without ozone depletion potential and with low global warming potential

Description
Prevention of emissions of substances that deplete the ozone layer or have a high global warming potential by using alternative refrigerants, such as water, CO₂ or ammonia.

Technical description
Hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), chlorine and ammonia are frequently used if the temperatures are below -10 °C. HCFCs have the disadvantage of depleting the ozone layer when released to the atmosphere. They also show considerable GWP. The use of HCFCs is generally prohibited [258, EC 2009]. HFCs have the disadvantage of possessing a much higher GWP than alternative refrigerants such as ammonia, carbon dioxide, chlorine and water. There are provisions aiming at containing, preventing and thereby reducing emissions of HFCs [259, EC 2014].

Refrigerants are widely used in the FDM sector in cooling, refrigeration and freezing operations. The interaction of halogen refrigerants with ozone in the air has resulted in the progressive prohibition of the placing on the market and use of ozone depleting substances and of products and equipment containing those substances. There is currently a proposal for a Regulation of the European Parliament and of the Council on certain fluorinated greenhouse gases [246, EC, 2003].

These compounds have been substituted by other refrigerants such as CO₂, ammonia, glycol or, in some cases, by chilled water.

Achieved environmental benefits
Reduced risk of ozone depletion and global warming.

Cross-media effects
The risk of ammonia and glycol leaks, which can cause health and safety problems.
Chapter 2

Environmental performance and operational data
The use of substances that deplete the ozone layer can be prevented or minimised by [35, Germany 2002]:

- using substitutes for such substances;
- when ozone depleting substances are used, using closed-circuit systems;
- enclosing systems in buildings;
- encapsulating parts of systems;
- creating a partial vacuum in the encapsulated space and preventing leaks in systems;
- collecting the substances during waste treatment;
- using optimised waste gas purification techniques;
- proper management of the recovered substances and the waste.

For example, a Norwegian ice cream plant is using a transcritical CO\textsubscript{2} cooling and freezing system with heat recovery and hot gas defrost capabilities [275, COM 2015].

Driving force for implementation
Legislation.

Example plants
This technique is implemented in multiple FDM installations [193, TWG 2015].

Reference literature
[35, Germany 2002], [193, TWG 2015], [258, EC 2009], [259, EC 2014], [275, COM 2015]

2.3.5 Techniques to reduce waste
2.3.5.1 Anaerobic digestion of residues

Description
Treatment of biodegradable residues by microorganisms in the absence of oxygen, resulting in biogas and digestate.

Technical description
The treatment of biodegradable solids by anaerobic digestion is used to transform the organic matter contained in the residues into biogas (containing 70% methane) and digestate. Anaerobic digestion is used to handle biodegradable solids very high in COD, and as a treatment process for sewage sludge after an aerobic waste water treatment.

The technique generally consists of the following steps:

- Anaerobic digestion: residues are directed to a sealed digester tank where anaerobic digestion takes place. This is a process by which microorganisms break down biodegradable material in the absence of oxygen, resulting in biogas and digestate.
- Biogas line: generated biogas is stored and at a later stage is dehumidified and used, e.g. in a co-generator. It can also be used to produce heat, i.e. hot water in a boiler, combined electricity and heat in a CHP unit, as an alternative fuel in vehicles or as a substitute for natural gas after upgrading to biomethane. Some of the heat generated may be recycled in the FDM process.
- Separation: the digestate is separated into solid and liquid fractions by centrifugation.
- Storage of the solid fraction of the digestate: the solid fraction of the digestate is stored for agricultural purposes (landspreading).
More detailed information on the process description, feed and output streams, biogas pretreatment techniques, and characteristics of digestate is available in the WT BREF [251, COM 2015]. A list of proven improvement techniques for anaerobic digestion of waste (e.g. micro anaerobic digestion, vertical flow dry) is described in the EC report ‘Towards a better exploitation of the technical potential of waste to energy’ [250, COM 2016].

Anaerobic co-digestion allows the operator to take advantage of the complementary nature of the composition of the waste. The best example is the co-digestion of manure and food wastes. The mixture of both types of waste leads to more stable processes and with a considerable increase in biogas production. The co-digestion allows the integration of the exploitation of organic waste in a given geographical area. Anaerobic digestion systems commonly used for the co-digestion of agro-industrial waste are called continuous stirred tank reactors [252, AINIA 2016].

**Achieved environmental benefits**

Waste generation and emissions to air are reduced (biogas is used for energy to replace fossil fuels). The recovery of by-products to produce digestate for agriculture conserves and recycles nutrients and reduces waste discharge and the use of chemical fertiliser.

**Environmental performance and operational data**

Emissions to water from anaerobic digestion in FDM installations are not an environmental issue, given that the digestate is usually treated in the WWTP.

Anaerobic digestion of food waste is usually carried out when the total solid content is below 15%. Water contained in food waste does not produce biogas and occupy part of the volume in the digestion tank. However, water is required for the fermentation. The volatile solid content is about 70–95% of the total solid content. The energy output from an anaerobic digestion plant depends to a great extent on the biomethane potential of the feedstock. The maximum potential can vary from 0.15 m$^3$ to 0.90 m$^3$ biogas/kg of volatile solid content [252, AINIA 2016].

In a meat installation (#331), a digester was fed with around 28 000 t/yr of proteins and fats recovered from the DAF step in the WWTP. The biogas produced powers a combustion engine to co-generate electricity and heat, which are then used in the meat production processes. The amount of solid fraction in the digestate produced was 1 361 tonnes during that period. The reduction of waste generation was approximately 95%.

**Cross-media effects**

The nitrogen content of residues is not reduced after anaerobic digestion. Further waste water treatment of liquid digestate is usually required (e.g. membrane filtration).

**Technical considerations relevant to applicability**

Digesters should be fed at a constant rate to operate properly. Due to the investment costs, a digester may not be applicable to installations with low amounts of residues. The lowest amount of residue treated by a digester was 396 tonnes/year, reported by installation #133.

**Economics**

An investment cost of EUR 3 500 000 has been reported, including an anaerobic biodigester plant, biogas co-generator, centrifuge and a scrubber as the abatement system. The amount of electricity produced by the biogas co-generator in a six-month period was approximately 40 000 MWe. The amount of solid fraction of the digestate produced is about 3 500 tonnes/year. Savings of EUR 50 000/year have been reported due to reduction of sludge considered as waste.

**Driving force for implementation**

Economic reasons are the main drivers for implementation, due to reduced energy consumption and waste generation.
Example plants
This technique is used in several FDM sectors [193, TWG 2015]. Example plants include #048, #133, #144, #250 and #331.

Reference literature
[193, TWG 2015], [245, EC 2015], [250, COM 2016], [251, COM 2015], [252, AINIA 2016]

2.3.5.2 Use of residues as animal feed

Description
Use of raw materials, partially processed foods and final products not suitable for human consumption as animal feed.

Technical description
Numerous examples exist in the FDM sector where raw materials, partially processed foods and final products either originally intended for human consumption or from which the part intended for human consumption has been removed, may be used as animal feed. For example, foods which are slightly outside the customer specification, or which have been over-produced, may be suitable for use as animal feed. Examples of sources of animal feed from FDM processes manufacturing for human consumption are shown in Table 2.46.
Table 2.46: Examples of sources of animal feed from FDM processes manufacturing for human consumption

<table>
<thead>
<tr>
<th>Source of animal feed</th>
<th>Example industry source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bones and fat</td>
<td>Meat processing (subject to hygiene regulations Regulation 1774/2002/EC (188, EC, 2002))</td>
</tr>
<tr>
<td>Rejected fish</td>
<td>Fish processing</td>
</tr>
<tr>
<td>Stalks, hulls and leaves</td>
<td>Fruit and vegetable processing</td>
</tr>
<tr>
<td>Fruit and vegetables, such as peel, cores and cutting residues</td>
<td>Fruit and vegetable processing</td>
</tr>
<tr>
<td>Apple and tomato pomace and citrus pulp pellets, without or after treatment</td>
<td>Fruit and vegetable processing</td>
</tr>
<tr>
<td>Crude olive cake (also called pomace)</td>
<td>From the first pressing of olives</td>
</tr>
<tr>
<td>Olive cake</td>
<td>From extraction of pomace oil (olive)</td>
</tr>
<tr>
<td>Recovered ffas</td>
<td>Vegetable oil processing</td>
</tr>
<tr>
<td>Toasted meal</td>
<td>Vegetable oil processing</td>
</tr>
<tr>
<td>Crude cake and spent meal/cake</td>
<td>Vegetable oil processing</td>
</tr>
<tr>
<td>Phospholipids</td>
<td>Vegetable oil refining</td>
</tr>
<tr>
<td>Spent bleaching (in the absence of a nickel catalyst)</td>
<td>Vegetable oil refining</td>
</tr>
<tr>
<td>Product retrieved from wrongly filled containers, e.g., by maceration of packaging</td>
<td>Dairies, but applicable to all FDM industries producing foods suitable for use in animal feed</td>
</tr>
<tr>
<td>Leaked and spilt ingredients and partly and fully processed materials</td>
<td>Dairies, but applicable to all FDM industries producing foods suitable for use in animal feed</td>
</tr>
<tr>
<td>Rinsings from yoghurt vats</td>
<td>Dairies</td>
</tr>
<tr>
<td>Whey which is not intended for making mizithra cheese, baby food or other products</td>
<td>Dairies</td>
</tr>
<tr>
<td>Milky waste water generated at the start-up of pasteurisers</td>
<td>Dairies</td>
</tr>
<tr>
<td>Cereals, fibre, gluten, vegetable protein and de-fatted meal</td>
<td>Cereals processing</td>
</tr>
<tr>
<td>Wet pulp and pressed pulp from the presssing of cossettes</td>
<td>Extraction of sugar from sugar beet</td>
</tr>
<tr>
<td>Vegetable matter separated from sugar beet fluming water</td>
<td>Extraction of sugar from sugar beet</td>
</tr>
<tr>
<td>Molasses</td>
<td>Sugar extraction</td>
</tr>
<tr>
<td>Vinasses produced during the processing of alcohol from sugar juices, syrups and molasses</td>
<td>Ethanol production Molasses distillation</td>
</tr>
<tr>
<td>Distiller’s dried grains with solubles (DDGS)</td>
<td>Ethanol production</td>
</tr>
<tr>
<td>Condensed stillage (CDS)</td>
<td>Ethanol production</td>
</tr>
<tr>
<td>Gluten, bran</td>
<td>Ethanol and starch production</td>
</tr>
<tr>
<td>Recovered strong liquors</td>
<td>Drinks manufacturing</td>
</tr>
<tr>
<td>Malt</td>
<td>Beer, lager and whisky production (from germinated kiln-dried grain)</td>
</tr>
<tr>
<td>Husk and malt grits, which may be mixed into brewers’ grains and trub</td>
<td>Breweries</td>
</tr>
<tr>
<td>Concentrated or dried stillage, pot ale, spent lees and spent wash</td>
<td>Whisky stills</td>
</tr>
<tr>
<td>Fermentation vessel cooling water containing raw materials and fermented produce residues</td>
<td>Whisky distilleries</td>
</tr>
<tr>
<td>Brewers’ Fermentation yeast</td>
<td>Breweries, ethanol production</td>
</tr>
<tr>
<td>Solid organic such as raw material and product residues and dust</td>
<td>Dehydration</td>
</tr>
<tr>
<td>Solids and oils removed from segregated waste water streams</td>
<td>Snack foods manufacturing</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006], [193, TWG 2015]
Chapter 2

Achieved environmental benefits
Increased use of materials and reduced waste generation. Consequently there is an associated reduced consumption of, e.g. energy for waste treatment and disposal, e.g. in WWTPs and reduced landfilling of FDM waste.

Cross-media effects
Some materials may need to be stored under controlled temperature conditions, before their use as animal feed.

Technical considerations relevant to applicability
Applicable in FDM installations using raw materials and partially processed ingredients and producing products which are suitable and fit for consumption by animals either directly or after further processing and which comply with relevant legislation governing animal feed.

Production of animal feed from, e.g. sugar beet pulp, apple and tomato pomace and citrus pulp pellets, without or after treatment is limited by several factors, including putrefaction during storage and transport, and the presence of undesirable constituents such as alkalis or salt. Water content is the major contributor to shipping costs and, to some extent, the putrefaction rate.

Economics
Reduced purchase of materials which are not used and sold and reduced waste treatment and disposal costs.

Driving force for implementation
Economic use of by-products, off specification products and excess materials, which would otherwise be sent for disposal as waste.

Example plants
This technique is widely applied in FDM installations [193, TWG 2015].

Reference literature

2.3.5.3 Segregation Separation of residues outputs, to optimise their use, reuse, recovery, recycling and disposal of

Description
Separation of residues, e.g. using positioned splash protectors, screens, flaps, catchpots, drip trays and troughs.

Technical description
Outputs, whether or not they are intended for use in the product, can be separated segregated for optimised and easier use, reuse, recovery, recycling and disposal. This also reduces both the consumption and the contamination of water. It can be done either manually or mechanically. These outputs may include, e.g. rejected raw materials, trimmings and off-specification product. Accurately positioned splash protectors, screens, flaps, drip trays and troughs can be used to contain individual materials separately. They can be fitted at processing, filling/packing and transfer lines and next to workstations, such as peeling, cutting and trimming benches. The position and design of, e.g. a tray or trough, the means of preventing mixing with water and the transportation of the liquids or solids depend on the unit operation, the degree of segregation of different materials desired or required and their ultimate intended use, or disposal route.
A catchpot is a fine mesh basket placed over floor drains, to prevent solids from entering the drainage system and the WWTP. Catchpots can be locked in place to ensure that solids are not
able to enter the WWTP during cleaning. If they are emptied after dry cleaning and locked in place again before wet cleaning, then entrainment of soluble materials and of particles broken off the solids by the cleaning water can be avoided.

Examples of materials which can be collected and transported dry include bones and fat from deboning and trimming meat. These may or may not be intended for human consumption. For materials destined for human consumption, temperature control is particularly important and deterioration can be avoided by quickly transferring the materials to chills.

Other examples include removal of sorted, untreated or partly treated fruit and vegetable residues, peel and cutting residues and collecting spent earth in sedimentation and filtration steps instead of washing it into the WWTP.

Where the amount of potential waste is high, manual or automated collection systems such as drains, pumps or suction devices can be installed, to minimise deterioration and maximise potential use, e.g. in animal feed. This also mitigates against the possibility of materials being washed into the WWTP during interval cleaning.

In the dairy industry, examples of materials which can be collected separately for optimal use or disposal include the drainings of yoghurt and fruit throughout the dairy; first rinses of buttermilk and residual fat in butter churning operations, for use in other processes, e.g. for low fat spreads and whey, e.g. for making mizithra cheese (see Section 5.4.4.1). In vegetable oil refining, dust produced during drying of desolventised meal can be added back to the meal (see Section 11.4.2.2.1).

Some water diluted materials can be recovered, if the water is collected, e.g. potato starch can be recovered from starch water, as described under Environmental performance and operational data and whey can be extracted from whey/water mixtures. This can be optimised by using turbidity meters. Additionally materials can be recovered for use or disposal by using dry cleaning methods.

**Achieved environmental benefits**
Reduced water consumption and less entrainment of materials in water, so generation of less waste water. If materials are collected efficiently, the volume of water required for cleaning is reduced and consequently less energy is used to heat the cleaning water. Less detergent is also required. The waste water load of, e.g. BOD, COD, nutrient and detergent emission levels are all reduced, per unit of production.

The segregation of liquids and solids destined for use or destruction has several advantages. If sufficient separate collection systems are provided, it reduces cross-contamination between different by-products. Segregation of by-products reduces potential odour problems from materials which, even when fresh, emit the most offensive odours, i.e. by storing/removing them separately under controlled conditions, instead of having to control a greater volume of mixed by-products.

Also, by minimising cross-contamination, segregation enables individual by-products which can be used to be used, instead of being disposed of because they are mixed with materials which cannot be used. All materials can, therefore, be used or disposed of in the most appropriate way for them.

**Environmental performance and operational data**
The following examples show how segregation can result in cleaner waste water, reduced water consumption and reduced waste.

In fish processing, using baskets or trays at cutting, eviscerating, skinning, and filleting can avoid the solid wastes reaching the floor and then the waste water. Fine mesh conveyor belts can be used to separate waste and water at cutting and evisceration stations and can reportedly
decrease COD emission levels by about 40%. The collected solid materials can be used to make fish-meal.

Dry systems have been developed for collecting solid waste from crustaceans and molluscs. Screens and efficient systems for the recovery of solids, prevent them from entering the WWTP and can reportedly lead to BOD\(_5\) level reduction of up to 35%.

In an example installation producing snack foods, waste water streams were segregated prior to on-site treatment and then treated to remove solids and oils, which were then processed into animal feed cake. This was as a result of a water action group consisting of managers, shift operators and the site adviser using a bucket-and-stopwatch approach to study the ideal flowrates for each piece of equipment. The results of this water audit showed that substantial savings could be made. Three main waste streams were identified, i.e. potato wash-water, cold starch water and hot starch water containing oils.

In fruit and vegetable processing, solid organic material from the peeling process and from blanching can be separated using, e.g. sieves, filters or centrifuges, to prevent them from entering the WWTP. Normally these solids, except after caustic peeling, can be used as animal feed.

In starch manufacture, potato wash-water can be reused after grit is removed. Cold starch water can be recycled after the good quality starch has been recovered. Water recycling and reuse have reportedly reduced water consumption by 19%, i.e. 165 000 m\(^3\)/yr.

**Cross-media effects**  
Potential generation of odour if separated solids are not periodically collected and sent to their subsequent destination.

**Technical considerations relevant to applicability**  
Applicable to all FDM installations.

**Economics**  
The 165 000 m\(^3\)/yr reduction in water consumption at the example snack food installation saved a reported EUR 145 000 in water supply costs.

**Driving force for implementation**  
- Reduced waste because materials recovered can be used.
- Reduced waste water treatment and waste disposal and the associated reduced costs.

**Example plants**  
At least one snack food installation in the UK. Dairies in the UK and fruit and vegetable processing installations in Belgium. Widely applied in drinks manufacturing, e.g. in winemaking.

**Reference literature**  
[1, CIAA 2002], [9, Envirowise (UK) 1998], [14, VITO et al. 2001], [23, Envirowise (UK) and Ashact 2001], [43, Italian contribution 2002], [71, AWARENET 2002]

**Automated filling incorporating recycling of spillages**

**Technical description**  
For foods that are preserved in liquids,

**Achieved environmental benefits**  
Reduced waste water contamination.
Environmental performance and operational data

When canning fish, the cans are filled with brine, sauce or oil. Seasoning liquids can spill giving rise both to a pollution load in the waste water and resulting in an under-use of processing materials if they are not recovered. Contamination of water, e.g. in the steriliser, due to spilled material on the sides of cans reduces the possibilities to reuse that water.

Technical considerations relevant to applicability

Driving force for implementation
Reduced water consumption and savings in waste water treatment.

Reference literature
[71, AWARENET 2002]

2.3.5.4 Recovery of spilled contents during filling and washing of cans, bottles and jars

Description
Use of can, bottle and jar filling and cleaning systems with recovery of spilled contents.

Technical description
Automated filling systems for seasonings can be used incorporating closed-circuit recycling of spilled liquids, such as sauce, brine or oil. Afterwards, filled cans, bottles and jars are washed with water and detergents to remove all of the contents that are spilled during filling, such as the sauces, brines or oil. The amount of water used will depend on how the cans, bottles and jars and the food have been handled. Floating oil can be recovered from cleaning tanks. This increases the possibility for recycling the water-detergent solution and reduces the contamination of the waste water.

Achieved environmental benefits
Reduced production of waste, water consumption and waste water generation. If hot water can be reused, there is a reduced consumption of water and energy.

Technical considerations relevant to applicability
Widely applicable, e.g. in preservation of meat, fish, crustaceans, molluscs and vegetables in cans, bottles and jars.

Applicable in the cleaning of cans, bottles and jars filled with vegetable oils, foods which contain fat or oil, or which are canned in oil.

Driving force for implementation
Reduced costs associated to reduced water consumption and savings in waste water treatment.

Reference literature
[71, AWARENET 2002]

2.3.5.5 Recovery and reuse of residues from the pasteuriser

Description
Residues from the pasteuriser are fed back to the blending unit and are thereby reused as raw materials.

Technical description
Combining in-line blending and pasteurisation makes it possible to recover mixed phases containing water from the pasteuriser. The diluted product is reused in the production line.
Figure 2.11 shows the possibilities of recovery.

Figure 2.11: Scheme for beverage processing with in-line blending and recovery functions

The terms used in Figure 2.11 are defined as follows:

- **Production concentrate recovery**: the premix tanks before the blending unit are emptied in order to concentrate the recovered phases and to achieve zero product losses in the blending unit.
- **Production start recovery**: the mixed phase in the pasteuriser is returned to the blending unit, which concentrates it up to real product levels. A recovery rate of 100% can be achieved. A densimeter on this stream is used to identify which part of the phase is product and which is water. The blending unit and the pasteuriser communicate with each other to know where the product and water phases are.
- **Production reject recovery**: if for some reason the production line stops and the pasteuriser needs to be emptied and go into hibernation mode, all the product in the pasteuriser is recovered and routed into the buffer tank of the blending unit. This option does not generate losses and does not require an extra reject tank.
- **Product return recovery**: a product recovery function between the pasteuriser and the packaging machine minimises the losses.

**Achieved environmental benefits**

In-line production reduces the need to invest in batch tanks. Running production with fewer tanks will:

- save water and CIP solution due to the lower number of tanks to clean;
- save power due to the reduced amount of electrical equipment;
- give a better yield due to the recovery functions and accuracy of the machine;
- reduce the effluent volume and COD load due to the recovery functions.

**Technical considerations relevant to applicability**

The technique is applicable in new and existing liquid food processing installations.

**Driving force for implementation**

- Increased yield.
- Improved product quality.
- Saved time in the blending area since operators prepare less tanks.
- Increased capacity.
Example plants
This technique has been implemented worldwide.

References
[186, Tetra Pak 2015]

Provision and use of catchpots over floor drains

Achieved environmental benefits
Solids which are not prevented from falling on the floor by other means do not enter the waste water. This reduces the TSS, BOD, FOG, total nitrogen and total phosphorus emission levels in the waste water. The solids collected in the catchpot can be sent for appropriate non-food uses or disposal treatment.

Cross-media effects
Increased solid waste.

Environmental performance and operational data
The mesh size may vary depending on the application and the frequency of emptying may also vary depending on the characteristics of the potentially spilled materials.

The use of catchpots in meat processing installations, combined with dry cleaning can minimise the entrainment of meat scraps in the waste water as well as the entrainment of FOG caused by the contact between cleaning water and scraps of meat and fat.

Technical considerations relevant to applicability
Applicable to all FDM installations.

Economics
Very cheap to operate. Reduced contamination of waste water and consequently cheaper waste water treatment.

Example plants
This technique is widely applied in the FDM sector.

Reference literature
[71, AWARENET 2002], [110, CIAA 2003]

Control flow or level by dedicated measurement of pressure

Technical description
Pressure or vacuum may be applied in several operations, e.g. in filtering, drying, fermenting, autoclaving. Pressure control can typically be applied, using pressure sensors for the indirect control of other parameters, e.g. flow or level. Using pressure sensors in transfer lines to control pump speed pressure and flow velocity, and to minimise waste from material damaged by shear or friction forces. Using a differential pressure system to monitor levels in storage or reaction tanks to minimise material loss from overflow or production downtime due to lack of stock. Using a differential pressure system to monitor pressure drops across filters, to control cleaning cycles and optimise operation and thereby minimise waste.

Pressure sensors used in FDM applications generally require seals and surfaces designed specifically for hygienic applications.

Achieved environmental benefits
Minimisation of waste.
Environmental performance and operational data
In an example fruit juice installation, the product is filtered to remove fruit pulp solids before bottling. Filter cleaning with a water sparge was initiated at regular intervals according to a timer. The company recognised that this resulted in the filters being cleaned more frequently than was necessary. Differential pressure sensors were installed on three filter units and the cleaning cycle is now initiated by a signal from these sensors. This signal is given when a preset pressure across the filters is reached. Water consumption for filter cleaning has fallen by 30%.

In an example dairy, pressure measurement is used in monitoring and controlling flow velocities in pipelines, via pump controls, to avoid friction damage to the product.

In an example brewery, pressure measurement is used in monitoring and controlling the water pressure for spraying water of the malt in the mash filters, i.e. sparging.

Technical considerations relevant to applicability
Applicable in installations where fluids flow or are pumped, such as in the drinks and milk sectors.

Economics
At a reported fruit juice installation, the reduction in water consumption for filter cleaning has resulted in a saving of GBP 8 000/yr in water consumption and waste water treatment costs. The cost of the modifications was GBP 6 000, so the payback period was 9 months.

Example plants
A fruit juice installation, a dairy and a brewery in the UK.

Reference literature
[10, Envirowise (UK) & Entec UK Ltd 1999]

pH measurement
Description
pH probes measure the acidity or alkalinity of a liquid. pH is important in many applications, e.g. controlling milk quality; monitoring cream and cheese ripening; fermentation processes; the production of baby foods and treatment of both water and waste water.

The probes can be fixed permanently into a process line or dipped manually into tanks or storage vessels. Various devices are available. These range from simple probes and transmitters to self-diagnostic probes that alert operators to equipment faults and can be maintained and calibrated without removal.

To minimise wastage and to check the quality of materials, the pH, conductivity and turbidity of a range of fluids are commonly checked in-line.

Achieved environmental benefits
Reduced consumption of acids and alkalies and consequent reduced waste water generation.
Reduced waste of process materials, due to inappropriate mixing during processing and cleaning.

Environmental performance and operational data
To avoid spurious readings, the fluid velocity should not exceed 2 m/s and the electrode should always be “wetted” first to avoid loss of function.

An example confectionery company uses a pH probe to control caustic dosing of a waste water stream. As well as ensuring compliance with its discharge consent, pH control helps to minimise the potential for expensive corrosion in the drainage system due to acid or alkaline attack.
Technical considerations relevant to applicability
Applicable to all FDM installations where acid and/or alkali materials are added to process, cleaning or waste water streams. Examples of the use of pH measurement in the FDM sector are shown in. Typical applications of pH measurement in the FDM sector are shown in.

Examples of the use of pH measurement in the FDM sector

<table>
<thead>
<tr>
<th>Activity</th>
<th>Reason for control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control of additions of acid or alkali to reaction vessels</td>
<td>Minimise waste from overdosing and production of out of specification product</td>
</tr>
<tr>
<td>Monitor waste water streams for use in mixing and neutralising prior to discharge</td>
<td>Minimise use of fresh caustic or acid for waste water treatment</td>
</tr>
</tbody>
</table>

Typical applications of pH measurement in the FDM sector

<table>
<thead>
<tr>
<th>Sector/activity</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy</td>
<td>pH analysis of milk deliveries to minimise losses through mixing of unsuitable milk with other raw materials</td>
</tr>
<tr>
<td>Jam production</td>
<td>pH measurement to identify correct gelling point</td>
</tr>
</tbody>
</table>

Driving force for implementation
Reduced consumption of acids and alkalis, e.g. in CIP and reduced waste generation.

Example plants
Dairy and jam making and waste water treatment.

Reference literature
[7, Environment Agency of England and Wales 2000] [10, Envirowise (UK) & Entec UK Ltd 1999]

Selection of materials

Selection of raw FDM materials which minimise solid waste and harmful emissions to air and water

Description
A proportion of virtually all of the raw and auxiliary materials used will end up as solid waste or in an installation’s WWTP. Auxiliary materials are those materials used in processing raw materials that do not end up in the final product, e.g. cleaning materials. The majority of raw materials used in the FDM sector are natural and they usually have a high organic matter content and their effect on the local terrestrial and aquatic environment can be considerable. In practice, the option of using different raw materials is often limited as the materials are specified in recipes and there are often few or no alternatives. Some sectors try to use raw materials which result in fewer by-products or wastes.

The selection of fresh materials and those which meet the quality standards required for processing at the installation, before the materials are received at the installation, can minimise the amount of waste due to disposal of, e.g. over ripe fruit and vegetables or fish that has started to decompose and is unsuitable for processing. This can be helped if agreements are made with the grower/supplier about, e.g. time of harvesting, harvest production and harvest processing. Additionally, agreements can be made about the use of pesticides, e.g. about ceasing their use sufficiently in advance of harvesting to minimise the contamination of waste water from washing fruit and vegetables.
Achieved environmental benefits
Reduced wastage of raw materials, waste water contamination and odour emissions.

Environmental performance and operational data
The specification for raw materials can be agreed with the supplier and off-specification raw materials can be returned to the source, if they are delivered to the FDM installation. This can maximise the proportion of the raw material which ends up in the product and consequently minimise the amount which ends up as waste or as a lower value by-product, such as animal feed.

This can be achieved by the supplier exercising quality control as well as the operator carrying out quality checks at the FDM processing installations. For example, this is routinely undertaken at dairies. The milk arrives in road tankers and staff at the dairy visually inspect the milk, smell it and carry out laboratory tests. If the milk does not meet the standard required, it is not accepted on the site.

Technical considerations relevant to applicability
Applicable to all FDM installations.

Driving force for implementation
Maximising product yield and minimising waste disposal costs.

Reference literature
[31, VITO, et al., 2001]

Selection of auxiliary materials used
Chemicals are also used in food manufacturing processes (e.g. in caustic peeling, vegetable oil hardening, coagulation, alkaliising, neutralisation). For some of the substances used in food manufacturing processes there is an EU-wide risk assessment compiled under the Existing Substances Regulation (793/93/EEC) available. These risk assessments cover risks to the environment and human health. For substances not assessed under 793/93/EEC, information on hazards and risks have to be gathered from other sources to ensure that the risk is minimised and less hazardous alternatives are chosen where practicable [199, Finland, 2003]. An example is the risk assessment and management strategy developed for Germany [154, Ahlers J. et al., 2002].

Substitutes can be used for carcinogenic, mutagenic or teratogenic input materials.

Packing and filling
For the purpose of this document, the minimisation of packaging waste associated with the production process is undertaken.

Extensive packaging is used throughout the FDM sector as products must be packaged appropriately for the distributor and consumer for hygiene, to convey information, be attractive to the consumer and to protect the product and also for, displaying a brand name, and presenting a high visibility in often very competitive markets [47, Envirowise (UK) and Aspinwall & Co., 1999]. This includes both bulk and individual packaging. Hygiene principles need to be considered, e.g. by following HACCP principles.

In the UK, the FDM sector is responsible for using over 50% of the total yearly packaging (4-5 million tonnes per year). This packaging has a value of approximately GBP 4000 million for raw materials alone. On average, packaging represents 13% of the UK sector’s production costs [47, Envirowise (UK) and Aspinwall & Co., 1999].

Selection of packaging materials
Chapter 2

Description
The life-cycle analysis of packaging is beyond the scope of this document.

Packaging materials can be selected to minimise the environmental impact. To keep waste to a minimum, the weight and volume of each material, together with its recycled content, need to be considered, as does the potential for reuse, recycling and disposal of the packaging. Often, one material can replace the need for another, e.g. recyclable shrink-wrap could replace the need for cardboard trays and shrink-wrap.

The choice of packaging material can affect the potential for it to be reused both within the installation and outside, e.g. after refilling at the supplier’s premises.

It is possible to select easily recyclable materials; to try not to use composite materials; to label packaging to indicate materials used and to reduce cross-contamination of materials, e.g. paper labels on plastic sleeves. This requires collaboration between the packaging manufacturer or supplier to the FDM installation and, in most cases, the downstream customer, especially if they are a retailer. A caterer may more readily accept bulk deliveries and not require eye-catching packaging.

The selection of packaging materials needs to be based on the essential requirements in Article 9 and Annex II of Directive 94/62/EC on packaging and packaging waste [213, EC, 1994]. This includes minimising the presence of noxious and other hazardous substances and materials with regard to their presence in emissions, ash or leachate when packaging or residues if they are finally incinerated or landfilled. Recycling of packaging can give rise to emissions to the environment as a result of the materials of construction and also from the residues of the product they contained. There are limits on the levels of cadmium, mercury, lead and hexavalent chromium allowed. The suitability for recovery by material recycling and/or composting, i.e. its biodegradability and/or energy recovery, i.e. its calorific value have to be considered. Directive 94/62/EC sets out further details. The emptying, collection, sorting, separation and recycling necessary for subsequent reuse of the recovered materials are affected by the materials and combination of materials used.

For example, natural materials such as wood, wood fibre, cotton fibre, paper pulp and jute which have not been chemically modified can be accepted as being biodegradable without further testing.

Achieved environmental benefits
Decreased consumption of non-renewable materials and reduced waste generation.

Cross-media effects
Packaging designed for reuse is often heavier than equivalent single-use packaging, so additional energy may be required for its handling and transportation. Packaging which can come into contact with the product needs to be cleaned before it is reused, so water and cleaning agents are consumed and waste water is generated.

Technical considerations relevant to applicability
Applicable to all FDM installations.

Economics
Reduced waste disposal costs.

Driving force for implementation
Legislation and in particular Directive 94/62/EC.

Reference literature
Optimisation of packaging design—to reduce the quantity

Description
The life-cycle analysis of packaging is beyond the scope of this document.

Pollution prevention with respect to waste packaging is addressed using the waste minimisation hierarchy, hence by avoiding packaging; reducing packaging; reusing packaging; and by recycling packaging.

The optimum amount of primary and secondary packaging can be used, taking account of product size, shape, weight, distribution requirements and packaging material selected. The packaging can be selected to fit the purpose, minimise the amount of packaging material used, maximise the amount of product per pallet and optimise warehouse storage. This can be done whilst ensuring that the packaging continues to provide the required degree of protection for the product and without increasing the risk of product waste.

The choice of packaging and packaging materials needs to be based on the essential requirements in Article 9 and Annex II of Directive 94/62/EC on packaging and packaging waste [213, EC, 1994]. One way towards compliance is to work to harmonised standards such as EN 13428 Packaging—Requirements specific to manufacturing and composition—Prevention by source reduction (working to this standard does achieve compliance with the third indent of Annex II(1) of the Directive) and EN 13432 Packaging—Requirements for packaging recoverable through composting and biodegradation—Test scheme and evaluation criteria for the final acceptance of packaging. At the time of writing, further harmonised standards are under preparation.

Achieved environmental benefits
Reduction in consumption of materials for packaging and reduced waste both at the installation and at the place of unpacking.

Environmental performance and operational data
A confectionery company invested in a new wrapping machine which enabled it to eliminate the inner collation wraps on its bumper packs of biscuits. Polypropylene use was consequently reduced by 100 t/yr.

A petfoods company lowered the sides of its cardboard transit trays, without loss of strength. This action reduced wastage and resulted in a 49 % reduction in the use of corrugated card and ink.

In a preserves and peanut butter factory, a packing line study identified that static electricity associated with the sleeve film affected the availability of the automated tamper-proofing sleeve machine. By increasing the film thickness by 20 μm, the machine speed could be maintained at 250 jars per minute and stoppages reduced by 40 %. Savings in film waste alone equated to GBP 25000/yr.

Technical considerations relevant to applicability
Widely applicable.

Economics
The confectionery company reported a payback period of under 2 years. The petfoods company reported annual savings of GBP 100000.

Driving force for implementation
Reduced packaging use.

Example plants
A biscuit manufacturer and a petfoods manufacturer.
Reference literature

Segregation of packaging materials to optimise use, reuse, recovery, recycling and disposal

Description
Suppliers of raw materials, additives and cleaning chemicals may take back, their empty containers, made from, e.g. plastic, wood or metal, for recycling. This may be easier for the operator of the installation and the supplier, if they arrange for use of the largest size container possible. In addition, used packaging materials, if separated from other materials, may be sent for recycling if they cannot be reused.

The segregation of packaging waste can produce opportunities for recycling waste and reducing the volumes sent to landfill. It may even be sold. This process can be as simple as putting, e.g. paper, wood, plastics and food, into separate skips. Alternatively, it can involve a more complex process, such as using a macerator, to help to separate packaging from product.

For example, the protective plastic film around bottles supplied to bottling lines can be collected, pressed into bales and sent for recycling.

Achieved environmental benefits
Prevents waste and facilitates recycling of both packaging and FDM materials.

Cross-media effects
If empty containers are returned without cleaning, no cross-media effects apply. Containers which come into direct contact with food need to meet the required hygiene standards so they will need to be cleaned before they are reused. This may cause dust emissions, chemical use, waste water and energy consumption. The transport back from the user to the supplier involves an environmental cost.

Environmental performance and operational data
A dessert manufacturer developed a machine in-house to separate waste end-of-line product from its packaging. This enabled plastic carton packaging to be compacted and recycled, and for the solid product waste to be mixed with liquid food waste and sold as pig feed. The result was reduced waste, and lower waste disposal and waste water treatment charges. Bottles, casks, kegs, plastic and metal crates, intermediate bulk containers, pallets, drums, plastic boxes and plastic trays can be reused. Cardboard, paper, plastic, glass and metals can be recycled. These packaging materials can be collected at the point in the installation where they are emptied.

For the packaging to be reused, it is necessary for companies to have arrangements, such as a closed loop system, where back-haulage allows the packaging to be returned for reuse. It is reported that this is usually more effective where transportation distances are relatively short. The use of a tracking system, e.g. using bar codes, could aid the management of transit packaging.

Technical considerations relevant to applicability
Applicable in all new and existing FDM installations using a variety of packaging materials.

Economics
Economic data differ from site to site and depend on the conditions agreed with the supplier and/or the recycling operator. Waste disposal and waste treatment charges are reduced.
Chapter 2

Driving force for implementation
Prevention and recycling schemes for waste and packaging waste legislation. Reduced waste generation and associated disposal costs.

Example plants
At least one dessert manufacturer in the UK.

Reference literature

Optimising packing line efficiency

Description
Poorly designed and operated packing lines cause many companies to lose as much as 4% of their product and packaging. To improve efficiency and productivity and to reduce wastage, individual machines can be correctly specified so that they work together as part of an efficient overall design.

It is important to keep the slowest machine in the production line running at maximum capacity. Ideally it is never starved of feedstock. Packing line efficiency can be monitored, e.g. on a weekly basis by measuring key performance indicators, e.g. the waste to production ratio. The optimum and the actual design values of the packing machine can be plotted to identify if the machinery is operating at optimum efficiency. Other values can also be plotted to show the reliability of individual machines. Key performance indicators could include the number of rejects during a shift or day and downtime.

Achieved environmental benefits
Reduced overall FDM and packaging waste.

Cross-media effects
Usually none, however, one of the examples quoted in the operational data section below used a thicker film, but this was outweighed by the savings in waste.

Environmental performance and operational data
In an example large brewery, to combat poor packing line efficiency, teams were set up to monitor performance and identify problem areas. An understanding of the packing lines enabled actions to be taken to reduce stoppages and to increase efficiency. This action resulted in reduced operating costs and wastage, producing cost savings in excess of GBP 137000/yr.

A study in a dairy identified that packing line sensors on a bottle top shoot were too close to the base filler. This caused the sensors to become covered by milk froth and unable to detect bottle top blockages. This caused the rejection of up to 20000 bottles per week. By repositioning the sensors, the company was able to save GBP 35000/yr in disposal costs from spoiled poly-bottles and a further GBP 5000/yr in milk waste and reprocessing costs, together with benefits in increased production.

Technical considerations relevant to applicability
Applicable to all FDM installations, i.e. new and existing, which have automated filling machines.

Economics
See savings reported from example plants, under Operational data, above.

Driving force for implementation
Reduced wasted product and packaging and associated cost savings.
Example plants
Widely applied in the FDM and other sectors.

Reference literature

Waste minimisation by optimising packing line speed

Description
The performance of packing lines can be optimised and an appropriate machine speed set to ensure that the product is weighed in accurate portions to coincide with the operation of the heat sealing equipment.

Achieved environmental benefits
Reduced wastage of product and packaging.

Environmental performance and operational data
An example sweet manufacturing company monitored its packing lines performance and discovered that an inappropriate machine speed was causing inaccurate weighing of the product and failure of the heat sealing equipment. A simple adjustment of the machine’s speed enabled savings to be made in product, packaging, reworking and waste disposal. Other benefits were increased production and a 500 t/yr reduction in waste.

Technical considerations relevant to applicability
Applicable in all FDM companies using form fill seal machines.

Economics
In the example company, savings of over GBP 120 000/yr were made. Other financial benefits were associated with an increase in production and the reduction in waste sent to landfill.

Driving force for implementation
Improved production efficiency.

Example plants
At least one sweet manufacturing company in the UK.

Reference literature

Use of in-line check-weighers to prevent overfilling of packaging

Description
Using in-line check-weighers can reduce the amount of product lost due to overflow. Overfilling can lead to product losses due to overflowing and due to the entrance of material intended to be packed which becomes stuck in seals, contaminating them, e.g. in form fill seal machines. This can lead to spillages and the need to reject products. Techniques such as statistical process control may be used to monitor overfill and to identify when the machinery requires adjustment. This can also be achieved by a vigilant trained operator maintaining the optimal settings on the filling machine.

Achieved environmental benefits
Reduced wastage if overfilling leads to spillage or contamination of packaging seals.

Environmental performance and operational data
On a new machine operating at a fill quantity of 400 g, one standard deviation of 0.5 g, i.e. 0.125 % can be achieved. On older machines this can be even higher, e.g. between 0.15 % and 0.25 %.
Technical considerations relevant to applicability
Applicable in all installations with automatic filling machines.

Economics
Money saved by not putting more in the packet than required to and by reduced losses due to spillage waste.

Driving force for implementation
Compliance with “weights and measures” legislation.

Example plants
Plants, including FDM plants with new filling machines, achieve as low as 0.125 % overfilling and those with old machines can achieve between 0.15 % and 0.25 % overfilling.

Reference literature

2.3.6 Waste water treatment techniques

2.3.6.1 Primary treatment

In this document, the term primary treatment is used to describe what is sometimes described as primary treatment, preliminary treatment or pretreatment.

2.3.6.1.1 Screening (T4)

Description
A device with openings, generally of uniform size, that is used to retain the coarse solids found in waste water.

Technical description
After solids are removed with process-integrated techniques and prevented from entering the waste water, e.g. using catchpots located at drainage points inside the installation, further solids can be removed from the waste water using screening. Large quantities of non-emulsified FOG can be removed if screening is carried out together with technical and operational measures to avoid clogging.

A screen is a device with openings, generally of uniform size that is used to retain the coarse solids found in waste water. The screening element consists of parallel bars, rods or wires, grating or a wire mesh or perforated plate. The openings may be of any shape but are generally circular or rectangular slots. The spacing between bars for removing very coarse materials prior to finer screening, may be of 60–20 mm. To remove smaller particles, such as vegetable pieces and, e.g. peas and beans in a canned food factory, the spacing between bars generally does not exceed 5 mm. The openings in automatic screens range from 0.5 mm to 5 mm, with openings of 1–3 mm in widespread use. Smaller openings (1–1.5 mm) are reported to be less susceptible to blockage than larger ones (2–3 mm).

The main types of screens used are static (coarse or fine), vibrating and rotary screens.

Static screens, brushed or run-down, can comprise vertical bars or a perforated plate. This type of screen requires manual or automatic cleaning.

Vibrating screens require rapid motion to be effective. They are normally used for primary treatments associated with by-product recovery, particularly of solids with a low moisture content and preferably where the waste water does not contain grease. Vibrating screens operate
between 900 and 1800 rpm; the motion can either be circular, rectangular or square, varying from 0.8–12.8 mm total travel. The speed and motion can be selected according to the particular application. Of prime importance in the selection of a proper fine vibrating screen is the application of the correct combination of wire strength and percentage of open area. The capacities of vibrating screens are based on the percentage of open area of the screen media.

Rotary or drum screens receive the waste water at one end and discharge the solids at the other. The liquid is passed outward through the screen to a receiving box for forward transfer. The screen is usually cleaned by a continuous spray via external spray nozzles, which are inclined towards the solids discharge end. This type of screen is effective for streams containing a relatively high solids content. Microscreens mechanically separate solid particles from the waste water by means of microscopically fine fabrics. The most important operating parameter is the headloss, i.e. the loss of operating pressure, with the best separation results reported to be between 5 and 10 mbar.

**Achieved environmental benefits**

SS, FOG and BOD/COD emission levels reduced. Recovery of products, e.g. pulp in the fruit and vegetable sector. Reduced risk of odour emissions further downstream in the WWTP.

**Environmental performance and operational data**

The estimated pollution load reduction in the fish sector, when using rotary wedge wire screens, is around 10-20% from white fish effluents and about 30-40% from fatty fish effluents [71, AWARENET 2002].

In the fish sector, it has been reported that the removal of small solids is carried out using a filtration belt and vibrating screen with a filter mesh of 0.1 mm or less.

The blockage of screens is a common problem leading to the need for frequent cleaning. A curved sieve can be used to overcome blockages. This consists of a feeding device and a concave surface; and it is self-cleaning in operation. Wedge-shaped profiled rods are arranged perpendicularly to the flow direction of the water. A relatively steady overflow ensures that the screen cleans itself. The various screen segments are all interchangeable. Typical gap widths are 0.02–2 mm for sieve areas of 0.1–3.0 m² (maximum throughput 300 m³/m²/h). Curved screens are frequently used in fruit and vegetable factories. Alternatively, rotary screens equipped with self-cleaning may be used. When the blockage is due to fatty deposits, e.g. in the meat, dairy and fish sectors, regular chemical cleaning and/or hot water cleaning can be applied.

**Cross-media effects**

There may be odour emissions, depending on, e.g. the type and size of the solids screened.

**Technical considerations relevant to applicability**

Applicable in all FDM installations.

**Economics**

TWG, please provide information.

**Driving force for implementation**

Reduced waste water treatment requirements. Screening removes the need for, and therefore the cost of, additional waste water treatment. It reduces the amount of sludge produced, which would otherwise require additional expenditure for its disposal.

**Example plants**

Used in most of the FDM sectors, as shown in Table 2.4 [193, TWG 2015], the meat, fruit and vegetables, fish, drinks and vegetable oil sectors.
2.3.6.1.2 Fat trap or oil separator for the removal of FOG and light hydrocarbons

Description
A fat trap (or oil separator) is a plumbing device designed to intercept most greases before they enter the biological waste water treatment.

Technical description
FOG in waste water has a negative impact on the performance of the waste water treatment. It is therefore important to remove FOG in a pretreatment. If FOG are not removed prior to aerobic biological treatment, they may hinder the operation of the WWTP as it is not easily degraded by bacteria. Free FOG may be separated from water using a fat trap (grease interceptor). Similar equipment is used to separate light hydrocarbons.

A further development of the fat trap is the parallel-plate separator. Here, the separator chamber contains plates inclined at an angle of 45°. The EU standardisation of separators for oils, fats and light hydrocarbons is currently ongoing (prEN 1825 and prEN 858, Parts 1 and 2). Furthermore, combinations of augers and flotation tanks have been used for FOG removal.

Achieved environmental benefits
Removal of free FOG from the waste water. The system does not usually require any chemical additions so the recovered fats may be reused.

Environmental performance and operational data
The efficiency of separation depends on the water temperature and is increased if the water temperature is low. The presence of emulsifiers can also reduce the separation efficiency. It has been reported that an efficiency of 95 %, related to the free oil/fat content, can be achieved [35, Germany 2002]. It has been reported that Parallel plate separators are very sensitive to clogging in the processing of vegetable oils and fats sector.

In a primary stage of a dairy installation (#405), solids are removed using twin compacting augers. This reduces the solids volume by approximately 90 %. The augers will squeeze congealed FOG through the filter mesh for recovery. The primary tank is heated to enable the liquefaction of all FOG content. The hydraulic separator then removes the FOG from the waste effluent by means of flotation. This process will typically remove FOG to below 100 ppm and often less than 30 ppm. Fat should not solidify, so the pipework and tank must be kept warm.

The correct sizing of chambers is critical to ensure proper separation and to avoid the danger of washout during high or abnormal flows. Flow diversion may be needed if inflows suffer large fluctuations. Ease of emptying and regular maintenance is essential to prevent odour problems.

Cross-media effects
The equipment requires energy consumption. Depending on the type of fat trap, e.g. without continuous fat removal, there may be odour emissions, particularly during emptying.

Installing fat traps within processing areas can cause food safety problems. Excessively hot water can cause fats to carry through and may melt pre-collected fat, so it should be avoided. The baffle material and ease of cleaning need to be considered.

Technical considerations relevant to applicability
Applicable in FDM installations with waste water containing animal and vegetable FOG.
Economics
An investment cost of EUR 500 000 and annual operating cost of EUR 8 000 have been reported for the installation of an integrated oil separator in a dairy (treating around 480 000 m$^3$/year). Around 70 % of operating costs is electricity for heating, and 30 % for the maintenance contract. The investment required is reportedly outweighed by the EUR 400 000 of annual savings in waste water treatment, EUR 5 000/yr in sludge treatment and EUR 3 000/yr transport costs and plant maintenance [193, TWG 2015].

Driving force for implementation
Reduction in problems caused by fat in waste water pipelines and WWTP, and reduced loads require treatment.

Example plants
Used in most of the FDM sectors [193, TWG 2015], the meat and vegetable oils and fats sectors.

Reference literature
[35, Germany 2002], [94, Germany 2003], [97, CIAA-FEDIOL 2004], [193, TWG 2015]

2.3.6.1.3 Flow and load equalisation (T3)
Description
Balancing of flows and pollutant loads at the inlet of the waste water treatment by using central tanks. Equalisation may be decentralised or carried out using other management techniques.

Technical description
Equalisation tanks or buffer storage are normally provided to cope with the general variability in flow and composition of waste water, or to provide corrective treatment, e.g. pH control or chemical conditioning. The need to equalise waste water discharges may need to be considered to ensure that the flow and composition of the waste water are within the design parameters of the WWTP.

Achieved environmental benefits
Enables downstream treatment techniques to operate at the optimum efficiency. Makes use of mixing effects to offset extremes of temperature or pH.

Environmental performance and operational data
Adequate mixing and aeration is needed to minimise the formation of scum on the surface of the equalisation tank and to maintain a sufficient dissolved oxygen level to ensure the contents do not become anaerobic, leading to acidity and odour. Nevertheless, where necessary, scum removal equipment is installed.

Equalisation tanks typically have a retention time of 6–12 hours. However, in Scandinavian countries the retention time may be up to several months. For example, many FDM installations in Finland store the waste water generated during autumn and winter in big pools, given the difficulties to operate the biological waste water treatment during these periods [243, COM 2015].

Cross-media effects
Excessive retention of waste water in the equalisation tank may lead to acidity and odour.

Technical considerations relevant to applicability
Widely applicable in the FDM sector.

Economics
The cost of constructing and operating an equalisation tank needs to be compared with the cost savings associated with the smooth running of the downstream treatment techniques.
Driving force for implementation
To present a virtually homogeneous feed to downstream WWTP processes.

Example plants
Equalisation tanks are widely used in the FDM sector [193, TWG 2015], meat, fruit and vegetable, starch, dairy, soft and alcoholic drinks and vegetable oils and fats sectors.

Reference literature

2.3.6.1.4 Neutralisation (T4) and self-neutralisation

Description
The adjustment of the pH of waste water to a neutral level (approximately 7) by the addition of chemicals. Sodium hydroxide (NaOH) or calcium hydroxide (Ca(OH)₂) is generally used to increase the pH; whereas, sulphuric acid (H₂SO₄), hydrochloric acid (HCl) or carbon dioxide (CO₂) is generally used to decrease the pH. The precipitation of some substances may occur during neutralisation.

Technical description
The objective of neutralisation is to avoid the discharge of strongly acid or alkaline waste water. It can also protect downstream waste water treatment processes. The following substances are normally used to neutralise waste water which has a low pH:

- limestone, limestone slurry or milk of lime (hydrated lime Ca(OH)₂);
- caustic soda (NaOH) or sodium carbonate (Na₂CO₃);
- ion exchangers (cationic).

The following substances are normally used to neutralise waste water which has a high pH:

- introduction of CO₂, e.g. flue-gas and gas from fermentation processes;
- sulphuric acid (H₂SO₄), nitric acid (HNO₃) or hydrochloric acid (HCl);
- ion exchangers (anionic).

The term self-neutralisation is used when, in some cases, the size of the equalising tank, in combination with suitable variations in the pHs of the waste water streams, means that no addition of chemicals is required. This can occur, e.g. in some dairies where both acid and alkaline cleaning solutions are used and are both sent to the neutralisation tank.

Achieved environmental benefits
Avoids the effects of strongly acidic or strongly alkaline waste water, i.e. corrosion, reduction on the efficiency of biological treatments and/or a reduction in the self-purifying properties of lakes and rivers, and possibly operating problems for other water users.

Environmental performance and operational data
In the brewery sector, the neutralisation can take place in production areas or in central neutralisation tanks with acid or caustic. The neutralisation of process waste water requires a tank with a hydraulic retention time of approximately 20 minutes. The mixing capacity should be sufficient to keep the tank completely mixed. Since both caustic and acidic cleaning agents are used at the breweries, a reduction in chemical usage for neutralisation can be obtained by increasing the hydraulic retention time in the neutralisation tank. Neutralisation tanks are often also used as equalisation tanks (see Section 2.3.6.1.3) with a hydraulic retention time of 3–6 hours [72, Brewers Europe 2002].
Furthermore, partial neutralisation through biological conversion will normally take place in process waste water from the brewery sector. It has been observed that the pH in equalisation tanks can drop without the addition of acids due to the hydrolysis of organic material. The effect is difficult to control but it reduces the dosing requirements of acid to caustic process waste water. To achieve biological acidification, a hydraulic retention time of 3–4 hours is required.

**Cross-media effects**
Due to the addition of chemicals to the waste water, the dissolved solids/salt content may increase significantly in the treated water and the solid waste produced might be difficult to dispose of.

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of this technique. Applicable in installations with strongly acidic or alkaline waste water.

**Example plants**
Neutralisation is widely used in FDM installations [193, TWG 2015], the fruit and vegetable, dairy, brewery and drinks sectors.

**Reference literature**
[5, German Dairy Association 1999], [35, Germany 2002], [72, Brewers Europe 2002], [193, TWG 2015]

### 2.3.6.1.5 Sedimentation (T5)

**Description**
The separation of suspended particles and floating material by gravitational settling.

**Technical description**
A detailed technical description of sedimentation can be found in the CWW BREF [242, COM 2016].

Sedimentation is the separation from water, by gravity settling, of suspended particles that are heavier than water. The settled solids are removed as sludge from the bottom of the tank, or periodically after the removal of water.

The equipment used for sedimentation can be either:
- rectangular or circular tanks equipped with the appropriate scraper gear (top scraper for FOG removal, and a bottom scraper for solids removal) and sufficient capacity to provide adequate residence time for separation to occur
- laminar or tube separators where plates are used to increase the surface area for separation.

**Achieved environmental benefits**
Reduction of TSS and FOG emission levels. Reduction of the waste produced, e.g. in the starch sector. The sludges generated might be recoverable as a by-product, e.g. for possible animal feed. Sedimentable and floatable dangerous and priority hazardous substances levels are reduced. TSS can also include particulate organics, i.e. sedimentation will reduce TOC or COD, TN and TP emission levels as well, as long as it is present as insoluble solid material. Its removal efficiency, however, depends on the proportion of solid TOC in the overall TOC.

**Environmental performance and operational data**
It has been reported that in the fish sector, up to 35 % of the solids present can be removed by sedimentation. Table 2.47 shows the typical performance data of the brewery sector after sedimentation.
Table 2.47: Typical performance data of the brewery sector after sedimentation

<table>
<thead>
<tr>
<th>Initial load (m³/m²/h)</th>
<th>Final TSS (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5–1.0</td>
<td>20–30</td>
</tr>
</tbody>
</table>

NB: the acceptable loading will depend on the sedimentation characteristics of the sludge

Source: [72, Brewers Europe 2002]

The advantages and disadvantages of sedimentation are shown in Table 2.48.

Table 2.48: Advantages and disadvantages of sedimentation

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplicity of installation, not liable to fail</td>
<td>Rectangular or circular tanks may occupy large surface areas</td>
</tr>
<tr>
<td></td>
<td>Unsuitable for finely dispersed material</td>
</tr>
<tr>
<td></td>
<td>Laminar separators may be prone to blockage with fat</td>
</tr>
</tbody>
</table>

In the sugar sector, the fluming or transport water contains mud, stones and waste vegetation, as well as high COD from damaged sugar beet. The heavy dust requires sedimentation. The use of large sedimentation ponds has been reported. The sludge taken from the settlement ponds can be further dewatered and the liquors recovered from the dewatering process can be returned to the factory, either via the diffusers or as fluming water.

An average of approximately 11% of the incoming phosphorus load is removed with the primary sludge during primary sedimentation [255, DESMIDT et al. 2015].

Cross-media effects
Sedimented sludge, if not suitable to recycle or reuse, needs to be disposed of as waste. Sources of noise are the pumps, which can be enclosed, and the sludge/scum removal system. When the waste water contains odorous substances, it might be necessary to cover the sedimentation tank, and to duct the arising waste gas, if necessary, to a treatment system.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique with waste water containing TSS. The application of this technique may be restricted due to space requirements.

Economics
Waste water treatment charges generally make it cost-effective for most installations covered by IPPC to carry out some sort of separation of TSS. Compared to DAF, sedimentation has higher capital costs but lower operating costs.

Example plants
Widely used in FDM installations [193, TWG 2015], the fish, fruit and vegetable, starch, soft and alcoholic drinks, and vegetable oils and fats sectors.

Reference literature
[8, Environment Agency of England and Wales 2000], [35, Germany 2002], [72, Brewers Europe 2002], [193, TWG 2015], [242, COM 2016], [255, Desmidt et al. 2015]
2.3.6.1.6 Dissolved air Flotation (DAF) (T6)

Description
The separation of solid or liquid particles from waste water by attaching them to fine gas bubbles, usually air. The buoyant particles accumulate at the water surface and are collected with skimmers.

Technical description
The separation of materials lighter than water, e.g. edible oil/fat, can be enhanced by using flotation. In the FDM sector, DAF is mostly used. This technique decreases the retention time but does not enable the separation of emulsified FOG from water and, therefore, is used widely in the FDM sector for the removal of free FOG.

The basic mechanism of dissolved air flotation (DAF) is the introduction of small air bubbles into the waste water containing the suspended solids to be floated. The fine air bubbles attach themselves to the chemically conditioned particles and as they rise to the surface, the solids float to the surface with them.

The air is dissolved under pressure 300–600 kPa (3–6 bar). The air is normally introduced into a recycle stream of treated waste water which has already passed through a DAF unit. This supersaturated mixture of air and waste water flows to a large flotation tank where the pressure is released, thereby generating numerous small air bubbles. Here they are accumulated, thickened and removed by mechanical skimming or suction withdrawal. Chemicals such as polymers, aluminium sulphate or ferric chloride can be used to enhance flocculation and therefore, the adhesion of bubbles. DAF equipment is similar to that used for sedimentation (see Section 2.3.6.1.5).

Achieved environmental benefits
Free FOG, BOD/COD, TSS, nitrogen and phosphorus emission levels are reduced. Reduction of the waste produced, e.g. The sludges generated might be recoverable as a by-product, e.g. in the meat and dairy sectors they are used for animal feed. The sludge can also be used for biogas production. The system is kept aerobic, so the risk of odour problems is low.

Environmental performance and operational data
DAF units have been somewhat successful in the treatment of seafood processing waste water. When used without coagulants and flocculants, DAF units can remove up to 50 % of suspended solids and 80 % of FOG. Addition of coagulants and flocculants can increase separation efficiencies between 80 % and 95 %. Removal of COD/TOC and BOD depends on the amount of dissolved materials and separation efficiencies can vary between 15 % and 65 %. When chemicals are used to improve removal of fat and oil to meet strict environmental regulations, the recovery of fat and oil is not easy to achieve. DAF units used in treatment of seafood processing waste water are usually operated at around pH 5 to minimise protein solubility [205, Nordic Council of Ministers 2015].

Removal efficiency of DAF in a herring filleting installation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Removal efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>70–75</td>
</tr>
<tr>
<td>BOD</td>
<td>80%</td>
</tr>
<tr>
<td>Total-nitrogen</td>
<td>45%</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>70–85</td>
</tr>
<tr>
<td>Oil</td>
<td>85%</td>
</tr>
<tr>
<td>Grease</td>
<td>98%</td>
</tr>
</tbody>
</table>

*Approximate figure
DAF is used when the free FOG content is high
Chapter 2

During DAF, the pressurisation system may be prone to blockage problems. Typically, sludges recovered from a DAF cell would be in the region of 3–4% dry solids content. For the sludges to be recovered, coagulants and flocculants either have to be avoided or suitable substances chosen.

Cross-media effects
The technique requires energy consumption for compressed air and, depending on the amount of protein in the waste water, addition of flocculant.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
Waste water treatment charges generally make it cost effective for most installations covered by IPPC to carry out some sort of separation of TSS. Compared to sedimentation, DAF has lower capital costs but higher operating costs.

Driving force for implementation
- It is beneficial to reduce TSS in the discharge in order to reduce the cost of charges for downstream waste water treatment.
- Compared to sedimentation, DAF requires less land, has a higher separation efficiency and can to some extent absorb shock loads.

Example plants
The technique is widely used in FDM installations [193, TWG 2015], the meat, fish, fruit and vegetable, dairy, soft and alcoholic drinks and vegetable oils and fats sectors.

Reference literature

2.3.6.1.7 Buffer storage for waste water incurred during other than normal operating conditions Diversion (emergency) tank (T7)

Description
A buffer tank capable of receiving typically 2–3 hours of peak waste water flow.

Technical description
Contingency measures can be provided to prevent accidental discharges from processes damaging the WWTP and/or the operation of the MWWTP, by them receiving a sudden high load. A buffer (or diversion) tank capable of receiving typically 2–3 hours of peak flow can be established. The waste water streams are monitored upstream of the WWTP so that they can be automatically sidetracked to the buffer system if necessary. The buffer tank is linked back to the equalisation tank (see Section 2.3.6.1.3) or primary treatment stage so that out-of-specification liquors can be gradually introduced back into the waste water stream. Alternatively, provision can be made to allow the disposal of the diversion tank contents off-site. Buffer tanks are also applied where there is no separate drainage system for surface water and it could enter the on-site WWTP. More detailed information on buffer storage is available in the CWW BREF [242, COM 2016].

Achieved environmental benefits
Avoids uncontrolled and untreated discharges of waste water.

Environmental performance and operational data
TWG, please provide information.
Cross-media effects
There are no cross-media effects associated with this technique.

Economics
TWG, please provide information.

Driving force for implementation
Compliance with legal requirements to limit pollution to a receiving water body.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Example plants
This technique is widely used in FDM installations [193, TWG 2015]. Used in the meat, dairy and soft and alcoholic drinks sector.

Reference literature
[193, TWG 2015], [242, COM 2016]

Centrifugation (T8)

Description
There are four main types of centrifuge available:

- the solid bowl and basket centrifuges dewater in a batch process. The solid bowl configuration relies on the supernatant liquors to either be scraped from the surface or over top a weir arrangement at the top of the centrifuge;
- the basket system uses a perforated mesh, so that the liquid phase passes through the screen medium during centrifugation;
- the disc-nozzle centrifuge is primarily used for liquid/liquid separation;
- the decanter centrifuge is a standard technology widely used for activated sludge separation. Centrifuges can be used to separate particles too small to sediment, due to the greater gravitational forces applied.

Achieved environmental benefits
Reduction of TSS, FOG and BOD/COD levels. Less waste produced, e.g. starch recovery in potato processing.

Cross-media effects
High-energy consumption.

Environmental performance and operational data

Tables show the removal efficiency of centrifugation in the herring industry.

Table: Removal efficiency of centrifugation in the herring industry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Removal efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD from strongly polluted waste water</td>
<td>45</td>
</tr>
<tr>
<td>COD from less polluted waste water</td>
<td>16–25</td>
</tr>
<tr>
<td>TSS</td>
<td>80</td>
</tr>
</tbody>
</table>

Technical considerations relevant to applicability

...
Widely applicable in the FDM sector, e.g. for thickening or dewatering waste activated sludges. The application of centrifuges as a primary treatment technique is rather limited.

**Economics**

Maintenance and energy costs can be substantial, therefore, it is not attractive for installations with relatively low flows.

**Example plants**

Used in the fish, fruit and vegetable and soft and alcoholic drinks sectors.

**Reference literature**

[1, CIAA 2002], [3, CIAA 2001], [13, Nordic Council of Ministers 1997], [78, Metcalf & Eddy 1991], [88, CIAA-CEFS 2003]

### 2.3.6.1.8 Coagulation and flocculation Precipitation (T9)

**Description**

Coagulation and flocculation occur in successive steps which are intended to overcome the forces stabilising the suspended particles, allowing particle collision and growth of the floc.

**Technical description**

When solid particles cannot be separated by simple gravitational means, e.g. when they are too small, their density is too close to that of water or when they form colloids/emulsions, coagulation and flocculation can be used. This technique converts the substances dissolved in the water into insoluble particles by means of a chemical reaction.

This process consists of three major parts. The first stage is coagulation, which is carried out to destabilise the colloidal/emulsion system by reducing the potential responsible for the system stability. This is generally undertaken by dosing with inorganic chemicals such as aluminium sulphate, ferric chloride, or lime. The next step is the flocculation of small particles into larger ones by mixing the waste water, which can be readily settled or floated. This may involve the addition of polyelectrolytes to form bridges to produce large flocs. Apart from coagulation-flocculation some precipitation of metal hydroxides occurs and these hydroxides adsorb particles of fat. Following precipitation, sludges are removed by either sedimentation (see Section 2.3.6.1.5) or DAF (see Section 2.3.6.1.6), and before the biological treatment.

This technique may also be applied simultaneously during secondary treatment, e.g. in the activated sludge process. For instances when precipitation is applied as a tertiary treatment precipitation may also be used for phosphorus removal, see Section 2.3.6.3.4.

**Achieved environmental benefits**

Reduction of TSS, FOG and phosphorus emission levels. If dangerous and priority hazardous substances are used in the production process, their levels in the waste water are reduced.

**Cross-media effects**

Due to the addition of chemicals to the waste water, the dissolved solids/salt content may increase significantly and the solid waste produced might be difficult to reuse or dispose of. Another cross-media effect is the energy consumption for mixing.

**Environmental performance and operational data**

The effectiveness of coagulation and flocculation and selection of the coagulants depend upon understanding the interaction between the charge, size, shape and density of the particles to be separated. Final selection of the coagulant(s) should be made following through thorough jar testing and plant-scale evaluation. Considerations must be given to the required effluent quality, effect on downstream treatment process performance, cost, method and cost of sludge handling and disposal, and overall net cost at the dose required for effective treatment.
Chemical treatment plants are difficult to operate as their performance is very susceptible to changing waste water characteristics so they are difficult to automate and require significant operator manpower.

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of this technique, e.g. to remove TSS, FOG and phosphorus. In the fish sector, this technique is used when the oil content of the waste water is low. It is used in the fruit and vegetable sector to remove phosphorus with alumina or iron salts.

**Economics**
This technique produces solid waste which is expensive to dispose of.

**Example plants**
The technique has been applied in several installations of the following FDM sectors: dairy, oilseed processing and refining, brewing, sugar manufacturing, starch production and fruit and vegetables [193, TWG 2015]. Used in the fish, fruit and vegetable, soft and alcoholic drinks and vegetable oils and fats sectors.

**Reference literature**
[35, Germany 2002], [109, Finland 2003], [193, TWG 2015]

### 2.3.6.2 Secondary treatment

#### 2.3.6.2.1 Aerobic processes

#### 2.3.6.2.1.1 Activated sludge (T10)

**Description**
The biological oxidation of dissolved organic pollutants with oxygen using the metabolism of microorganisms. In the presence of dissolved oxygen (injected as air or pure oxygen), the organic components are transformed into carbon dioxide, water or other metabolites and biomass (i.e. the activated sludge). The microorganisms are maintained in suspension in the waste water and the whole mixture is mechanically aerated. The activated sludge mixture is sent to a separation facility from where the sludge is recycled to the aeration tank.

**Technical description**
The activated sludge technique produces an activated mass of microorganisms capable of stabilising a waste aerobically. The general arrangement of an activated sludge process for removing carbonaceous matter includes the following items:

- aeration tank where air (or oxygen or a combination of the two) is injected into the mixed liquor;
- settling tank (usually referred to as the final clarifier or secondary settling tank) to allow the biological flocs to settle, thus separating the biological sludge from the clear treated water.

Treatment of nitrogenous matter involves additional steps where the mixed liquor is left in an anoxic condition (see Section 2.3.6.3.1). The biomass is aerated and maintained in suspension within a reactor vessel. Plants can use air, oxygen. When they use oxygen they are called pure oxygen systems (see Section 2.3.6.2.1.2).

**Achieved environmental benefits**
Reduced BOD, TOC or COD, phosphorus and nitrogen emission levels. If dangerous and priority hazardous substances are used in the production process, its waste water levels are reduced.
Environmental performance and operational data

After a given residence time, which can vary from several hours to an excess of 10 days, based on an organic loading rate or F/M ratio of about 0.1–0.15 kg BOD/kg MLSS per day, the mixed suspension of microorganisms is passed to a sedimentation facility (see Section 2.3.6.1.5). The hydraulic retention time or sludge age and F/M ratio can all vary as a function of the raw waste water characteristics, e.g. composition, availability and degradability of organic substances, and the required final waste water quality. For example, nitrification occurs with lower (<0.1 kg BOD/kg MLSS per day) F/M ratios. In the sedimentation facility, the settlement of microbial flocs occurs and clear waste water is passed over a weir to a watercourse. Settled sludge is produced and mostly returned to the aeration tank. However, a proportion, i.e. the excess sludge, is wasted to maintain MLSS at a reasonable level, e.g. 3 000 mg/l [78, Metcalf & Eddy 1991].

The performance data of an activated sludge WWTP in the brewery sector is shown in Table 2.49.

Table 2.49: Performance data of an activated sludge WWTP reported for the brewing sector

<table>
<thead>
<tr>
<th>Initial load (kg COD/m³ per day)</th>
<th>1.2–1.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final BOD level (mg/l)</td>
<td>15–25</td>
</tr>
<tr>
<td>Sludge generated per kg of BOD removed (TSS/kg)</td>
<td>0.45–0.55</td>
</tr>
<tr>
<td>NB: These performance figures are valid at a temperature range of 25–35 ºC and thus not applicable during winter.</td>
<td></td>
</tr>
</tbody>
</table>

Phosphorus removal efficiencies of 40–20–30 25% have been reported using activated sludge [255, Desmidt et al. 2015].

In the sugar sector, it has been reported that low winter air and water temperatures depress the treatment capacity as bacterial activity is reduced. However, low grade waste heat from the sugar process can usually be used to increase temperatures in the system and enhance bacterial activity.

The most common problem associated with activated sludge is that of bulking. This term is used to describe biological sludge of poor settling characteristics. It is generally due to the presence of filamentous bacteria and/or excessive water bound within biological floc. One important and fundamental point to emphasise regarding bulking sludge is that prevention is better than a cure. It is reported that a typical cure for bulking is the use of chemicals, i.e. chlorination, use of other oxidative chemicals or precipitation chemicals, to kill all filamentous organisms that are not protected by activated sludge flocs. These curing methods are reportedly not very selective and can destroy the whole biological activity. Bulking can be prevented by, e.g. ensuring that the optimum balance of added nutrients is maintained, minimising both the release of nutrients and the overproduction of filamentous bacteria. Procedures to deal with bulking when it occurs, include reducing the load. The presence of ammonia as a breakdown product, provides evidence of the emission levels and shows whether denitrification is needed. The hydraulic residence time, the sludge age, and the operating temperature are the most important parameters to consider. The parameters need to be justified in terms of the breakdown of the more resistant organic substances. In addition, the use of a separate compartment or selector has been recognised as a good tool to prevent and control filamentous growth. This is an initial contact zone where the primary waste water and the returned sludge are combined. The selector involves the selective growths of floc forming organisms by providing high F/M ratios at a controlled dissolved oxygen level. The contact time is short, generally 10–30 minutes. The anoxic selector, which requires the presence of nitrate in the water, is often the choice for activated sludge systems that nitrify. In addition to providing an effective control of filamentous bacteria, anoxic selectors provide the benefits of reducing process oxygen requirements, since
nitrate-nitrogen is used as a terminal electron acceptor for the oxidation of influent biodegradable organic matter, and reducing the consumption of alkalinity during nitrification, as a result of recovery of the alkalinity in the anoxic zone. Anoxic selectors can also be quite effective in controlling filament growth because they use both kinetic and metabolic selection mechanisms.

In the dairy sector, sludge-bulking has been reported in activated sludge systems with fluctuating loads and low F/M ratios, e.g. insufficient BOD. If a selector is not used, the final sedimentation needs to be designed according to the inferior sludge settling characteristics.

To ensure that the activated sludge has enough nutrients, phosphoric acid and/or urea may be added to the influent in the event that the concentration of TP and/or TN is too low.

Cross-media effects
High energy consumption for aeration combined with mixing in the aeration tank. Installation #466 reported an energy use of approximately 2.2 kWh/kg of COD [193, TWG 2015]. Volatile waste water content can be released into the atmosphere, giving rise to odour. Aerobic biological treatment produces a relatively large amount of excess activated sludge that needs to be disposed of.

Technical considerations relevant to applicability
Widely used in the FDM sector. The technique can be used to treat high or low BOD wastewater, but will treat low BOD water highly efficiently and cost effectively. The application of this technique may be restricted due to space requirements.

Economics
The activated sludge technique provides a cost-effective treatment of soluble organic matter. Nevertheless, it is better if the waste water from the starch sector, with a COD level higher than 10 000 mg/l, is best not subjected to aerobic treatment alone.

In the soft and alcoholic drinks sector, due to the seasonal variation of the waste water, the application of the technique is usually over-dimensioned, with the corresponding high investment and operating costs.

Example plants
This technique is widely used in FDM installations [193, TWG 2015]. Used in the meat, fish, fruit and vegetable, starch, dairy, brewing, sugar, soft and alcoholic drinks and vegetable oils and fats sectors.

Reference literature
[35, Germany 2002], [72, Brewers Europe 2002], [78, Metcalf & Eddy 1991], [109, Finland 2003], [193, TWG 2015], [255, Desmidt et al. 2015]

2.3.6.2.1.2 Pure oxygen systems (T44)

Technical description
Pure oxygen systems are essentially an intensification of the activated sludge process, i.e. the injection of pure oxygen into an existing conventional aeration plant. This is often undertaken after increased or variable plant production which has rendered the aeration plant ineffective, for at least some part of its operational cycle.

Achieved environmental benefits
Reduction of BOD, TOC or COD, phosphorus and nitrogen emission levels. In comparison with activated sludge systems, odour, noise and VOC emissions are reduced as the surface of the aeration tank is essentially unbroken; and energy use is reduced.
Environmental performance and operational data
Compared to conventional activated sludge, pure oxygen systems have the ability to intensify the process by operating at a higher MLSS level. Furthermore, this technique uses less energy since 70% of the energy in conventional activated sludge is wasted due to the nitrogen occupying 70% of the air by volume [78, Metcalf & Eddy 1991].

Cross-media effects
Energy consumption for aeration combined with mixing in the aeration tank. Aerobic biological treatment produces a relatively large amount of excess activated sludge that needs to be disposed of.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique. As well as in new installations, a number of pure oxygen retrofits have been made in the FDM sector.

Economics
Since the system is operating at extremely long sludge ages and encouraging endogenous respiration, whereby the biomass ingests itself, there is a significant reduction of sludge disposal costs. Nevertheless, plants that use oxygen instead of air, have higher operational costs.

Driving force for implementation
The use of pure oxygen improves control and performance and can be retrofitted to existing plants.

Example plants
This technique has been reported in several installations of the brewing, starch, dairy, meat and fruit and vegetable sectors [193, TWG 2015].

Reference literature
[8, Environment Agency of England and Wales 2000], [193, TWG 2015]

2.3.6.2.1.3 Sequencing batch reactors (SBR) (T12)

Technical description
The SBR is a variant of the activated sludge process. It is operated on the fill and draw principle and normally consists of two identical reaction tanks. The various stages of the activated sludge processes are all carried out within the same reactor.

Achieved environmental benefits
Reduction in BOD, TOC or COD, phosphorus and nitrogen emission levels.

Environmental performance and operational data
The process is very flexible as a number of process changes are possible within the operating cycles, e.g. enhanced denitrification during the idle phase. A typical total cycle period is about six hours. The time taken for each stage of the process can be adjusted to suit local circumstances. Finally, the process sequence is independent of any influences caused by hydraulic input fluctuations. In this sense, SBR has a simpler and more robust operation if sufficient capacity is installed, i.e. fill and draw system rather than conventional activated sludge.

Since the batch wise filling leads to the formation of a readily settling activated sludge, this process is suitable for industrial waste water that has a tendency towards bulking sludge. The typical operation of a typical SBR is shown in Table 2.50.
Chapter 2

Table 2.50: Characterisation of a typical SBR

<table>
<thead>
<tr>
<th>Step</th>
<th>Purpose</th>
<th>Operation (aeration)</th>
<th>Maximum volume (%)</th>
<th>Cycle time (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill</td>
<td>Add substrate</td>
<td>Air on/off</td>
<td>25–100</td>
<td>25</td>
</tr>
<tr>
<td>React</td>
<td>Biological degradation</td>
<td>Air on/cycle</td>
<td>100</td>
<td>35</td>
</tr>
<tr>
<td>Settle</td>
<td>Clarify</td>
<td>Air off</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Draw</td>
<td>Remove waste water</td>
<td>Air off</td>
<td>35–100</td>
<td>15</td>
</tr>
<tr>
<td>Idle</td>
<td>Waste sludge</td>
<td>Air on/off</td>
<td>25–35</td>
<td>5</td>
</tr>
</tbody>
</table>

*Waste sludge may occur in other steps as well. In multitank systems, the idle phase is used to provide time for the second tank to be filled. This step may be omitted.

Source: [192, COM 2006]

Cross-media effects
Energy consumption for aeration combined with mixing in the aeration tank. Aerobic biological treatment produces a relatively large amount of excess activated sludge that needs to be disposed of.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique. The application of this technique may be restricted due to space requirements. This technique can be used to treat high or low BOD waste water, but will treat low BOD waste water very efficiently and cost effectively.

Economics
Lower capital and higher operational costs than conventional activated sludge.

Driving force for implementation
The technique is used to comply with waste water legislation and to reduce waste water charges/fees.

Example plants
This technique has been reported in several installations of the dairy, brewing, meat, oilseed and fruit and vegetable sectors. [193, TWG 2015]. Used in the meat, fruit and vegetable, dairy, vegetable oils and fats, and soft and alcoholic drinks sectors.

Reference literature
[1, CIAA 2002], [35, Germany 2002], [78, Metcalf & Eddy 1991], [193, TWG 2015], [226, EDA 2016]

2.3.6.2.1.4 Aerobic lagoon (T13)

Description
Shallow, earthen basins for the biological treatment of waste water, the contents of which are periodically mixed to allow oxygen to enter the liquid through atmospheric diffusion.

Technical description
Aerobic lagoons are large shallow earthen basins that are used for the treatment of waste water by natural processes. They involve the use of algae, bacteria, sun and wind. Oxygen, in addition to that produced by algae, enters the liquid through atmospheric diffusion. The contents of the lagoons are normally mixed periodically using pumps or surface aerators.

A variation on the aerobic lagoon is the facultative lagoon, where stabilisation is brought about by a combination of aerobic, anaerobic and facultative bacteria. Oxygen can be maintained in the upper layer of a facultative lagoon by surface re-aeration.
Achieved environmental benefits
Reduced BOD, TOC or COD, phosphorus and nitrogen emission levels.

Cross-media effects
Potential odour nuisance, soil deterioration and groundwater contamination. Energy consumption for aeration combined with mixing in the lagoon.

Environmental performance and operational data
It has been reported that lagoons provide buffer capacity due to large areas and volumes, volume and concentration equalisation in seasonal operations, and that they establish adapted biocoenoses given very long residence times. Depending on the soil characteristics, lagoons may need to be sealed, to avoid groundwater contamination.

In the sugar sector, it has been reported that surface area and depth are key elements in the rate of degradation of BOD. Degradation of BOD relies on natural processes such as the carbon, nitrogen and sulphur cycles, and the action of the bacteria. Furthermore, surface aeration is used in this sector to increase the rate of aerobic bacterial activity when needed, e.g. at low temperatures. Additional oxygen is diffused into the water by electrically driven free or fixed floating aerators. Occasionally, wind powered aerators are used where weather conditions are favourable. Mixed wind and electrical systems are available.

In wineries and olive oil mills, the use of evaporation lagoons has been reported. The waste water is left to evaporate in open basins for months.

Technical considerations relevant to applicability
Applicable in all FDM installations; The application of this technique may be restricted due to space requirements. This technique can be used to treat high or low BOD waste water, but will treat low BOD water highly efficiently and cost effectively.

In the fruit and vegetable sector, lagoons are used provided they have adequate capacity to prevent uncontrolled overflows and to enable a controlled discharge of waste water during high flow periods.

Economics
TWG, please provide information.

Driving force for implementation
The technique is used to comply with waste water legislation and to reduce waste water charges/fees.

Example plants
Lagoons are widely used in most of the FDM sectors [193, TWG 2015], the sugar, fruit and vegetable, soft and alcoholic drinks and vegetable oils and fats sectors.

Reference literature
[35, Germany 2002], [88, CIAA-CEFS 2003], [109, Finland 2003], [193, TWG 2015]

2.3.6.2.1.5 Trickling filters (T14)

Description
Waste water is distributed over a filter media where biomass grows as a film.

Technical description
In fixed film aerobic processes such as trickling filters, the biomass grows as a film on the surface of packaging media and the waste water is distributed so as to flow evenly across it. The
trickling filter medium normally consists of rocks or various types of plastic. The treated liquid is collected under the media and passed to a settling tank from where part of the liquid can be recycled to dilute the pollutant load of the incoming waste water. Variations include alternating double filtration or permanent double filtration.

**Achieved environmental benefits**
Reduction in BOD, TOC or COD, phosphorus and nitrogen emission levels. If dangerous and priority hazardous substances are used in the production process, its waste water emission levels are reduced.

**Environmental performance and operational data**
It has been reported that in the dairy sector, high rate trickling filters are typically designed to remove 50–60 % BOD. For an efficient operation, it is essential that FOG emission levels are minimised prior to being fed into the high rate filter. Following high rate filtration, secondary sedimentation may be required, depending upon the consent to discharge conditions. In the soft and alcoholic drinks sector, this technique is reported to be 70 % effective, so a further polishing step is normally needed. Phosphorus removal efficiencies of 8–12 % have been reported using trickling filters [192, COM 2006].

**Cross-media effects**
Potential odour nuisance. Energy consumption for waste water distribution.

**Technical considerations relevant to applicability**
Applicable for waste water with a relatively low BOD, or as a polishing stage after an activated sludge process or high rate filtration. Its use within the FDM sector has decreased because of the relatively large land area it requires and because of operational problems due to blockage.

**Economics**
*TWG, please provide information.*

**Driving force for implementation**
The technique is used to comply with waste water legislation and to reduce waste water charges/fees.

**Example plants**
Used in the fish, dairy, soft and alcoholic drinks and vegetable oils and fats sectors. High rate trickling filters have been used at some dairies in the UK. The FDM data collection showed that this technique is in use in one installation (#471) from the oilseed processing and refining sector [193, TWG 2015].

**Reference literature**
[192, COM 2006], [193, TWG 2015]

**2.3.6.2.1.6 Bio-towers (T15)**

**Description**
Tanks where microbial film adheres to the plastic media contained and consumes the organic material. The waste water is often recycled through the bio-tower.

**Technical description**
Waste water from the processing of FDM often has an organic load too high for conventional aerobic treatment. Consequently, treatment is necessary to reduce the BOD to an acceptable level prior to further treatment, e.g. at a MWWTP. Bio-towers or roughing filters are specially designed trickling filters (see Section 2.3.6.2.1.5) operated at high organic loading rates that can achieve high levels of BOD removal.
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The technique uses aboveground tanks containing plastic media with a high surface area. Microbial film adheres to the media and consumes the organic material. The waste water is often recycled over the bio-tower to achieve a further treatment. The waste water from these units is then discharged to a conventional biological process.

**Achieved environmental benefits**
Reduced BOD, TOC or COD, phosphorus and nitrogen emission levels.

**Cross-media effects**
Potential odour nuisance. Noise emissions may arise from blowing air into the bio-tower. TSS may be created.

**Environmental performance and operational data**
Plastic media of the type used in bio-towers has a surface area ratio of 100–240 m$^2$/m$^3$. Loading rates of 0.5 kg BOD/m$^3$/day have been reported to achieve over 90% removal; up to 60% removal is possible with loadings of 2.5 kg BOD/m$^3$/day. Blockage and unstable sludge might occur.

**Technical considerations relevant to applicability**
Applicable in all FDM installations with high organic load in waste water.

**Economics**
TWG, please provide information.

**Driving force for implementation**
Bio-towers are an effective method for reducing BOD to something closer to that of domestic sewage.

**Example plants**
This technique has been reported in several installations of the dairy, brewing and starch sectors [193, TWG 2015].

**Reference literature**

2.3.6.2.1.7 Rotating biological contactors (RBC) (T16)

**Description**
An RBC consists of a series of closely spaced circular discs of polystyrene or polyvinyl chloride. The discs are submerged in waste water and rotated slowly through it.

**Technical description**
In operation, biological growths become attached to the surface discs and eventually form a slime layer over the entire wetted surface area of the discs. The rotation of the discs puts the biomass into contact with the organic material in the waste water and then with the atmosphere for the adsorption of oxygen alternately. The rotation is also the mechanism for removing excess solids from the discs so they can be carried from the unit to a sedimentation tank.

**Achieved environmental benefits**
Reduced BOD, TOC or COD, phosphorus and nitrogen and TSS emission levels.

**Environmental performance and operational data**
Properly designed RBCs are quite reliable because of the large amount of biological mass present (low operating F/M ratio). This large biomass also permits them to withstand hydraulic and organic surges more effectively. Staging in this plug-flow system eliminates short circuiting.
and dampens shock loadings. It is reported that blockage of the discs may occur. Phosphorus removal efficiencies of 8–12% have been reported using RBCs.

**Cross-media effects**
Potential odour nuisance.

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of this technique, e.g. to reduce BOD, phosphorus nitrogen and TSS levels.

**Economics**
TWG, please provide information.

**Driving force for implementation**
The technique is used to comply with waste water legislation and to reduce waste water charges/fees.

**Example plants**
Used in the fish and vegetable oils and fats sectors. The FDM data collection showed that this technique is in use in one installation (#406) from the dairy sector [193, TWG 2015].

**Reference literature**
[78, Metcalf & Eddy 1991], [193, TWG 2015]

**Biological aerated flooded filters (BAFF) and submerged biological aerated filters (SBAF) (T17)**

**Technical description**
Biological aerated flooded filters (BAFF) and submerged biological aerated filters (SBAF) are hybrid suspended/attached growth systems, which are best described as activated sludge plants which contain high voidage media to encourage bacterial growth. Generally, they also allow a certain amount of physical filtration within the same structure.

**Achieved environmental benefits**
Reduced BOD/COD levels.

**Environmental performance and operational data**
Backwashing takes place approximately every 24 hours to remove surplus biomass. Consequently, secondary sedimentation is not required. To treat the backwashing water, a sedimentation or flotation facility is required.

**Technical considerations relevant to applicability**
Primary use is as a polishing stage in domestic waste water treatment, however SBAF is being used increasingly in the FDM sector.

**Economics**
BAFF reactors are reported to be a cost effective treatment of soluble organic matter.

**Example plants**
Used in the meat, fruit and vegetable, soft and alcoholic drinks and dairy sectors.

**Reference literature**
[8, Environment Agency of England and Wales 2000]
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2.3.6.2.1.8 High- and ultrahigh-rate aerobic filters (T48)

Description
Biological treatment of waste water where air is introduced through the nozzle, providing a high shear force on the bacteria and an intense degree of turbulence/oxygenation.

Technical description
High- and ultrahigh-rate aerobic filters give the potential for higher than usual loading rates to aerobic systems. The process employs a high waste water recycle rate, directed through an integral nozzle assembly. Air is introduced through the nozzle, providing a high shear force on the bacteria and an intense degree of turbulence/oxygenation. It is this high shear force undergone by the bacteria which makes this process so different from other aerobic techniques, i.e. microorganisms are passed through the nozzle resulting in the existence of only very small bacteria in the system, which differs from other systems where bacteria are not subjected to such shear and where higher life forms also exist.

Achieved environmental benefits
Reduced BOD, TOC or COD, phosphorus and nitrogen emission levels.

Cross-media effects
High energy consumption. These filters do not give a quality of waste water suitable for river discharge.

Environmental performance and operational data
Ultrahigh rate aerobic systems offer the potential for loading aerobic systems up to 50 - 100 times greater than conventional aerobic treatment. Nevertheless, since they do not give a quality of waste water suitable for river discharge, a second aerobic stage, which is more conservatively loaded, is required.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
Reduced capital investment.

Driving force for implementation
Reduced plant size and capital investment.

Example plants
This technique has been reported in two FDM installations belonging to the starch production sector [193, TWG 2015]. Used in the fish sector.

Reference literature
[193, TWG 2015]

2.3.6.2.2 Anaerobic processes

2.3.6.2.2.1 Anaerobic lagoons (T19)

Description
Shallow earthen basins for the anaerobic treatment of waste water, the contents of which are not mixed.

Technical description
Anaerobic lagoons are similar to aerobic lagoons (see Section 2.3.6.2.1.4), with the difference that the anaerobic lagoons are not mixed [78, Metcalf & Eddy 1991]. They may give rise to
odour problems, due to \( \text{H}_2\text{S} \) emissions [116, CIAA-AAC-UFE 2003]. In the soft and alcoholic drinks sector, it has been reported that anaerobic lagoons are more than 2 m deep.

**Achieved environmental benefits**
Reduced BOD and TOC or COD emission levels and sludge stabilisation.

**Environmental performance and operational data**
TWG, please provide information.

**Cross-media effects**
Potential odour nuisance, soil deterioration and groundwater contamination.

**Technical considerations relevant to applicability**
Applicable in FDM installations with waste water containing a high load of soluble wastes.

**Economics**
TWG, please provide information.

**Driving force for implementation**
To pretreat waste water with high TOC or COD and BOD loads before aerobic treatment.

**Example plants**
This technique has been reported in several FDM installations belonging to the sugar manufacturing sector [193, TWG 2015].

**Reference literature**
[78, Metcalf & Eddy 1991], [116, CIAA-AAC-UFE 2003], [193, TWG 2015]

### 2.3.6.2.2.2 Anaerobic contact processes (T20)

**Description**
Untreated waste water is mixed with recycled sludge solids and then digested in a reactor sealed off to prevent entry of air.

**Technical description**
Untreated waste water is mixed with recycled sludge solids and then digested in a reactor sealed off from the entry of air. The waste water/sludge mixture is externally separated (e.g. by sedimentation or by DAF). The anaerobic contact process can be linked to the aerobic activated sludge process, as separation and recirculation of the biomass is incorporated into the design. The anaerobic degradation process results in a mixture of methane and carbon dioxide in a ratio of 1/1 to 3/1, thus producing a combustible gas with a high energy content which is normally used for fuel replacement or other energy supply facilities.

**Achieved environmental benefits**
Reduced BOD and TOC or COD emission levels and sludge stabilisation. Reduced generation of sludge compared to aerobic processes.

**Environmental performance and operational data**
Compared with the high performance processes of UASB (see Section 2.3.6.2.2.4) and expanded and fluidised bed reactors (see Section 2.3.6.2.2.6), contact stabilisation processes do not produce such high biomass concentrations in the reactor and are, therefore, run at comparatively lower space loadings (usually up to 5 kg COD/m³ per day). Their main advantage, however, lies in their relatively trouble-free operation and, in particular, their lack of clogging problems.
Since the anaerobic sludge produces gas outside the reactor and the gas volume continues to rise, there is frequently a need for a degasification unit between the methane reactor and the separator unit. The degasification may be achieved by means of vacuum degassing, stripping, cooling or slowly rotating agitators. This feature allows the process to be operated at 6–14 h retention times.

In a fruit and vegetable installation (#030), the addition of an anaerobic stage as a first step in an existing waste water treatment plant led to an organic load reduction of more than 60%. In a brewery installation (#360), waste water was treated in an anaerobic reactor with a capacity of 8 000 m³/d and 40 000 kg COD/day, achieving an 80% reduction in COD emission levels [193, TWG 2015].

Cross-media effects
Normally anaerobic processes are run as biological high-load stages that need an additional downstream biological (aerobic) treatment. Compared with aerobic processes, the energy consumption is considerably less, because energy is not needed for air or oxygen supply to the reactor, only for efficient stirring.

The arising of combustible gases and the formation of metabolites such as short chain carboxylic acids make the use of closed equipment necessary to prevent the efflux of odour. Odour abatement might be necessary.

Technical considerations relevant to applicability
Applicable in FDM installations with waste water containing a high load of soluble wastes.

Economics
An investment cost of EUR 1 600 000 and annual operating cost of EUR 50 000 have been reported for the anaerobic treatment stage, associated with a WWTP capacity of 2 500 m³/day [193, TWG 2015].

Driving force for implementation
- Pretreatment of waste water with high TOC or COD and BOD loads before aerobic treatment.
- Energy recovery from methanisation.
This technique provides a relatively trouble-free operation and lack of clogging problems.

Example plants
This technique is reported in various FDM sectors [193, TWG 2015] the meat and sugar sectors.

Reference literature

2.3.6.2.2.3 Anaerobic filters (T24)

Technical description
In the anaerobic filter, the growth of anaerobic bacteria is established on a packaging material. The packaging retains the biomass within the reactor and it also assists in the separation of the gas from the liquid phase. The system can be operated in the upflow or downflow mode.

Achieved environmental benefits
Reduced BOD and TOC or COD emission levels and waste sludge stabilisation.
Environmental performance and operational data
Because the bacteria are retained on the media and do not wash off in the waste water, mean cell residence times in the order of 100 days can be obtained. Suitable for treating heavily polluted waste water having COD concentration of 10 000–70 000 mg/l.

In a dairy (#296), an anaerobic filter is installed and designed to treat 4 500 m$^3$ of effluent and to achieve a COD reduction of between 80 % and 90 %. The system achieves a COD reduction of 80 % on a consistent basis. The filter vessel is randomly packed with plastic rings which provide a host for the growth of fixed biofilms. The system is designed as a downflow system whereby the effluent is pumped to the top of the vessel from where it is directed to a series of sprinkler heads which disperse the water over the bed. The effluent falls through the bed via gravity and is collected at the base. It is noted that a recirculation loop is incorporated within the anaerobic system to recirculate approximately 50 % of the flow to the top of the bed. Biogas generated from the system is collected from the top of the tank and is directed to a CHP plant for electricity generation. The anaerobic plant uses approximately 680 KWh of electricity per day. Overall, the system is a net producer of electricity with 350 litres of methane produced per kg of COD [193, TWG 2015].

Cross-media effects
There is a need for an additional downstream biological (aerobic) treatment. Odour abatement might be necessary.

Technical considerations relevant to applicability
Applicable in FDM installations with waste water containing a high load of soluble wastes.

Economics
TWG, please provide information.

Driving force for implementation
- Pretreatment of waste water with high TOC or COD and BOD loads before aerobic treatment.
- Energy recovery from methanisation.

Example plants
This technique has been reported in two FDM installations (#296, #378) belonging to the dairy sector [193, TWG 2015].

Reference literature

2.3.6.2.2.4 Upflow anaerobic sludge blanket (UASB) (T22)

Description
Waste water is introduced at the bottom of the reactor where it flows upward through a sludge blanket composed of biologically formed granules or particles. The waste water phase passes into a settling chamber where the solid content is separated; the gases are collected in domes at the top of the reactor.

Technical description
In the UASB system, the waste water is directed to the bottom of the reactor for uniform distribution. The waste water passes through a blanket of naturally formed bacterial granules with good settling characteristics so that they are not easily washed out of the system. The bacteria carry out the reactions and then natural convection raises a mixture of gas, treated waste water and sludge granules to the top of the reactor. Patented three-phase separator arrangements are used to separate the final waste water from the solids (biomass) and the biogas.
Achieved environmental benefits
Reduced BOD and TOC or COD emission levels and sludge stabilisation.

Environmental performance and operational data
Loadings of up to 60 kg COD/m\(^3\) per day have been reported, but a more typical loading rate is 10 kg COD/m\(^3\) per day with a hydraulic retention time of 4 hours [8, Environment Agency of England and Wales 2000]. Table 2.51 shows the reported performance of a UASB reactor in the brewing sector.

Table 2.51: Reported performance of a UASB reactor in the brewing sector

<table>
<thead>
<tr>
<th>Initial load (kg COD/m(^3) per day)</th>
<th>5–10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final COD level (mg/l)</td>
<td>100–500</td>
</tr>
<tr>
<td></td>
<td>500–1,000</td>
</tr>
<tr>
<td>Sludge generated per kg of COD removed (TSS/kg)</td>
<td>0.04–0.08</td>
</tr>
</tbody>
</table>

NB: Further treatment is necessary to discharge waste water with these concentrations to a receiving water body. 
Source: [72, Brewers Europe 2002]

One disadvantage of the UASB reactor is the technique’s sensitivity to FOG. Fat emission levels have to be below 50 mg/l in the waste water, otherwise they have a detrimental effect on the process. On the other hand, a particular advantage of the process is the formation of pellets. This allows not only rapid reactivation after month-long breaks in operation, but also the sale of surplus sludge pellets, e.g. for the inoculation of new systems.

This process is particularly suitable for waste water with a low solid content and with relatively low influent COD levels (< 2 000 mg/l) and when small surface area is available.

Cross-media effects
There is a need for an additional downstream biological (aerobic) treatment. Odour abatement might be necessary.

Technical considerations relevant to applicability
Applicable in FDM installations with waste water containing a high load of soluble wastes.

Economics
TWG, please provide information.

Driving force for implementation
- Pretreatment of waste water with high TOC or COD and BOD loads before aerobic treatment.
- Energy recovery from methanisation.

Example plants
This technique has been reported in several FDM installations belonging to the meat, dairy, fruit and vegetable, brewing, starch and sugar sectors [193, TWG 2015]. Sludge-bed reactors are currently the most widespread used reactors in the FDM sector.

Reference literature
2.3.6.2.2.5 Internal circulation (IC) reactors (T23)

Technical description
There is a special configuration of the UASB process (see Section 2.3.6.2.2.4), i.e. the IC reactor, in which two UASB reactor compartments can be put on top of each other, one high loaded and one low loaded. The biogas collected in the first stage drives a gas-lift resulting in an internal recirculation of the waste water and sludge, hence the process name.

Achieved environmental benefits
Reduced BOD and TOC or COD emission levels and sludge stabilisation.

Environmental performance and operational data
One of the main advantages of the IC reactor is that it can undergo a certain amount of self-regulation, irrespective of the variations in incoming flows and loads. As the load increases, the quantity of methane generated also increases, and further increases the degree of recirculation and hence dilution of the incoming load. Typical loading rates for this process are in the range: 15–35 kg COD/m³ per day [8, Environment Agency of England and Wales 2000].

Technical considerations relevant to applicability
Applicable in FDM installations with waste water containing a high load of soluble wastes.

Economics
TWG, please provide information.

Driving force for implementation
- Pretreatment of waste water with high TOC or COD and BOD loads before aerobic treatment.
- Energy recovery from methanisation.

Example plants
This technique has been reported in several FDM installations belonging to the brewing, oilseed processing and refining, starch and dairy sectors [193, TWG 2015].

Reference literature
[8, Environment Agency of England and Wales 2000], [193, TWG 2015]

Hybrid UASB reactors (T24)

Technical description
The hybrid process is a variation of the conventional UASB (see Section 2.3.6.2.2.4). This incorporates a packed media zone above the main open zone. This allows for the collection and retaining of non-granulated bacteria which, in conventional UASB reactors, would be lost from the process. The lower sludge zone acts in exactly the same way as within a conventional UASB reactor and is responsible for the majority of the biodegradation of the organic material. The role of the microorganisms and media in the packed zone is to provide a certain amount of polishing treatment, to hold biological solids in reserve, and to prevent the biomass from washing out of the reactor.

Achieved environmental benefits
Reduced BOD/COD levels.

Environmental performance and operational data
Anaerobic hybrids are high rate systems with typical loading rates in the range of 10–25 kg COD/m³ per day.

Technical considerations relevant to applicability
Widely applicable in the FDM sector.
2.3.6.2.2.6 Fluidised and expanded bed reactors (T25)

Technical description
These reactors are similar to the anaerobic filters (see Section 2.3.6.2.2.3). If the particles and biomass are completely mixed, the process is known as a fluidised bed, whereas a partially mixed system is known as an expanded bed.

Achieved environmental benefits
Reduced BOD and TOC or COD emission levels and waste sludge stabilisation.

Environmental performance and operational data
To achieve high volume-time yields of 15–35 kg COD/m$^3$ per day, it is absolutely essential to fill the methane reactors with as constant a volume of adequately acidified solids-free waste water as possible. For this reason, all large scale systems have been built as two-stage systems, i.e. with a separate acidification stage. In operational large-scale systems the influent waste water for treatment has relatively low pollution loads with an average COD of between 1 500 and 3 600 mg/l [35, Germany 2002].

In the fluidised bed reactor the carrier material is constantly in motion, with a bed expansion of 50% or more. The carrier material (usually sand but sometimes pumice or plastic pellets) is kept in suspension by means of high recirculation rates. The recirculation is strong enough to keep the carrier material in suspension, but care should be taken to ensure that excessive circulation does not cause the biomass to become detached from the carrier material.

The expanded bed reactor also incorporates support media, often sand or synthetic plastic materials. Light materials are often used to minimise the up-flow velocities required to fluidise the beds, particle sizes are typically in the range 0.3–1.0 mm [8, Environment Agency of England and Wales 2000].

Cross-media effects
There is a need for an additional downstream biological (aerobic) treatment. Odour abatement might be necessary.

Technical considerations relevant to applicability
Applicable in FDM installations with waste water containing a high load of soluble wastes.

Economics
TWG, please provide information.

Driving force for implementation
- Pretreatment of waste water with high TOC or COD and BOD loads before aerobic treatment.
- Energy recovery from methanisation.

Example plants
Used in the sugar sector. This technique has also been reported in one FDM installation (#096) belonging to the oilseed sector [193, TWG 2015].

Reference literature
2.3.6.2.2.7 Expanded granular sludge bed reactors (EGSB) (T26)

Technical description
EGSB reactors use granular sludge of the type found in UASB reactors (see Section 2.3.6.2.2.4) but they operate with a much greater depth of granular sludge and a higher water rise rate. The digester uses recirculated treated water and is fitted with a three-phase (solid, liquid, gas) separator.

Achieved environmental benefits
Reduced BOD and TOC or COD emission levels and sludge stabilisation, and nitrogen levels. Reduced electrical energy requirements due to power generation by burning the methane produced in the CHP unit, e.g. in a molasses distillery.

Environmental performance and operational data
Loading rates up to 35 kg COD/m$^3$ per day have been reported [Environment Agency of England and Wales 2000]. The water rise rate is typically of 3 m$^3$/h, compared to 1 m$^3$/h for a UASB. The initial commissioning/acclimatisation phase is not long for EGSB reactors. Table 2.52 shows the reported performance of an EGSB reactor in the brewing sector.

Table 2.52: Reported performance of an EGSB reactor in the brewing sector

| Initial load (kg COD/m$^3$ per day) | 15-25 |
| Final COD level (mg/l) | 100-500, 500-1000 |
| Sludge generated per kg of COD removed (SS/kg) | 0.04-0.08 |

In an example molasses distillery, an EGSB reactor treats the condensed vapours from the condensation unit and the singlings from distillation/rectification. The reactor reduces the COD and nitrogen load in the downstream activated sludge unit. The methane gas produced is burned in a CHP plant, to generate electricity and heat. The high efficiency of the reactor, results in the production of only small quantities of surplus aerobic sludge. In this example, it is concentrated in a decanter and used for agricultural purposes or disposed of to a MWWTP.

Cross-media effects
There is a need for an additional downstream biological (aerobic) treatment. Odour abatement might be necessary.

Technical considerations relevant to applicability
Applicable in FDM installations with waste water containing a high load of soluble wastes.

Economics
TWG, please provide information.

Driving force for implementation
- Pretreatment of waste water with high TOC or COD and BOD loads before aerobic treatment.
- Energy recovery from methanisation.
Example plants
This technique has been reported in several FDM installations belonging to the sugar, soft and alcoholic drinks and brewing sectors: ethanol brewing, oilseed processing and refining, starch and dairy sectors [193, TWG 2015].

Reference literature
[35, Germany 2002], [72, Brewers Europe 2002], [193, TWG 2015]

2.3.6.2.3 Aerobic/anaerobic combined processes

2.3.6.2.3.1 Membrane bioreactor (MBR) (T27)

Description
A combination of activated sludge treatment and membrane filtration. Two variants are used:
- an external recirculation loop between the activated sludge tank and the membrane module;
- immersion of the membrane module into the aerated activated sludge tank, where the effluent is filtered through the hollow fibre membrane, the biomass remaining in the tank (this variant is less energy-consuming and results in more compact plants).

Technical description
A MBR is a variation on a conventional activated sludge treatment system whereby a number of membrane modules, or cartridges, replace the secondary clarifier and the tertiary filtration step (see Figure 2.12) within the body of the reactor vessel. Following biological treatment, the mixed liquor is pumped under static head pressure to the membrane unit where the solids and liquids are separated, the clean waste water is discharged, and the concentrated mixed liquor is pumped back to the bioreactor.

The MBR can be operated in either aerobic or anaerobic mode, thereby increasing the range of suitable chemicals, e.g. used for membrane cleaning in biological treatment. Typical arrangements consist of vacuum-driven membrane units submerged in the aerated part of the bioreactor or pressure-driven membrane systems located outside the bioreactor. Membranes are typically configured hollow tube fibres or flat panels and have pore sizes ranging from 0.1 microns to 0.4 microns.

Figure 2.12: Simplified process flow diagram of the MBR system
Achieved environmental benefits
The achieved environmental benefits of the use of a membrane bioreactor include \[242, \text{COM 2016}\]:

- reduction of the load of suspended solids, COD, BOD, TOC, TP by 95–99 %;
- reduction of the microbiological health risk to levels that comply with Directive 2006/7/EC concerning the management of bathing water quality;
- reduction of the volume of sludge compared to conventional aerated sludge treatment;
- reduction of the plant footprint compared to conventional aerated sludge treatment, especially if tertiary filtration and a UV disinfection unit are necessary to achieve comparable output quality.

Reduced BOD/COD levels.

Environmental performance and operational data
An MBR operates across a range of loading rates, but can achieve a higher treatment rate in a number of ways, i.e. increased static pressure increases the amount of dissolved oxygen thereby aiding mass transfer; using oxygen instead of air and using multistage system to optimise the process. For oil and grease applications, concentrations of BOD in the waste water may be reduced to less than 15 mg/l.

A MBR provides highly efficient biomass separation, allowing the biomass concentration within the upstream reactor to be up to ten times greater than the concentration normally attainable in a conventional suspended growth system. When using a MBR, no secondary sedimentation is required and:

- very broad MLSS levels can be achieved in the bioreactor, i.e. 12–17 000 mg/l;
- very low COD and TSS emission levels can be achieved after treatment; the dairy installation #409 reported emission levels in the range of 2–4 mg COD/l and 4.6–11 mg TSS/l as yearly averages \[193, \text{TWG 2015}\].

The energy consumption, for pumping, might be significantly higher than conventional activated sludge but it can be minimised by applying gravity feed of the waste water. An example dairy in Ireland treats 9 000 m$^3$/d of waste water to high standards for discharge to a local watercourse, applying gravity feed to make the process low energy intensive. The dairy installation #409 reported an energy consumption of 2.6–3.2 kWh/m$^3$ of waste water treated, when applying ultrafiltration almost continuously, and reverse osmosis to reuse waste water in the CIP process when needed.

Fouling of the membranes may be a major problem. Aeration and backwashing are used to control this problem, which may result in additional waste water being produced. DAF (see Section 2.3.6.1.6) is used to scour and clean the membrane surfaces to prevent biofouling.

Cross-media effects
Cross-media effects include energy consumption (mainly for pumping and aeration) and chemical consumption (for membrane cleaning), as well as membrane replacement. Higher energy consumption than conventional activated sludge and additional waste water produced when the fouling of the membranes occurs.

Technical considerations relevant to applicability
A MBR is applicable in all FDM installations. This technique has the advantage of having low space requirements. This system is ideal for higher pollutant load, lower volume waste water. It is especially attractive in situations where a long solids retention time is required to achieve the necessary biological degradation of the pollutants. Furthermore, waste water containing not readily degradable compounds, e.g. phenols, pesticides, herbicides and chlorinated solvents, and high organic pollution can be treated with a MBR. Advantages and disadvantages compared to the conventional activated sludge process are given in Table 2.53.
Table 2.53: Advantages and disadvantages associated with membrane bioreactors

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Smaller space requirements</td>
<td>• High energy costs because of the high pressure drop and high air flushing rate required for its operation</td>
</tr>
<tr>
<td>• Reduced amount of sludge (compared to conventional activated sludge system)</td>
<td>• Membranes are sensitive to abrasion so when retrofitting an existing WWTP with a MBR unit, it should be verified that abrasion will not occur (e.g. the quality of the concrete of the tanks should be checked)</td>
</tr>
<tr>
<td>• For medium to highly loaded influents (3–30 g/l of COD), a major benefit of MBR treatment plants is the ability to keep a good efficiency with inlet COD variations, whereas keeping the same performance with a conventional activated sludge plant requires larger equalisation tanks than with MBRs</td>
<td>• Silicones in the influent must be prohibited as they rapidly plug the membranes</td>
</tr>
<tr>
<td>• Contrary to a conventional clarifier, the MBR system may act as a physical barrier in upset conditions</td>
<td>• Pressure variations must be controlled as membranes are quite sensitive and can break</td>
</tr>
<tr>
<td>• Can operate at much higher solids concentrations (typically 8 000–12 000 mg/l) compared to the conventional activated sludge system (typically 3 000–6 000 mg/l)</td>
<td>• Once abrasion and pressure variations are under control, ceramic membranes have constant performance without aging loss</td>
</tr>
<tr>
<td>• Once abrasion and pressure variations are under control, ceramic membranes have constant performance without aging loss</td>
<td>• High energy costs because of the high pressure drop and high air flushing rate required for its operation</td>
</tr>
<tr>
<td>• Membranes are sensitive to abrasion so when retrofitting an existing WWTP with a MBR unit, it should be verified that abrasion will not occur (e.g. the quality of the concrete of the tanks should be checked)</td>
<td>• Silicones in the influent must be prohibited as they rapidly plug the membranes</td>
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<tr>
<td>• Pressure variations must be controlled as membranes are quite sensitive and can break</td>
<td>• Silicones in the influent must be prohibited as they rapidly plug the membranes</td>
</tr>
</tbody>
</table>

Source: [242, COM 2016]

Economics
High energy costs, although the running costs are comparable or lower than an alternative aerobic waste water treatment with similar emission levels to those obtained by a MBR.

Driving force for implementation
Possibility to reuse the water and therefore reduced costs.

Example plants
This technique has been reported in several FDM installations belonging to the dairy, fruit and vegetable, and oilseed processing and refining sectors [193, TWG 2015]. Example installations include #401, #406 and #409. Used in the meat, fruit and vegetable, dairy and soft and alcoholic drinks sectors. It is reported to be under development in the starch sector.

Reference literature

2.3.6.2.3.2 Multistage systems (T28)

Description
Combination of various aerobic and anaerobic techniques for waste water treatment.

Technical description
The various aerobic and anaerobic waste water treatment processes can be applied alone or in combination. When they are applied in combination arranged in series, the technique is called multistage systems. Waste water treatment takes place successively in individual stages, which are kept separate from each other by means of separate sludge circuits.

The following process combinations are generally used:

- activated sludge/activated sludge;
trickling filter/trickling filter;
- trickling filter/activated sludge;
- activated sludge/trickling filter;
- lagoons/activated sludge;
- lagoons/trickling filter;
- activated sludge/UASB reactor.

**Achieved environmental benefits**
Reduced BOD and TOC or COD emission levels and water reuse.

**Environmental performance and operational data**
In the meat, fruit and vegetable and soft and alcoholic drinks various FDM sectors, a two-stage biological system, anaerobic followed by aerobic, can be used to achieve a quality of waste water suitable for reuse or direct discharge to a watercourse.

The waste water from the oilseed installation (#086) for the processing of rape and soy, and the refining of rape, soya and palm oil, is generated from several unitary operations such as vacuum systems (by the use of vacuum ejectors), water and acid degumming, hexane recovery techniques, and wet scrubbers for air cleaning purposes, among others. The COD concentration of the waste water lies between 1 000 mg/l and 5 000 mg/l, which is mainly constituted of a mixture of long-chain fatty acids and volatile fatty acids. The waste water is treated in two consecutive stages: anaerobic treatment, by the use of a high-rate UASB reactor, and an activated sludge process divided into a high load and a low load phase. Phosphoric acid is used (0.5 m³/month) as a source of phosphorus in the anaerobic reactor. Each stage includes aeration basins and DAF units for sludge separation. The electricity consumption of the waste water treatment plant is 187 000–212 000 KWh per month. The global removal efficiency is 96–98 % for total COD (49 mg/l as a yearly average). The removal of total nitrogen is normally in the range of 65–85 %. The removal of phosphorus lies between 15 % and 40 %. Biogas is produced at a rate of 0.27–0.7 Nm³ per kg of COD removed in the anaerobic reactor. The biogas is used in the co-generation plant to reduce natural gas consumption [193, TWG 2015].

In a sugar manufacturing installation (#412), the water used to convey sugar beet into the factory is separated from the beet using vibrating screens. The water, containing soil washed from the beet (during the fluming of the beet), is passed to a clarifier where the soil concentration is increased. The overflow from the clarifier is returned to the fluming system while the underflow is passed to settlement lagoons. Some natural treatment of the BOD in the water occurs in these lagoons while the soil settles. The water from these lagoons is then passed to anaerobic/aerobic treatment; where there is an excess of water for treatment, a certain quantity will be stored for water treatment. The effluent from the anaerobic treatment stage is split. Part is recycled to the fluming system to control pH and odour, while the rest is passed to anoxic and aerobic treatment, where it is co-processed with condensate that contains ammonia. The aerobic treatment has a removal capacity of approximately 7 tonnes of COD per day with an influent COD concentration of 1 000 mg/l and effluent COD concentration of 150 mg/l at 300 m³/d [193, TWG 2015].

**Cross-media effects and Driving force for implementation**
Those indicated for the corresponding techniques combined.

**Technical considerations relevant to applicability**
Applicable in FDM installations with highly polluted waste water.

**Economics**
An operating cost of EUR 2–3 per m³ of treated waste water was reported for an activated sludge/UASB reactor system. An annual operating cost of around EUR 650 000 (costs of fuel, electricity, consumables, labour and maintenance) was reported for a combined aerobic and anaerobic waste water treatment system with a capacity of around 1 300 000 m³/year [193, TWG 2015].
Example plants
This technique has been reported in several FDM installations belonging to the sugar, dairy, soft drinks and juice and starch sectors [193, TWG 2015]. Used in the meat, fruit and vegetable, soft and alcoholic drinks, vegetable oils and fats and starch sectors.

Reference literature
[193, TWG 2015]

2.3.6.3 Tertiary treatment
2.3.6.3.1 Biological Nitrification and denitrification (T29)

Description
A two-step process that is typically incorporated into biological waste water treatment plants. The first step is the aerobic nitrification where microorganisms oxidise ammonium (NH$_4^+$) to the intermediate nitrite (NO$_2^-$), which is then further oxidised to nitrate (NO$_3^-$). In the subsequent anoxic denitrification step, microorganisms chemically reduce nitrate to nitrogen gas.

Technical description
A more detailed technical description of biological nitrification and denitrification can be found in the CWW BREF [242, COM 2016].

In preceding denitrification, the incoming waste water first enters the denitrification basin. NH$_4^-$N passes through the basin unchanged, whereas organic N is partially hydrolysed to NH$_4^-$N. In the subsequent nitrification basin, the hydrolysis is completed and the ammonium in particular is nitrified. The nitrate formed is transported via the return sludge and also via intensive recirculation from the nitrification basin outlet to the denitrification basin, where it is reduced to nitrogen.

In a system with simultaneous denitrification, aerobic and anoxic zones are created on a targeted basis by controlling the input of oxygen into the basin. Simultaneous denitrification systems are mostly designed as circulation basins or carousel basins.

In intermittent denitrification, fully stirred activated sludge basins are periodically aerated. In the activated sludge basin, aerobic and anoxic processes take place successively in the same basin. The extent of nitrification and denitrification can largely be adjusted to the feed conditions by varying the operating times.

In cascaded denitrification, several basin compartments consisting of anoxic and aerobic tones (preceding denitrification) are arranged in series without intermediate sedimentation. The untreated water is fed into the first cascade to ensure optimum utilisation of the substrate present in the waste water. The return sludge flow is fed into the first basin. Here, there is no need for internal recirculation within the individual stages.

Achieved environmental benefits
Nitrogen emission levels are reduced and energy is saved.

Environmental performance and operational data
This technique has a high potential for removal efficiency, a high process stability and reliability, relatively easy process control and space requirements.
In the starch sector, it is reported that nitrification and denitrification reactions occur in an anoxic medium which can be obtained either by a sequenced aeration of the activated sludge tank or in a separated anoxic zone. The removal of nitrogen is carried out using preceding denitrification.

**Cross-media effects**

Biological nitrification and denitrification imply the consumption of energy. In some cases, an external carbon source needs to be added.

**Technical considerations relevant to applicability**

Although nitrification may not be applicable in the case of high chloride concentrations (i.e. around 10 g/l), such a high emission level is improbable in the FDM sector. This technique is not applicable when the final treatment does not include a biological treatment. **Applicable in FDM installations with waste water containing nitrogen compounds.**

**Economics**

TWG, please provide information.

**Driving force for implementation**

Member States' legislation to reduce eutrophication of fresh water.

**Example plants**

This technique is widely used in FDM installations [193, TWG 2015]. Used in the fruit and vegetable and starch sectors.

**Reference literature**

[35, Germany 2002 ], [14, VITO et al. 2001 ], [78, Metcalf & Eddy 1991 ], [193, TWG 2015], [242, COM 2016]

### 2.3.6.3.2 Ammonia stripping (T30)

**Description**

Waste water is brought into contact with a high flow of an airstream in order to transfer ammonia from the water phase to the gas phase.

**Technical description**

In addition to biological processes, a number of physico-chemical processes are available for the purification of nitrogen loaded waste water streams. In the FDM sector, condensate, which contains high concentrations of ammonium, can be stripped of ammonia in a two-step system. The system consists of a desorption and an absorption column, which are both filled with packaging material to increase the water-air interface.

The desorption column is charged with an alkalised condensate from the top, to shift the \( \text{NH}_4^+ - \text{NH}_3 \) equilibrium in the direction of \( \text{NH}_3 \), which subsequently drops downwards in the column. At the same time, air is injected at the base of the column. In the countercurrent process, a transfer of ammonia, therefore, takes place from the aqueous phase into the gaseous phase.

Subsequently, the air enriched with ammonia is transferred into the adsorption column, where the removal of the ammonia from the stripping air is effected by an acidic solution, approximately 40 % ammonium sulphate, being circulated in the desorption column. The air now cleansed of ammonia is finally reused for stripping.

The condensate, which has a low ammonium content after stripping, is partially reused as service water and the remaining condensate surplus is channelled into the aerobic biological purification process. The technique is summarised in Figure 2.13.
Figure 2.13: The ammonia stripping process

**Achieved environmental benefits**
Reduced nitrogen emission levels. Less waste created, i.e. the ammonium sulphate \((\text{NH}_4\text{}_2\text{SO}_4)\) solution created during this process can be utilised as a liquid fertiliser or non-protein source of nitrogen for the feeding of ruminants. Cleansed water can be reused as service water, i.e. reuse of condensate, which has a low ammonium content.

**Environmental performance and operational data**
Ammonium concentrations of < 2 mg/l can be achieved in the outflow. This corresponds to an efficiency degree of approximately 99 %. Example design parameters for ammonia stripping from condensate generated in the sugar sector are shown in Table 2.54.

**Table 2.54: Design parameters for ammonia stripping of sugar industrial waste water (condensate)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water throughput</td>
<td>m³/h</td>
<td>400</td>
</tr>
<tr>
<td>Ammonia concentration in the condensate</td>
<td>mg/l</td>
<td>150</td>
</tr>
<tr>
<td>Ammonium concentration in the outflow (at 55 °C)</td>
<td>mg/l</td>
<td>1.7</td>
</tr>
<tr>
<td>Air consumption</td>
<td>Nm³/h</td>
<td>320000</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>kW</td>
<td>300</td>
</tr>
</tbody>
</table>

**Cross-media effects**
Energy consumption is required for pouring the waste water into the adsorption columns. The condensate should be treated in the WWTP.
Technical considerations relevant to applicability
Technically, the process of ammonia stripping has proven itself for waste water streams with high ammonia concentrations.

Economics
TWG, please provide information.

Driving force for implementation
The low ammonium content condensate and the ammonium sulphate solution can both be reused.
Ammonia concentration in waste water is normally regulated because of its toxic effect on the ecosystem of the receiving water.

Example plants
This technique has been reported in one FDM installation (#295) belonging to the dairy sector [193, TWG 2015].

Reference literature
[35, Germany 2002], [192, COM 2006], [193, TWG 2015]

2.3.6.3.3 Enhanced biological phosphorus removal (T34)

Description
A combination of aerobic and anaerobic treatment is applied to stress the microorganisms in the sludge so that they will take up more phosphorus than is required for normal biological treatment.

Technical description
FDM waste water may contain significant amounts of phosphorus if the cleaning agents used have phosphate ingredients. 10–25 % of the phosphorus entering the system can be removed during primary or secondary treatment. If further removal is needed, biological treatment methods can also be used. These methods are based on stressing the microorganisms in the sludge so that they will take up more phosphorus than is required for normal cell growth. Two types of processes used for enhanced biological phosphorus removal (EBPR) are described:

- the proprietary A/O process for mainstream phosphorus removal is used for combined carbon oxidation and phosphorus removal from waste water. This process is a single-sludge suspended growth system that combines anaerobic and aerobic sections in sequence;
- in the proprietary phostrip process for side-stream phosphorus removal, a portion of the return activated sludge process is diverted to an anaerobic phosphorus stripping tank.

Under certain operating conditions, more phosphorus than is needed may be taken up by the microorganisms, which is known as the luxury uptake. Under anaerobic conditions, the microorganisms break the high-energy bonds in internally accumulated polyphosphate, resulting in the release of phosphate and the consumption of organic matter in the form of volatile fatty acids (VFAs) or other easily biodegradable organic compounds. When the microorganisms are then put under aerobic conditions, they take up phosphate, forming internal polyphosphate molecules. This luxury uptake results in more phosphate being included in the cells than was released in the anaerobic zone, so the total phosphate concentration in the solution is reduced. When the microorganisms are wasted, the contained phosphate is also removed. A sufficient supply of VFAs is the key to removing phosphorus biologically [242, COM 2016].

EBPR can be accomplished in conjunction with treatment plants that nitrify and/or denitrify, with and without primary sedimentation. Where both nitrogen and phosphorus are to be removed, combined processes are used most commonly.
Achieved environmental benefits
Reduced phosphorus, BOD and TOC or COD emission levels.

Environmental performance and operational data
Phosphorus removal efficiencies of various waste water treatment methods are summarised in Table 2.55.

Table 2.55: Phosphorus removal efficiencies of various waste water treatment techniques

<table>
<thead>
<tr>
<th>Waste water treatment technique</th>
<th>Phosphorus removal efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary treatment (see Section 2.3.6.1)</td>
<td>10–20</td>
</tr>
<tr>
<td>Precipitation (see Section 2.3.6.1.8)</td>
<td>70–90</td>
</tr>
<tr>
<td>Activated sludge (see Section 2.3.6.2.1.1)</td>
<td>10–25</td>
</tr>
<tr>
<td>Trickling filter (see Section 2.3.6.2.1.5)</td>
<td>8–12</td>
</tr>
<tr>
<td>RBC (see Section 2.3.6.2.1.7)</td>
<td>8–12</td>
</tr>
<tr>
<td>EBPR</td>
<td>70–90</td>
</tr>
<tr>
<td>Carbon adsorption (see Section 0)</td>
<td>10–30</td>
</tr>
<tr>
<td>Filtration (see Section 2.3.6.3.6)</td>
<td>20–50</td>
</tr>
<tr>
<td>RO (see Section 2.3.6.3.7)</td>
<td>90–100</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

In the brewery #157, waste water from the anaerobic reactor is driven to a reservoir where it is mixed with aerobic sludge (from the second sedimentation) and with untreated neutralised waste water (taken before anaerobic digestion). All these flows are recirculating and, in these conditions, the aerobic sludge encourages the growth of phosphorus-assimilating bacteria. Phosphorus concentrations of around 2–3 mg/l have been reported after the application of this technique (around 80 % of abatement efficiency).

EBPR is reported to be more difficult to handle than precipitation. The sludge age should be kept below seven days. The residence time should be less than an hour.

Cross-media effects
Pumping is needed to send the waste water to further aerobic treatment.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique. Applicable in FDM installations with waste water containing phosphorus.

Economics
An investment cost of around EUR 160 000 was reported for a waste water flow rate of 300 m³/h in a brewery. This was compensated with an annual economic saving of EUR 170 000 due to the avoidance of chemicals previously used for phosphorus precipitation [193, TWG 2015].

Driving force for implementation
To reduce the potential for eutrophication of fresh water.

Example plants
This technique has been reported in several FDM installations belonging to the brewing, fruit and vegetable, meat, starch and dairy sectors. Example installations include #024, #157 and #442 [193, TWG 2015].
Used in the fruit and vegetable sector.

Reference literature
[14, VITO et al. 2001], [78, Metcalf & Eddy 1991], [192, COM 2006], [193, TWG 2015], [242, COM 2016]

2.3.6.3.4 Phosphorus removal by chemical precipitation (T32)

Description
Transformation of the soluble phosphates present in the waste water to insoluble chemical compounds (salts) followed by the removal of these insoluble precipitates by sedimentation or filtration.

Technical description
Chemical precipitation of phosphorus is a frequently utilised method of phosphorus removal that can be carried out at different stages of a biological WWTP. Phosphorus precipitation is the transformation of the soluble phosphates present in the waste water to insoluble chemical compounds (salts) followed by the removal of these insoluble precipitates by sedimentation or filtration. The most commonly utilised chemicals contain lime, aluminium (mainly alum) and iron (mainly ferric chloride).

The consumption of precipitants can be optimised by online phosphorus monitoring of the influent to the reactor [249, VITO 2015]. For a general description of chemical precipitation (coagulation and flocculation) see Section 2.3.6.1.8.

Achieved environmental benefits
Reduced phosphorus emission levels.

Environmental performance and operational data
In a dairy example installation (#296), a precipitation system for phosphorus removal comprises four tanks: a softening tank, a coagulation tank (where lime is added), a flocculation tank (where microsand is added) and a settling tank with lamella and a scraper. As the solids settle, they are transferred to the hydrocyclone which separates the microsand from the sludge. The microsand is returned to the flocculation tank to minimise loss. For a total volume of around 2 750 000 m³ of waste water in 2014, the amount of lime used was 516 tonnes; dewatering polyelectrolyte consumption was 9 000 kg and flocculating polyelectrolyte consumption was 5 000 kg. The orthophosphate load was reduced by 84 %, achieving a TP concentration of 0.36 mg/l as a yearly average [193, TWG 2015].

In another dairy installation (#406), nutrient-rich process water from the production of demineralised whey powder is routed to the phosphate removal plant (see Figure 2.14). Process water is mixed with solubilised hydrated lime to chemically combine the phosphate as Ca₅(PO₄)₃(OH) of stoichiometric composition (19 wt-% P). A coagulant (ferric chloride) is added to assist the physical separation of the calcium phosphate precipitate in a lamella separator. The calcium phosphate precipitate is dewatered in a belt press assisted by the addition of wash water and a low concentration of flocculant (a synthetic anionic polymer). The calcium phosphate cake comprising 19 wt-% P is conveyed from the belt press to a container for export from the site as wet cake (up to 40 % dry solids) at a rate of approximately 6 tonnes per day. The nutrient-rich stream from the production of demineralised whey is approximately 460 m³/d containing approximately 360 kg/d of total phosphorus (as P). A reduction of 90 % of the total phosphorus is achieved, obtaining a TP concentration in the effluent of 1.8 mg/l as a yearly average [193, TWG 2015].
The elimination of phosphorus from edible oil refinery waste water requires a biological waste water treatment to transform organically bound phosphorus into inorganic forms, as the former does not react with inorganic precipitants. Subsequently, precipitation by, e.g. aluminium salts, can achieve final emission levels of less than 4.5 g/t unrefined oil [35, Germany 2002].

It is reported that in some cases the addition of phosphorus makes it more valuable for agricultural use, but in others such use would add to eutrophication problems. The total phosphorus emission levels from five Finnish potato starch installations with an activated sludge and simultaneous precipitation are shown in Table 2.56.

Table 2.56: Total phosphorus emission levels from five Finnish potato starch installations with an activated sludge and simultaneous precipitation

<table>
<thead>
<tr>
<th>Total phosphorus level (mg/l)</th>
<th>Influent</th>
<th>Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30–90</td>
<td>1–2</td>
</tr>
</tbody>
</table>

NB: Activated sludge load 0.1–0.3 kg BOD/m³ d.

Source: [192, COM 2006]

Cross-media effects
Generation of sludge and consumption of chemical precipitants. Metal phosphate salts, such as iron or aluminum, might not be used as fertilisers in agriculture because the iron or aluminum phosphates are not available for plants under normal pH conditions [255, Desmidt et al. 2015].

Economics
A total cost of around EUR 2 700 000 for the phosphorus precipitation plant in an existing dairy installation processing around 100 000 t raw materials/yr and average operating costs of around EUR 0.45 per m³ of treated waste water have been reported. The cost of an online tool for monitoring total phosphorus is around EUR 15 000 [193, TWG 2015].

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.
Driving force for implementation
When phosphorus removal is applied before the biological treatment, a reduction of the energy costs of the WWTP can be achieved.

Example plants
This technique is widely used in FDM installations. Example installations include #296 and #406 [193, TWG 2015].

Reference literature
[35, Germany 2002], [192, COM 2006], [193, TWG 2015], [249, VITO 2015], [255, Desmidt et al. 2015]

2.3.6.3.5 Phosphorus recovery as struvite

Description
Phosphorus is recovered by chemical precipitation in the form of struvite, from waste water in stirred tank reactors, after anaerobic digestion.

Technical description
In the case of waste water containing high concentrations of phosphate, phosphorus can be recovered by precipitation of struvite. The reaction takes place by adding magnesium chloride or magnesium oxide, at pH levels of 8.5 to 10. The result will be the formation of struvite (magnesium ammonium phosphate):

\[ \text{Mg}^{2+} + \text{NH}_4^+ + \text{HPO}_4^{2-} + 6 \text{H}_2\text{O} \rightarrow \text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O} \]

The most common technique for phosphorus recovery as struvite in the FDM sector is carried out using waste water in stirred tank reactors, after anaerobic digestion. The waste water is usually aerated in a first tank (see Figure 2.15), which results in a pH increase due to CO₂ stripping. The process continues in a second reactor (where the magnesium chloride or magnesium oxide is mixed with the waste water) and a separation unit, where struvite is removed from the waste water, dewatered and dried. Recovered struvite has a crystal structure that is pure and can be reused as a slow fertiliser.

Source: [254, Colsen b.v. 2013]

Figure 2.15: Flow diagram for phosphorus recovery as struvite in batch mode
In sectors other than FDM, struvite can be obtained from sludge. For a general description of chemical precipitation (coagulation and flocculation) see Section 2.3.6.1.8.

**Achieved environmental benefits**
Reduced total phosphorus emission levels. Reduction of sludge production in the WWTP compared to chemical phosphorus precipitation. Recovery of phosphorus for other uses (e.g. as fertiliser). The EU depends on imports for 99.5% of its phosphorus.

**Environmental performance and operational data**
Struvite precipitation is carried out at full scale at several potato processing installations. For example in Belgium, the struvite recovery system was installed in the bypass between the UASB and the aerobic treatment in two potato processing installations.

In the Netherlands, a potato processing installation produces 1.8 t/d of struvite from 5,000 m³ waste water/day; the average TP concentration is 50 mg/l in the influent, and 10 mg/l in the effluent. Another potato processing installation produces 1.1 t/d of struvite from 2,880 m³ waste water/day; the average TP concentration is 90 mg/l in the influent, and 15 mg/l in the effluent [254, Colsen srl 2013].

In summary, average removal efficiencies of 80–90% have been reported. The effluent concentration that can be reached is not lower than 10–20 mg P-PO₄/l. When phosphate is recovered from the sewage sludge directly after anaerobic digestion, the risk of scaling problems in the remainder of the sludge line can be significantly reduced.

**Technical considerations relevant to applicability**
Potato processing installations are suitable for phosphate recovery since their waste water contains high concentrations of phosphate. Dairy, brewery and starch manufacturing industries have less phosphorus in their waste water and therefore the operational cost to recover phosphate as struvite will be more expensive.

**Economics**
An investment cost of around EUR 983,000 for the treatment of 120 m³/h of waste water has been reported, for achieving an outlet P-PO₄ concentration of 20 ppm (inlet P-P0₄ concentration around 150 ppm) [193, TWG 2015]. The cost of recovery is lower compared to phosphorus removal by chemical precipitation using, for example, FeCl₃.

P recovery as struvite can also result in a decrease in the costs for the treatment and disposal of sludge. There are potential revenues from selling the recovered struvite.

**Driving force for implementation**
The recovered phosphate can be reused as a fertiliser, either directly or after further processing, improving the economic feasibility of the investment. For direct use as a fertiliser, the produced struvite has to be certified and recognised. P recovery as struvite can help to prevent scaling problems in the WWTP.

**Example plants**
- Two FDM installations for processing potatoes (#453 and #461) in the Netherlands.
- Three potato processing installations in Belgium [257, NuReSys 2016]:
  - Agristo: 750 kg struvite/d generated from 60 m³ waste water/h, start-up in 2008.
  - Clarebout potatoes (two installations): 1,800 kg struvite/d generated from 120 m³ waste water/h, start-up in 2012; 1,100 kg struvite/d generated from 80 m³ waste water/h, start-up in 2012.
- A dairy installation has a struvite plant in operation since 2006 with a capacity of 1,580 kg struvite/d generated from 125 m³ waste water/h, in Germany [257, NuReSys 2016].
Technical description
Organic solvents, pesticide residues, and toxic organic and inorganic chemicals may appear in waste water. Directive 76/464/EEC [114, EEC 1976] on pollution caused by certain dangerous substances discharged into the aquatic environment and its daughter directives established the List I ‘particularly dangerous’ and List II ‘less dangerous’ groups of substances on the basis of the chemicals’ toxicity, persistence and bioaccumulation. Directive 2000/60/EC [164, WFD 2000/60/EC 2000] on water policy aims to achieve the elimination of priority hazardous substances. This Directive states that pollution through the discharge, emission or loss of priority hazardous substances must cease or be phased out. The European Parliament and the Council, on a proposal from the Commission, agreed on the substances to be considered for action as a priority and on specific measures that need to be taken against pollution of water by those substances.

The removal of many of these substances can be implemented through the appropriate use of some treatments, such as sedimentation (see Section 2.3.6.1.5), precipitation (see Section 2.3.6.1.8), filtration (see Section 2.3.6.3.6) and membrane filtration (see Section 2.3.6.3.7). Further removal can be implemented using tertiary treatments such as carbon adsorption and chemical oxidation.

Carbon adsorption is an advanced waste water treatment method. Granular medium filters are commonly used upstream of the activated carbon contactors to remove the soluble organics associated with the TSS present in secondary effluent. Both granular and powdered carbons are used and appear to have a low affinity for low molecular weight polar organic species. Granular activated carbon works by adsorbance of the contaminants onto and within the carbon granules. These types of filtration media are also used to remove some chemicals, tastes and odours.

Chemical oxidation can be used to remove ammonia, to reduce the concentration of residual organics, and to reduce the bacterial and viral content of waste waters. The oxidants used include chlorine, chlorine dioxide and ozone.

Achieved environmental benefits
Reduced levels of dangerous and priority hazardous substances, BOD/COD and phosphorus. Disinfection of waste water, if chemical oxidation is used.

Cross-media effects
Waste production.

Environmental performance and operational data
When using carbon adsorption, high influent TSS concentrations will form deposits on the carbon granules resulting in pressure loss, flow channelling or blockages and loss of adsorption capacity. Lack of consistency in pH, temperature and flowrate may also affect the performance of carbon contactors. Phosphorus removal efficiencies of 10–30 % have been reported using carbon adsorption.

Technical considerations relevant to applicability
Applicable for all FDM installations with waste water containing dangerous and priority hazardous substances.

Economics
High energy costs.
Driving force for implementation
Legislation compliance.

Example plants
Carbon adsorption is used in the meat, fruit and vegetable and soft and alcoholic drinks sectors.

Reference literature

2.3.6.3.6 Filtration (T33)

Description
The separation of solids from waste water by passing them through a porous medium, e.g. sand filtration, microfiltration and ultrafiltration.

Technical description
Filtration, e.g. slow filtration, fast filtration, deep bed filtration, surface filtration (microscreening), biofiltration and coagulation filtration, can be used as a waste water polishing step to remove solids. Unlike sedimentation (see Section 2.3.6.1.5) or DAF (see Section 2.3.6.1.6), filtration does not require any difference in density between the particles and liquid. The separation of particles and liquid is brought about by a pressure difference between the two sides of the filter allowing the passage of water through the filter. Thus, the particles are held back by the filter medium. A detailed technical description of filtration can be found in the CWW BREF [ 242, COM 2016 ]. Information on membrane filtration is specifically given in Section 2.3.6.3.7.

Filters may be either gravity filters or pressure filters. Depending on the nature of the solids, a standard sand or dual media filter (sand/anthracite) can be used. There are now a number of constantly self cleaning sand filters available which have proven to be extremely effective at polishing suspended solids from the final waste water.

Achieved environmental benefits
Reduced emission levels of TSS and phosphorus.

Environmental performance and operational data
In the brewing sector, the use of sand filters to achieve waste water requirements more stringent than 15 mg/l of BOD and 20–30 mg/l of TSS has been reported. Sand filters are used to remove TSS, as the soluble BOD is very low after extended aerobic treatment. Phosphorus removal efficiencies of 20–50 % have been reported using filtration.

Technical considerations relevant to applicability
Applicable in all FDM installations to achieve low TSS emission levels.

Example plants
This technique has been reported in several FDM installations belonging to the brewing, dairy, soft drinks, oilseed, meat and fruit and vegetable sectors [ 193, TWG 2015 ]. Used in the meat, fruit and vegetable, brewing, drinks and vegetable oils and fats sectors.

Reference literature
[ 1, CIAA 2002 ], [ 8, Environment Agency of England and Wales 2000 ], [ 35, Germany 2002 ], [ 72, Brewers Europe 2002 ], [ 193, TWG 2015 ], [ 242, COM 2016 ]
2.3.6.3.7 Membrane filtration (T34)

Description
Use of a pressure-driven, semi-permeable membrane (e.g. ultrafiltration, reverse osmosis) to achieve selective separations of substances.

Technical description
Membrane filtration processes use a pressure driven, semi-permeable membrane to achieve selective separations of substances in waste water. Much of the selectivity is established by designations relative to pore size. The pore size of the membrane is relatively large if precipitates or suspended materials are being removed or very small for the removal of inorganic salts or organic molecules. During operation, the feed solution flows across the surface of the membrane, clean water permeates through the membrane, and the contaminants and a portion of the feed remain in the solution. The clean or treated waste water is referred to as the permeate or product water stream, while the stream containing the contaminants is called the concentrate, brine or reject. An example of a membrane unit is shown in Figure 2.16.

![Figure 2.16: Example of a membrane unit implemented in a dairy](source: [193, TWG 2015])

For the cases when membrane filtration is combined with a biological waste water treatment, see the membrane bioreactor technique (MBR) in Section 2.3.6.2.3.1.

Cross-flow microfiltration (CFM) is cross-flow filtration using membranes with pore sizes in the range of 0.1–1.0 µm. The feed stream does not require extensive primary treatment, while the membrane is relatively resistant to fouling and can be easily cleaned. The CFM technique is applicable for removing bacteria and contaminants from feed streams, but not for effective pesticide treatment unless the active ingredients are relatively insoluble or attached to the suspended material. CFM is used in the UK to remove heavy metals from industrial waste water.

Ultrafiltration (UF) is similar to CFM, but the UF membranes have smaller pores, 0.001 - 0.02 µm. The smallest pore size UF membrane has the capacity to reject molecules with diameters greater than 1 nm or nominal molecular weights greater than 2 000. Some primary treatment may be necessary to prevent membrane fouling. For most UF designs, the introduction of adsorbents or flocculants to the feed stream is not recommended since they may...
plug the membrane module. Applications of UF include the removal of oil from waste water and the removal of turbidity from colour colloids.

Reverse osmosis filtration (RO) has the ability to reject dissolved organic and inorganic molecules. Water is separated from dissolved salts by filtering through a semi-permeable membrane at a pressure greater than the osmotic pressure caused by the salts. The advantage of RO is that dissolved organics are less selectively separated than in other processes. The purified solution permeates through the membrane.

Nanofiltration (NF) is a relatively new technique combining features of UF and RO with a high selectivity. Its name is derived from its approximate cut-off size of some nanometres or more exactly molar masses of 200–1000 g/mol. This is achieved with special nanofiltration membranes which still have pores of a defined size, but their retention depends on the electrostatic charge of the molecules to be separated. The membranes have selective permeability for minerals, i.e. high permeability for monovalent cations and anions and lower permeability for bivalent cations. Nanofiltration systems are operated at medium pressures in the range of 1–5 MPa. Electro dialysis enables ionic separation by using an electrical field as a driving force as opposed to a hydraulic force. The membranes used are adapted to make them ion selective (for cations and anions). A number of cells are required to make up the complete electro dialysis unit. Chemical precipitation of salts on the membrane surface and clogging by the residual organic colloids can be prevented by pretreating the waste water with activated carbon, or chemical precipitation or by some sort of multimedia filtration.

Achieved environmental benefits
Suspended, colloidal and dissolved solids emission levels are reduced. Phosphorus emission levels can be reduced, i.e. using RO. The implementation of this technique can also lead to:

- concentration of waste water streams to reduce volumes prior to further treatment/disposal, e.g. possible concentration of dilute waste to concentrations suitable for reuse;
- possible recovery of expensive ingredients for reuse or return/sales to suppliers on-site or elsewhere; Recovery of ingredients / materials at source
- recovery of water for reuse.

Cross-media effects
Additional waste water may be produced. Use of chemicals for cleaning the membranes.

Environmental performance and operational data
Problems may arise from the fouling of membranes and gel polarisation. Since the flux rates through membranes are relatively low, an extensive membrane area is required to recover material.

Using UF, up to 90–95% of the feed can be recovered as product water. Phosphorus removal efficiencies of 90–100% have been reported using RO.

RO membranes are very susceptible to fouling and may require an extensive degree of primary treatment. In a starch installation (#419), the removal of naturally occurring bacteria within the borehole water greatly reduced the cycle life of the filters within the RO plant, dedicated to purifying water before using it in a cooling water circuit [193, TWG 2015]. Oxidants which may attack the membrane and particulates, e.g. oil, grease and other materials which may cause a film or scale to form, should be removed by primary treatment or the membrane will need to be subjected to frequent cleaning cycles. RO product streams are normally of very high quality and suitable for reuse in the manufacturing process. Standard practice is to dispose of the reject stream or to apply a suitable treatment to the concentrated brine. The recovery that can be obtained, as well as the operating pressure required, will depend on the type of dissolved solids
and their concentrations. RO has been used to remove heavy metals and pesticides whose active ingredient molecular weights are greater than 200.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
The operating cost associated with the use and cleaning of membranes can be very high. There are also high energy costs. In the fish sector, the use of UF to treat waste water from minced fish production has been reported, however, this method is reported not to be cost-effective for separating proteins from fish-meal waste water.

A total cost of around EUR 3 600 000 has been reported for the installation of a RO plant in a dairy, for recycling about 130 000 m$^3$ waste water/year [193, TWG 2015].

Example plants
This technique has been reported in several FDM installations belonging to the brewing, dairy, oilseed and fruit and vegetable sectors [193, TWG 2015].

Used in the meat, fish, fruit and vegetable, soft and alcoholic drinks and vegetable oils and fats sectors.

Reference literature

Biological nitrifying filters (T35)
Ammonia is usually removed during secondary biological treatment by allowing for extended sludge time periods to facilitate the proliferation of nitrifying bacteria. Nevertheless, it is also common to install separate tertiary biological nitrifying filters. These are usually variations on the standard percolating or high rate aerobic filters. They may be followed by activated sludge plants or attached growth systems.

Disinfection and sterilisation (T36)
The disinfection and sterilisation techniques all operate on the same basic principle. They affect the cell structure within a bacteria and prevent their replication. Disinfectants used for FDM production are within the scope of Directive 98/8/EC [132, EC 1998]. Assessment of the environmental and human health effects of active substances in disinfectants will start in 2007. Several types of treatment can be applied. This involves the use of oxidising biocides, non-oxidising biocides and UV radiation. Steam is also used for disinfection, to kill thermo-resistant microorganisms.

Biocides
Technical description
Oxidising biocides work by oxidising the bacterial cell walls in order to prevent replication. This relies on the use of strong oxidising agents such as chlorine/bromine, ozone and hydrogen peroxide. The use of chlorine compounds, e.g. chlorine gas, chlorine dioxide, sodium or calcium hypochlorite, relies upon the formation of hypochlorous acid (the active biocide) in aqueous solution. Bromine based biocides are becoming more prevalent in industrial applications due to the hypobromous acid species dissociating at a higher pH than the equivalent chlorine based compounds.
Chapter 2

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Ozone can be generated from air or pure oxygen when a high voltage is applied across the gap of narrowly spaced electrodes. Ozone dissipates rapidly after generation, so no chemical residual persists in the treated waste water but its dissolved oxygen content is high. No halogenated compounds are produced. Ozone is also used as an oxidising agent.

**Non-oxidising biocides** operate by chemically altering the cell structure in order to prevent bacterial cell replication. They are being used increasingly in the FDM sector; some examples are quaternary ammonium salts, formaldehyde and glutaraldehyde.

**Achieved environmental benefits**

Waste water reuse, even as drinking water.

**Cross-media effects**

When using chlorine compounds, organic compounds present in the waste water may react with chlorine to form toxic substances, e.g. chloramines and other organic halogen compounds. Furthermore, this reaction can reduce the effective chlorine dose rate. Chlorine can also be very aggressive towards construction materials, even stainless steel. The organic halogen compounds can impair subsequent biological waste water treatment, after waste reuse. When using ozone, carcinogenic or mutagenic compounds may be formed and ozone is a respiratory irritant, so occupational exposure needs to be controlled.

**Environmental performance and operational data**

Ozonation is carried out in deep and covered contact chambers. It is effective without the need for further chemicals. Ozone will naturally decay back to oxygen after a few hours.

In the fish sector, ozone has been used to treat a variety of waste water streams and is reported to be most effective in treating more dilute types of wastes. For more concentrated waste water, e.g. from squid processing operations, ozone can be applied as a polishing step.

**Technical considerations relevant to applicability**

Applicable in all FDM installations.

**Economics**

The use of ozone has a moderately high cost. The use of other biocides has relatively low capital and operating costs.

**Example plants**

Used in the meat, fish, fruit and vegetable and soft and alcoholic drinks sectors.

**Reference literature**


**2.3.6.3.8 UV radiation (T35)**

**Description**

UV light is readily absorbed by the cellular genetic material within bacteria and viruses, and prevents the cell from replicating.

**Technical description**

UV radiation is perhaps the most significant advancement in disinfection technology over the past 10 years. UV light at 254 nm is readily absorbed by the cellular genetic material within bacteria and viruses, and prevents the cell from replicating. The dose rate is measured in milliwatts per square centimetre multiplied by the contact time in seconds. The actual dose depends on the transmittance, i.e. related to the presence of other compounds which can absorb and reduce UV light effectiveness, of the waste water stream.
Achieved environmental benefits
There is no residual effect that can be harmful to humans or aquatic life.

Environmental performance and operational data
The main advantages of UV disinfection over the other techniques include, no storage and no need for the use of chemicals and the absence of harmful by-products (e.g. organic halogenated substances). On the other hand, the main disadvantage of UV disinfection is that a direct line of sight should be maintained between the lamp and the bacteria/virus. Any appreciable levels of suspended solids or turbidity (which decrease the transmittivity) will shield the bacteria and prevent their disinfection. Waste water containing compounds with high transmittance values require higher doses of UV radiation. UV radiation is unstable and should be generated as used.

Cross-media effects
Energy consumption required to generate UV waves. Treated water with UV radiation is liable to reinfection, so they need to be used quickly and hygienically.

Technical considerations relevant to applicability
Applicable in all FDM installations.

Economics
Relatively low capital and operating costs.

Driving force for implementation
- Waste water recycling, even as drinking water.
- No need for use of chemicals.

Example plants
This technique has been reported in two FDM installations belonging to the brewing (#079) and dairy (#406) sectors [193, TWG 2015].

Used in the meat, fish, fruit and vegetable, dairy and soft and alcoholic drinks sectors.

Reference literature
[1, CIAA 2002], [8, Environment Agency of England and Wales 2000], [71, AWARENET 2002], [193, TWG 2015]

2.3.6.4 Natural treatment

2.3.6.4.1 Integrated constructed wetlands (ICW) (T37)

Description
Interconnected basins or lagoons planted with a wide variety of aquatic plant species, allowing subsequent waste water treatments.

Technical description
ICW are distinguished from other constructed wetland techniques on the basis that they are designed to facilitate the widest possible range of ecological conditions, as found in natural wetlands including those of soil, water, plant and animal ecology. In addition, the ICW concept strives to achieve landscape fit and habitat restoration/creation into its designs. Emphasis is placed on monitoring water quality within the wetlands and the surrounding land and watercourses. Strategically located monitoring wells are also monitored regularly.

The ICW design simultaneously applies primary, secondary and subsequent levels of treatment in its free surface water flow. This is achieved by the construction of a series of shallow interconnected basins or lagoons planted with a wide variety of aquatic plant species. The waste water is introduced at the highest point in these lagoons and is gravity fed through the lagoons. These sequentially arranged lagoons are self-contained individual ecosystems. With each step, a
cleaner level of waste water is attained. The relationship of the volume of waste water to the area of wetland in the overall ICW design determines the outflowing water quality.

The macrophytic vegetation used in the ICW design performs a variety of functions. Its primary function is the support of biofilms (slime layers), which carry out the principal cleansing functions of the wetland. It also facilitates the sorption of nutrients and acts as a filter medium, and through the use of appropriate emergent vegetation, can control odours and pathogens. While the vegetation has the capacity to filter suspended solids it also increases the hydraulic resistance, thus increasing the residence time.

Achieved environmental benefits

TSS, BOD and TOC or COD, nitrogen and phosphorus emission levels are reduced. Energy is saved, compared to conventional treatment. Reduced greenhouse gas emissions. No chemicals are used. No sludge disposal is required.

Environmental performance and operational data

An example dairy installation in Ireland produces 85 tonnes of cheese per day from 800,000 litres of milk and generates up to 1,300 m$^3$ of waste water. The installation has an ICW comprising 8 hectares of lagoons occupying 20 hectares which treat 1.1 million litres of waste water per day. The waste water is pumped to the wetland about half a mile from the dairy and fed in at the highest point. The system of lagoons progresses downwards along the contours of the land and the treatment is achieved progressively as the waste water passes through the system. Performance levels from this ICW are shown in Table 2.57.

Table 2.57: Performance levels reported for an ICW

<table>
<thead>
<tr>
<th>Sample point</th>
<th>COD mg/l</th>
<th>Total P mg/l</th>
<th>Ammonia mg/l</th>
<th>Nitrate mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent waste water</td>
<td>3167</td>
<td>212</td>
<td>12</td>
<td>102</td>
</tr>
<tr>
<td>Final monitoring pond</td>
<td>36.5</td>
<td>0.5</td>
<td>0.05</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

*Source: [112, Ireland 2003]*

In another example dairy (#388), a constructed wetland area with the capacity for 600 m$^3$/day is used for the treatment of lightly contaminated waste water with a maximum influent BOD concentration of 100 mg/l. Regarding the effluent of the ICW, the average COD concentration is in the range of 75.6–108.9 mg/l, the average TN concentration in the range of 39.3–53.3 mg/l, and the average TP concentration in the range of 0.4–1.0 mg/l. Only a little electricity is used for cleaning the water and no chemicals are required [193, TWG 2015].

Cross-media effects

The groundwater that flows beneath the wetlands has lower nutrient levels than surrounding terrestrial sites. Phosphorus is retained in the soil. An ICW can provide suitable effluent to be used for irrigation of crops and pasture.

Technical considerations relevant to applicability

The ICW technique can be applied in a wide range of circumstances, e.g. high or low concentrations of contaminants and hydraulic loading rates that may vary over time. ICWs may be built as an entirely new entity or may form part of an existing wetland, aquatic landscape feature or WWTP. The land requirement associated with ICWs can restrict its application, e.g. land requirements can range from 10 m$^2$ to many hectares depending on the volume of the waste water produced and its pollution characteristics.

Economics

It has been reported that, compared to a conventional WWTP, the ICW approach allows a saving on operational, depreciation and capital costs of EUR 0.03, EUR 0.49 and EUR 0.46/kg of COD, respectively. The reduction is mainly due to the reduced energy costs, lack of chemical usage, lack of sludge production and storage.
The example dairy installation in Ireland reported that its ICW system cost EUR 120 000, which is comparable to EUR 3.175 million reported for a conventional WWTP [112, Ireland 2003].

Driving force for implementation
- Economic savings in the example plant.
- ICW provide a habitat for a wide variety of plants and animals. They may be a local amenity and educational resource. The site may be reclaimed. There are nutrient recycling opportunities, e.g. by composting.
- The recovered biomass can have a wide range of applications (e.g. substrate for biogas or bioethanol production).

Example plants
This technique has been reported in one dairy installation (#388) in Sweden [193, TWG 2015]. Several farms, a cheese plant (dairy sector) and a village MWWTP, all in Ireland.

Reference literature
[112, Ireland 2003], [193, TWG 2015], [245, EC 2015]

2.3.6.5 Sludge and waste treatment

2.3.6.5.1.1 Sludge conditioning (T38)

Technical description
The purpose of conditioning is to improve the characteristics of the sludge so that it is easier to thicken and/or dewater. The techniques generally used are chemical or thermal. Chemical conditioning (using for example ferric chloride, lime, alum and organic polymers (coagulants and flocculants)) assists in the separation of the bound and entrained water from within the sludge. Thermal conditioning involves heating the sludge under pressure for short periods of time.

Achieved environmental benefits

Cross-media effects
Chemical conditioning results in a considerable rise in the solids content to be disposed of.

Economics
Associated chemical costs are generally quite high.

Example plants
Conditioning of sludge is widely applied in Europe.

Reference literature
[78, Metcalf & Eddy 1991], [193, TWG 2015], [242, COM 2016]

2.3.6.5.1.2 Sludge stabilisation (T39)

Technical description
Sludges are stabilised by chemical, thermal, anaerobic and aerobic processes to improve sludge thickening and/or dewatering and reduce odour and pathogens. A detailed technical description of sludge stabilisation can be found in the CWW BREF [242, COM 2016].
Achieved environmental benefits

Environmental performance and operational data
A chemical stabilisation process has low technical requirements and can improve downstream dewatering and reduce odours and pathogens. Nevertheless, it increases the solids content of the sludge. A thermal stabilisation process has low space requirements and is an effective treatment for dewatering sludge and destroying bacteria. Its selection can depend on whether the heat is natural, recovered as a by-product of the processes operating in the installation or whether direct energy consumption is required. An aerobic stabilisation process has long residence time, produces odourless sludge and produces gas, which is a source of energy. Nevertheless, the process is significantly affected by temperature and the sludge has poor mechanical dewatering characteristics.

Cross-media effects
Thermal stabilisation has high energy requirements and may release odours. Aerobic stabilisation also has high energy requirements for stirring and the supply of oxygen. Because lime (chemical) stabilisation does not destroy the organics necessary for bacterial growth, the sludge must be treated with an excess of lime or disposed of before the pH drops significantly.

Technical considerations relevant to applicability
Applicable in all FDM installations that produce sludge.

Economics
Thermal and anaerobic stabilisation have high capital costs. Aerobic stabilisation has low capital costs.

Driving force for implementation
To reduce odorous emissions and improve subsequent treatment operations.

Example plants
Stabilisation of sludge is widely applied in Europe.

Reference literature

2.3.6.5.1.3 Sludge thickening (T40)

Description
The solids content of sludge is increased by removing a portion of the liquid fraction.

Technical description
Thickening is a procedure used to increase the solids content of sludge by removing a portion of the liquid fraction. The techniques generally used for sludge thickening are sedimentation, centrifugation and DAF. The simplest thickening technique is to allow the sludge to consolidate in sludge sedimentation tanks.

Sludge thickening can be applicable to both primary and secondary treatment sludge. Primary treatment sludge consists mainly of inorganic material and/or primary organic solids. They are
generally able to settle and compact without chemical supplementation, as associated water is not excessively entrained within the sludge. The water in secondary treatment sludge is bound within the flocs and is generally more difficult to remove.

**Achieved environmental benefits**
Sludge volume reduction.

**Environmental performance and operational data**
Sludges that are taken from the bottom of primary and secondary sedimentation tanks will generally be around 0.5–1.0 % dry solids content and up to 4 % dry solids for DAF sludges. When using DAF, the system is kept aerobic. In this case, blockage has been reported.

The thickening efficiency of the sedimentation process is affected by the height of the sludge layer and not by the volume of the supernatant above it. Therefore, a tall and narrow tank is more effective than a low tank with a large surface area. This technique has a low energy consumption.

Depending upon the pattern of primary sludge removal, consideration can be given to the use of two tanks to allow for quiescent sedimentation in one tank whilst the other is in the fill cycle. If this is not possible, the sludge inlet is arranged to be near the top of the tank, possibly onto a baffle plate, to minimise hydraulic disturbance. Residence time within the tank will depend on the nature of the sludges. Excessive retention is avoided to minimise the possibility of anaerobic conditions occurring with consequent odour and corrosion problems.

Gentle agitation is allowed for within the tank. A picket fence thickener within the tank is most commonly used, to help reduce stratification of the sludge and to assist in the release of any entrained gases and water. A conventional gravity/picket fence thickener is capable of thickening the sludge up to 4–8 % dry solids, depending on the nature of the raw sludge and in particular on the relative content of primary sludge. Addition rates to the thickener are in the range of 20–30 m³ of feed/m² of surface area per day.

Centrifugation provides a good capture of solids that are difficult to filter, has low space requirements and is easy to install, but it achieves a low solids concentration in the cake. It has a high energy consumption and requires skilled maintenance personnel.

For many sites, sludge thickening alone is sufficient to reduce the volume of sludge to a level that enables off-site disposal to be undertaken in a sufficiently cost-effective manner. For larger sites, the thickening process is a first stage prior to further dewatering.

**Cross-media effects**
Possible release of odour when using DAF. High energy consumption and noise and vibration generation when using centrifugation.

**Technical considerations relevant to applicability**
Applicable to all FDM installations that produce sludge.

**Economics**
Reduction of pumping costs in large WWTPs. Sedimentation thickening has low operational costs.

**Driving force for implementation**
Reduction of pipe size and pumping costs on large WWTPs.

**Example plants**
This technique is widely applied in Europe.
2.3.6.5.1.4 Sludge dewatering (T44)

Technical description
The objective of sludge dewatering is the same as that of thickening (see Section 2.3.6.5.1.3) with the difference that the solid content is much higher. A number of sludge dewatering processes exist and selection will depend upon the nature and frequency of the solids produced, and the sludge cake required. The dewatering techniques generally used are centrifugation, belt filter press, filter press and vacuum filters.

Achieved environmental benefits
Sludge volume reduction.

Environmental performance and operational data
Centrifuges are continuous processes which produce a cake of up to 40 % dry solids for certain sludges. Because of the closed nature of the centrifuge, associated odour problems are minimal. Furthermore, centrifugation provides a good capture of solids that are difficult to filter, has low space requirements and easy installation. Nevertheless, this process needs a high consumption of energy, achieves a low solids concentration in the cake and requires skilled maintenance personnel.

Filter presses are batch processes, and can be manually intensive. The plates are covered with a suitable filter cloth, dependent upon the application, and the sludge is fed into the plate cavity. The sludge is dewatered under pressure with the filtrate passing through the filter cloth. Once the pressure is released and the plates separated, the cake is either manually scraped off or vibration mechanisms are employed to automate the process. A filter press can produce up to 40 % dry solids cake and attain a filtrate with low TSS. The disadvantages of using this technique are that it is essentially a batch operation and that it has a limited filter cloth life.

Flocking agents (e.g. powder) are also normally used. For instance, consumption of around 4 500 kg/year has been reported for the fruit and vegetable processing installation #035, when applying centrifugation and obtaining 7 600 m³/year of recycled water. The efficiency of the process partially depends on the quality of the flocking agent used [193, TWG 2015].

The belt press and vacuum filters are continuous processes with the filter cloth continually running through rollers that forcefully dewater the sludge. Performance optimisation requires regular and specialised maintenance.

A belt press can produce up to 35 % dry solids cake. Furthermore, the belt presses have high dewatering efficiency and relatively easy maintenance. Disadvantages of using them include hydraulic limitations, a short life and sensitivity to sludge feed characteristics.

The vacuum filters are complex systems with a maximum differential pressure of 1 bar. The filtrate may have high TSS.

Cross-media effects
High energy use, noise and vibration generation when using centrifugation, although this varies depending on the speed and intensity of the individual operation.

Technical considerations relevant to applicability
Applicable to all FDM installations that produce sludge.
Economics
Sludge with over 10% dry solids becomes difficult and expensive to pump. Dewatering produces a sludge cake, which may be between 20–50% dry solids. Disposal costs fall as the water content is reduced. Filter presses have high labour costs. Vacuum filters have high operating and maintenance costs.

An investment cost of EUR 120,000 and annual operating cost of EUR 38,000 have been reported in an installation applying centrifugal dewatering to approximately 5,000 t of sludge/year, with annual savings of EUR 88,000 due to the reduced sludge transport costs [193, TWG 2015].

Driving force for implementation
Reduction of disposal costs.

Example plants
This technique is widely applied in Europe.

Reference literature
[1, CIAA 2002], [35, Germany 2002], [109, Finland 2003], [193, TWG 2015]

2.3.6.5.1.5 Sludge drying (T42)

Technical description
Sludge drying is a technique that involves reducing the water content by vaporisation of water to the air. The purpose of drying is to remove the moisture from the wet sludge so that it can be used or disposed of efficiently.

Achieved environmental benefits
Sludge volume reduction.

Environmental performance and operational data
The moisture content of the dry sludge can be as low as 10%. Drying can be achieved by using natural evaporation, where the local weather and climate conditions make this possible, by recovery of heat produced in the installation or by using an off-site energy source.

Cross-media effects
High energy consumption when using an off-site energy source.

Technical considerations relevant to applicability
Applicable to all FDM installations that produce sludge.

Economics
TWG, please provide information.

Driving force for implementation
Reduction of disposal costs.

Example plants
This technique has been reported in installations belonging to the brewing, dairy, fruit and vegetable, and starch sector [193, TWG 2015].

Reference literature
[78, Metcalf & Eddy 1991], [193, TWG 2015]
Chapter 2

2.3.6.6 Analysis of key parameters

This section discusses the reported performance of the 353 FDM reference installations (see Table 19.1) for a number of parameters. The graphs contained in Section 2.3.6.6 refer to waste water discharged (direct discharge) from FDM installations. Influent and effluent data were gathered for the reference years 2012 to 2014. In general, the most recent dataset of each point of release is displayed except for some questionnaires where an earlier year contains a more complete set of data and no significant differences in terms of the emission levels were observed.

Separate graphs have been prepared for the following parameters: biochemical oxygen demand in five days (BOD₅), chemical oxygen demand (COD), total organic carbon (TOC), total suspended solids (TSS), total nitrogen (TN), ammonium nitrogen (NH₄-N), total phosphorus (TP), and chloride (Cl⁻).

Concentration and specific load values are shown in separate graphs. The symbols used in this section are given in Table 2.58.

Table 2.58: Symbols used in the graphs of Section 2.3.6.6

<table>
<thead>
<tr>
<th>Average values</th>
<th>Waste water (WW) stream</th>
<th>Type of monitoring regime</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Symbol</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effluent</td>
<td>Frequent sampling – campaign period</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequent sampling – non-campaign period</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Periodic sampling – campaign period</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Periodic sampling – non-campaign period</td>
</tr>
</tbody>
</table>

Waste water treatment is usually a combination of individual treatment steps. The most commonly used activated sludge process is generally preceded and followed by a solids removal step. The activated sludge process may be combined with biological nitrification and denitrification, and/or chemical phosphorus precipitation depending on the composition of the waste water. Other installations do not implement a biological treatment, only a physico-chemical one.

In the following graphs, each average effluent value (with the exception of the graphs on total suspended solids) is also labelled with 'Bio' or 'PC' to indicate whether the waste water treatment is biological (Bio) or only physico-chemical (PC). When there is no information provided about the techniques implemented, the label 'NI' is shown together with the emission data. In the event that the technique(s) implemented does not abate the pollutant displayed in a specific graph, or when no technique is implemented, the label 'NT' is shown together with the emission data.

Due to the large volume of data reported, some of the graphs are split to improve their readability.

2.3.6.6.1 Chemical oxygen demand (COD)

COD is commonly used to indirectly measure the amount of organic compounds in water by measuring the mass of oxygen needed for their total oxidation to carbon dioxide. The most widespread COD monitoring methods use dichromate as an oxidising agent and mercury salts to suppress the influence of inorganic chloride. COD has to be considered in relation to TSS since
the TSS removal efficiency affects the performance achieved with respect to COD. For economic and environmental reasons, COD is being replaced to some extent by TOC.

Performance of reference installations
Often 24-hour composite samples are taken on a daily or monthly basis.

Table 2.59 shows some general statistics in relation to the data reported for COD emission levels.

### Table 2.59: General statistics of data reported for COD emission levels (direct discharge)

<table>
<thead>
<tr>
<th>Units</th>
<th>Concentration</th>
<th>Specific load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of influent data values reported for COD</td>
<td>92</td>
<td>54</td>
</tr>
<tr>
<td>Number of effluent data values reported for COD</td>
<td>138</td>
<td>78</td>
</tr>
</tbody>
</table>

*Source: [193, TWG 2015]*

Figure 2.17 (lower values) and Figure 2.18 (higher values) show BOD₅ emissions to water (concentrations for direct discharges) from FDM installations.

![COD concentration in the effluent of the WWTP (direct discharge) in FDM installations (1/2)](source: [193, TWG 2015])
Figure 2.18: COD concentration in the effluent of the WWTP (direct discharge) in FDM installations (2/2)

Figure 2.19 shows TSS emissions to water as specific loads for direct discharges from FDM installations.

Figure 2.19: COD specific load in the effluent of the WWTP (direct discharge) in FDM installations

Techniques reported to reduce COD emission levels
There are many techniques for the reduction of COD emission levels, belonging to primary and/or secondary treatment (see Section 2.3.6), implemented in all reference installations.

There is no clear performance trend associated with the use of certain technologies or combinations thereof. The final effluent concentration very much depends on the way the WWTP is designed, maintained, and operated. Regardless of the type of treatment system selected, one of the keys to effective biological treatment is to develop and maintain an
acclimated, healthy biomass, sufficient in quantity to handle maximum flows and the organic loads to be treated.

2.3.6.6.2 Total organic carbon (TOC)

Total organic carbon (TOC) analysis is used to directly measure the amount of organic compounds in water. The most widespread methods use a combustion chamber to completely oxidise the organic substances to carbon dioxide which is then measured by spectrometry. Inorganic carbon is not included in TOC. Identifying changes in the normal/expected TOC concentrations can be a good indicator of potential threats to a waste water treatment system. Various online TOC analysers exist. There is a tendency to replace COD with TOC for economic and ecological reasons.

Performance of reference installations
Often 24-hour composite or time-proportional samples are taken on a daily or monthly basis.

Table 2.60 shows some general statistics in relation to the data reported for TOC emission levels.

Table 2.60: General statistics of data reported for TOC emission levels (direct discharge)

<table>
<thead>
<tr>
<th>Units</th>
<th>Concentration</th>
<th>Specific load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of influent data values reported for TOC</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Number of effluent data values reported for TOC</td>
<td>15</td>
<td>6</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

Figure 2.20 shows TOC emissions to water as concentrations for direct discharges from FDM installations.

Figure 2.20: TOC concentration in the effluent of the WWTP (direct discharge) in FDM installations

Source: [193, TWG 2015]
Figure 2.21 shows TOC emissions to water reported as specific loads for direct discharges from FDM installations.

Techniques reported to reduce TOC emission levels
The techniques are the same as those indicated in the COD section (see Section 2.3.6.6.1).

2.3.6.6.3 Biochemical oxygen demand in five days (BOD₅)

BOD₅ measures the amount of dissolved oxygen required or consumed in five days at a constant temperature for the microbiological decomposition (oxidation) of organic material in water. The concentration in the effluent is generally a more pertinent parameter than the abatement efficiency.

The parameters COD and TOC can be determined more quickly than BOD₅. Furthermore, the use of BOD₅ as a parameter to describe the efficiency of biological treatment has some disadvantages such as:

- the monitoring method used is not very accurate considering reproducibility and methodology dependence (dilution method versus respirometer for example);
- the analytical result depends on the local conditions of the laboratory, such as the inoculum used for the test;
- the BOD₅ measurement does not allow for any prediction of the performance within the WWTP; it only provides an indication as to whether the waste water is easily degradable to a certain rate.

Performance of reference installations
Often 24-hour composite samples are taken on a weekly or monthly basis.

Table 2.61 shows some general statistics in relation to the data reported for BOD₅ emission levels.
Table 2.61: General statistics of data reported for BOD$_5$ emission levels (direct discharge)

<table>
<thead>
<tr>
<th>Units</th>
<th>Concentration</th>
<th>Specific load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of influent data values reported for BOD$_5$</td>
<td>44</td>
<td>25</td>
</tr>
<tr>
<td>Number of effluent data values reported for BOD$_5$</td>
<td>115</td>
<td>64</td>
</tr>
</tbody>
</table>

*Source:* [193, TWG 2015]

Figure 2.22 (lower values) and Figure 2.23 (higher values) show BOD$_5$ emissions to water (concentrations for direct discharges) from FDM installations.

*Source:* [193, TWG 2015]
Figure 2.24 shows BOD₅ emissions to water as specific loads for direct discharges from FDM installations.

Techniques reported to reduce BOD₅ emission levels
The techniques used to remove COD (see Section 2.3.6.6.1) may remove (part of the) BOD₅ too. On the other hand, pretreatment of COD may in certain cases raise the BOD₅ (conversion of nondegradable to biodegradable matter, e.g. by partial oxidation). The only technique which is *a priori* dedicated to removing BOD₅ is biological treatment.

### 2.3.6.6.4 Total suspended solids (TSS)

There are some reasons to link the analysis of TSS with other parameters. If BOD/COD/TOC removal functions poorly, TSS emissions may be affected. Conversely, high TSS values can correlate with or cause high concentrations of other parameters, namely BOD, TOC or COD, total phosphorus and total nitrogen.

It is possible to have higher TSS values in the effluent than in the influent, for example due to the growth of biomass during biological treatment or due to the precipitation of compounds during physico-chemical treatment. In most cases, it therefore does not make sense to calculate abatement efficiencies for the WWTP.

**Performance of reference installations**
Often 24-hour composite samples are taken on a daily or monthly basis.

Table 2.62 shows some general statistics in relation to the data reported for TSS emission levels.
Table 2.62: General statistics of data reported for TSS emission levels (direct discharge)

<table>
<thead>
<tr>
<th>Units</th>
<th>Concentration</th>
<th>Specific load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of influent data values reported for TSS</td>
<td>30</td>
<td>22</td>
</tr>
<tr>
<td>Number of effluent data values reported for TSS</td>
<td>100</td>
<td>64</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

Figure 2.25 (lower values) and Figure 2.26 (higher values) show TSS emissions to water (concentrations for direct discharges) from FDM installations.

Figure 2.25: TSS concentration in the effluent of the WWTP (direct discharge) in FDM installations (1/2)

Figure 2.26: TSS concentration in the effluent of the WWTP (direct discharge) in FDM installations (2/2)
Figure 2.27 shows TSS emissions to water as specific loads for direct discharges from FDM installations.

Techniques reported to reduce TSS emission levels
As indicated in Table 2.4, sedimentation is most widely used, followed by screening and flotation. Filtration and flotation are often preceded by a sedimentation step. Installations using membrane filtration as the main solids removal step (often as part of a membrane bioreactor) show lower TSS values in the effluent.

2.3.6.6.5 Total nitrogen (TN)

The parameter total nitrogen (TN) includes free ammonia and ammonium (NH₄-N), nitrites (NO₂-N), nitrates (NO₃-N) and organic nitrogen compounds. Dissolved elementary nitrogen (N₂) is not included. TN is frequently measured by combustion with subsequent analysis of nitrogen oxides via chemiluminescence (i.e. total nitrogen bound = TN₅, e.g. according to EN 12260), or by oxidation with peroxodisulphate with subsequent wet-chemical analysis of nitrate (Koroleff method, e.g. according to EN ISO 11905-1). TN can also be determined by summing up the individual concentrations of total Kjeldahl nitrogen (TKN), NO₂-N and NO₃-N.

Performance of reference installations
Often 24-hour composite samples are taken on a daily or monthly basis.

Table 2.63 shows some general statistics in relation to the data reported for TN emission levels.

Table 2.63: General statistics of data reported for TN emission levels (direct discharge)

<table>
<thead>
<tr>
<th>Units</th>
<th>Concentration</th>
<th>Specific load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of influent data values reported for TN</td>
<td>53</td>
<td>27</td>
</tr>
<tr>
<td>Number of effluent data values reported for TN</td>
<td>108</td>
<td>58</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]
Figure 2.28 (lower values) and Figure 2.29 (higher values) show TN emissions to water (concentrations for direct discharges) from FDM installations.

**Figure 2.28:** TN concentration in the effluent of the WWTP (direct discharge) in FDM installations (1/2)

**Figure 2.29:** TN concentration in the effluent of the WWTP (direct discharge) in FDM installations (2/2)

Figure 2.30 shows TN emissions to water as specific loads for direct discharges from FDM installations.
Techniques reported to reduce TN emission levels
As indicated in Table 2.4, biological nitrification and denitrification (as part of the overall biological waste water treatment) are widely implemented for abating TN emissions to water.

2.3.6.6.6 Total phosphorous (TP)

Phosphorus is present in waste water in inorganic and organic forms. The inorganic forms are orthophosphates (i.e. $\text{HPO}_4^{2-}$/$\text{H}_2\text{PO}_4$) and polyphosphates. Organically bound phosphorus is usually of minor importance. Polyphosphates can be used as a means of controlling corrosion. Phosphorus discharge has to be controlled in the same way as nitrogen discharge in order to avoid eutrophication of a surface water body. It was reported that, to avoid algal blooms under summer conditions, the critical level of inorganic phosphorus is near 0.005 mg/l.

Performance of reference installations
Often 24-hour composite samples are taken on a daily or monthly basis.

Table 2.64 shows some general statistics in relation to the data reported for TP emission levels.

<table>
<thead>
<tr>
<th>Units</th>
<th>Concentration</th>
<th>Specific load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of influent data values reported for TP</td>
<td>62</td>
<td>30</td>
</tr>
<tr>
<td>Number of effluent data values reported for TP</td>
<td>130</td>
<td>61</td>
</tr>
</tbody>
</table>

Figure 2.31 (lower values) and Figure 2.32 (higher values) show TN emissions to water (concentrations for direct discharges) from FDM installations.
Figure 2.31: TP concentration in the effluent of the WWTP (direct discharge) in FDM installations (1/2)

Figure 2.32: TP concentration in the effluent of the WWTP (direct discharge) in FDM installations (2/2)

Figure 2.33 shows TP emissions to water as specific loads for direct discharges from FDM installations.
Techniques reported to reduce TP emission levels
As indicated in Table 2.4, phosphorus removal by biological treatment and chemical precipitation is commonly applied.

2.3.7 Techniques to reduce emissions to air

2.3.7.1 Techniques applicable for a number of pollutants

2.3.7.1.1 Collection of emissions to air at source and local exhaust ventilation

Description
Enclosure of sources of emissions to air and the use of local exhaust ventilation, rather than treating the whole room.

Technical description
Enclosure of emissions to air sources, and the use of local exhaust ventilation uses considerably less energy than treating the whole room volume. Emissions to air include, e.g. odours, which often arise due to VOC emissions and dusts, such as grain and flour. To be effective, the dimensions of suction capacity need to be adequate and features such as guide plates and hoppers with swing flaps and lids can contribute to the minimisation of dust and gas emissions.

The identified emissions requiring treatment are ducted at source and possibly combined before being transported to an abatement technique. The objective of the equipment is that it prevents, where possible, and controls to a minimum, the escape of all emissions to air. The following are examples of areas of concern:

- vehicle loading/unloading points;
- access points to the process plant;
- open conveyors;
- storage vessels;
- transfer processes;
- filling processes;
- discharge processes.
Adequate ventilation of the workplace and specific process operations are required to ensure suitable working conditions, provide oxygen for combustion for oil- or gas-fired equipment and to form part of the system of controlling emissions to air. General and local ventilation removes, e.g. products of combustion from oil- and gas-fired equipment and odours, vapours and steam from cooking processes.

It is important to distinguish between general ventilation of the installation and local exhaust ventilation. General ventilation involves the movement of much larger volumes of air, so uses more energy and is more expensive. Local exhaust ventilation can provide protection from hazards to health arising from some cooking fumes, such as those involving direct application of heat to the food. Unless such ventilation is designed to be kept clean and free from fat residues it can lose efficiency and cause fire risks. If incoming replacement air is too hot or too cold, there is a risk that staff will switch it off. Where incoming air is drawn in naturally, some means of control over pest entry is usually required. The ventilated air can be extracted to an abatement plant and, in some cases, it may be recirculated, taking into consideration the hygiene requirements. In some applications, it is possible to collect airborne materials for reuse.

**Achieved environmental benefits**
Reduced emissions to air and potential reuse of airborne materials.

**Environmental performance and operational data**
The majority of abatement techniques are designed based on the volumetric airflow to be treated. This requires effective containment of the separate emissions whilst still maintaining an adequate volumetric flowrate of air to ensure no ingress of emissions to air into the working environment. Examples where air is recirculated include:

- recirculation of coffee roasting gases from continuous or discontinuous roasting
- dust-laden feed air can be recirculated to pneumatic conveyors, thereby also collecting the dust for reuse
- smoke from smoking chambers can be partially or wholly recirculated.

Records of design criteria, performance tests, maintenance requirements and tests and inspections can facilitate future maintenance, modification and testing against the original specification.

**Cross-media effects**
Energy consumption.

**Technical considerations relevant to applicability**
Applicable to all FDM installations with emissions to air, e.g. during loading and unloading vehicles; at hoppers, transfer points, chutes, loading pipes.

**Economics**
TWG, please provide information.

**Driving force for implementation**
Occupational health.

- There can be considerable cost savings made in the capital cost of the abatement plant by minimising the volumetric flowrate requiring treatment.

**Example plants**
This technique is widely applied in the FDM sector.

**Reference literature**
[16, Willey et al. 2001], [35, Germany 2002], [139, Health and Safety Executive 2000]
2.3.7.1.2 Exhaust gas recirculation (EGR) Oxidation of waste gases in an existing boiler

Description
Recirculation of (part of) the waste gas to a combustion chamber to replace part of the fresh combustion air.

Technical description
It may be possible to direct the malodorous waste gases to an existing on-site boiler. This has the advantage of using existing equipment and avoiding the expense of investing in an additional treatment option. The principle of operation is essentially the same as for thermal oxidation in a purpose built plant.

The malodorous exhaust stream is ducted to the combustion airflow fan of the boiler or boilerhouse, then to the boiler. It provides oxygen to the combustion process and the malodorous organic compounds are destroyed.

The overall feasibility of using an existing boiler largely depends upon the volume of malodorous air waste gas to be treated in relation to the boiler combustion air requirements under the extremes of load. If the volume of malodorous air waste gas is significantly less than the combustion air requirements then it is unlikely to present a problem. The total volume of malodorous air waste gas could simply be ducted through the combustion fan. However, the vast majority of operating conditions result in the boiler operating in a cyclic mode in response to a steam pressure signal.

Potential implications for the boiler operation need to be fully ascertained. The safety features associated with routing a malodorous waste gas discharge to a boiler are essentially included in the existing boiler operation. Flame arrestors or water seals may need to be added to prevent flame flashback between the boiler and the gas stream to be treated.

For more information please consult the LCP BREF [256, COM 2016].

Achieved environmental benefits
Reduced dust, SO$_2$, NO$_X$, CO, TVOC gas and odour emissions.

Environmental performance and operational data
This technique is highly efficient and, if correctly operated, as efficient at eliminating odours, including intense odours, as other burning methods.

The normal operation of a boiler is to generate steam in line with the demand from the installation as judged continuously from the steam pressure signal at the boiler outlet. As the steam pressure increases to its set point, the boiler will respond by reducing the fuel flowrate to the burner. The combustion airflow, being electrically or mechanically linked to the fuel feed rate, will also reduce to maintain optimum combustion conditions. If the combustion airflow rate at this low firing condition is lower than the volume of malodorous air to be treated, then the control strategy of the boiler would need to be changed. Also, a knowledge of the oxygen content of the malodorous air, if it is suspected to be less than 21 %, will further help with the initial feasibility exercise.

An important initial consideration is to check whether the boiler would be operating when malodorous waste gases are produced. This, for most operations, is likely to be the case. The control strategy for the boiler could change from being dependent upon the steam pressure to being dependent upon the combustion airflow rate. The combustion airflow rate would then be set to a minimum, i.e. equivalent to the volume of waste gas malodorous air to be treated, which in turn would set a minimum fuel flowrate and firing rate. When the steam set point pressure is achieved, the boiler reverts to operation at the minimum combustion airflow rate and the unwanted heat is discharged through the boiler stack. A key part of the evaluation is to ascertain
the percentage of time that the boiler operates with a combustion airflow rate lower than the malodorous waste gas flowrate, to calculate additional fuel costs.

Cross-media effects
Energy consumption. Fuel consumption may be raised as it may be necessary to keep the boiler running, when it would otherwise not have been required.

Technical considerations relevant to applicability
Airstreams containing significant quantities of dust generally require pretreatment prior to the thermal oxidation process.

Used for the removal of gaseous pollutants and odour. Suitable for low volume, high concentration odours.

Economics
The potential to use an existing boilerhouse has economic benefits, both in terms of capital costs and operating costs.

Driving force for implementation
Compliance with legal requirements.

Example plants
Installation #352 [193, TWG 2015].

Reference literature
[16, Willey et al. 2001], [193, TWG 2015], [256, COM 2016]

2.3.7.1.3 Combustion optimisation
For more information please consult the LCP BREF [256, COM 2016].

Description
Measures taken to maximise the efficiency of energy conversion, e.g. in the furnace/boiler, while minimising emissions (in particular of CO). This is achieved by a combination of techniques including good design of the combustion equipment, optimisation of the temperature (e.g. efficient mixing of the fuel and combustion air) and the residence time in the combustion zone, and/or use of an advanced control system.

Technical description
The technique includes the good design of the furnace, combustion chambers, burners and associated devices and the regular planned maintenance of the combustion system according to suppliers' recommendations.

Achieved environmental benefits
Reduction of NOX, N2O, CO and other unburnt emissions to air in a balanced way.

Example plants
TWG, please provide information.

Reference literature
[256, COM 2016]
Chapter 2

Transport of ducted emissions to the treatment or abatement equipment

Description
Ducted emissions are transported to the end-of-pipe treatment or abatement equipment. There are three major factors to be taken into account when designing equipment to transport emissions to the treatment plant. These are transport velocity, ventilation ducting design and discontinuous flows.

Achieved environmental benefits
Reduced emissions to air.

Cross-media effects
Energy consumption.

Environmental performance and operational data
Selecting a low transport velocity minimises extraction fan costs. If the presence of dust is considered to be a problem, then a transport velocity of not less than 10 m/s is chosen. A transport velocity of 5 m/s is considered to be a minimum.

If the presence of dust is likely to cause operational problems, in spite of operation at high transport velocities, then a plenum chamber, i.e. an enlarged duct where the particulate laden airstreams enter and the overall velocity is reduced to between 2.5 and 5.0 m/s, can be installed. The chamber is purposely designed to enhance particulate deposition and is fitted with a hoppered side and a number of clean-out doors along its length. The outlet ducting from the plenum chamber is reduced in diameter to reattain the system transport velocity.

The extract ventilation ducting is designed with a common transport velocity throughout, so that the air velocity in all duct and exhaust branches is the same. The entry of branches to the main duct can be angled at a maximum of 45°, although an angle of 30° is more efficient. At the entry point of the branch into the main duct, the main duct diameter gradually increases at an angle of 15°. To ensure that the required performance is achieved, the design of the ventilation ductwork is frequently conducted by a specialised contractor.

Discontinuous exhaust flows are quite common where there are a number of exhausts being discharged to a central treatment plant, if some are continuous and others are discontinuous. This may give the potential for certain exhausts to contaminate other process emissions during a failure mode and the operation of the fan under varying load conditions may need to be considered.

The control system required for this type of arrangement can be complex. For instance, the fan can be specified as a single speed system, so that it always pulls the design flowrate. This system requires an additional inflow to the ventilation system to rectify any deficiency in the design flowrate once a process goes off line. This additional inflow could be extracted from the operator workplace or that used to provide additional ventilation to the building. Alternatively, a fan operating with a frequency inverter can be used. The fan speed would then be controlled by a static pressure measurement at the inlet to the fan and downstream of the last branched entry. This system would result in a variable flowrate to the treatment plant in line with the particular processes that are in operation. The choice of a fixed speed or inverter system largely depends on the type of abatement plant installed and whether there are any treatment efficiency disadvantages with a changing flowrate.

Technical considerations relevant to applicability
Applicable to all FDM installations with emissions to air.

Reference literature
[34, Willey A R and Williams D A, 2001]
Selection of end-of-pipe odour/VOCs abatement techniques

Description

Achieved environmental benefits
Reduced odour emissions.

Technical considerations relevant to applicability
Applicable to all FDM installations.

Driving force for implementation
Reduced odour emissions.

Reference literature
[16, Willey A R and Williams D A 2001]

2.3.7.2 Techniques to reduce dust emissions

2.3.7.2.1 Separator

Description
The waste gas stream is passed into a chamber where the dust, aerosols and/or droplets are separated from the gas under the influence of gravity/mass inertia.

Technical description
The waste gas stream is passed into a chamber where the dust, aerosols and/or droplets are separated from the gas under the influence of gravity/mass inertia. The effect is increased by reducing the gas velocity by design means, e.g. baffles, lamellae or metal gauze.

Separators could resemble a horizontally mounted fan body, but the air is fed into a circular body where the dust moves to the outside wall of the separators under centrifugal force. The dust is collected from the outside wall by a collection vessel and diverted down into a rotary airlock seal and on to recovery. The air, now without the dust, is expelled vertically through a stack to atmosphere.

The design should ensure a good uniform speed distribution inside the vessel. Preferential flows have an adverse effect on efficiency. The use of internal obstructions in the inertia separator enables operation at higher speeds, which represents a reduction in volume of the separator compared with the settling chamber. The drawback is the increasing pressure drop. Further information is available in the “Waste water and waste gas treatment BREF” [217, EC, 2003].

Achieved environmental benefits
Reduction of dust emissions to air pollutants. Potential reuse of airborne materials.

Environmental performance and operational data
Separators are characterised by a simple and robust design, small space requirements and high operating reliability. The technique requires minimum airflow to maintain performance.

Deflection or inertia separators enable effective dust removal. Due to their inertia, larger particles are unable to follow the repeatedly deflected gas stream and are separated. With the appropriate design, it is possible to achieve separation rates of 50% for particles in excess of 100 µm.

Cross-media effects
Energy consumption.
Technical considerations relevant to applicability
Separators are suitable for use where:

- there are high emission levels of dust in the untreated gas;
- there is no great requirement for the removal of fine particles;
- there is a need for preliminary separation and/or protection and relief of downstream systems;
- pressures are high, e.g. high pressure dedusting;
- temperatures are high, e.g. high temperature dedusting.

Economics
Low cost technique.

Example plants
See Table 2.8.

Reference literature
[35, Germany 2002]

2.3.7.2.2 Bag filter

Description
Bag filters, often referred to as fabric filters, are constructed from porous woven or felted fabric through which gases are passed to remove particles. The use of a bag filter requires the selection of a fabric suitable for the characteristics of the waste gas and the maximum operating temperature.

Technical description
Bag filter or fabric filter systems work by passing air containing particulates through a filter medium which traps the particles as the air is forced through the filter media. The process takes place inside filter units which are placed in the flow of the air to be filtered. To maintain the efficiency of the filter media, they are cleaned at regular intervals either by being vigorously shaken or a reverse jet of air blown through them to release any material held on the filter - this material is then collected and reused in the production process. It is necessary to change the filter media regularly to ensure that they remain efficient and that there are no microbiological risks to the installation resulting from accumulation of material on the filter media.

Most bag filters use long, cylindrical bags (or tubes) made of woven or felted fabric as a filter medium, suitable for the characteristics of the flue-gas and the maximum operating temperature.

Bag filters are made up of filter material up to about 30 mm thick and measure up to 0.5 m high and 1.5 m long. The filter bags are fitted with their open end towards the clean gas duct. In tubular filters, the filter medium consists of tubes up to 5 metres long with a diameter of between 12 and 20 cm. The untreated gas stream always flows from outside to inside, usually in the upper region of the filter bag.

Table 2.65 shows a comparison between different bag filter systems and Figure 2.34 shows an industrial bag filter.
Table 2.65: Comparison between different bag filter systems

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pulse jet filter</th>
<th>Membrane fibreglass filter</th>
<th>Fibreglass filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air to cloth ratio</td>
<td>22–25 m/s</td>
<td>19–25 m/s</td>
<td>8–10 m/s</td>
</tr>
<tr>
<td>Temperature limits</td>
<td>200 °C</td>
<td>280 °C</td>
<td>280 °C</td>
</tr>
<tr>
<td>Bag type</td>
<td>Polyester</td>
<td>Membrane/fibreglass</td>
<td>Fibreglass</td>
</tr>
<tr>
<td>Bag size</td>
<td>0.126 x 6.0 m</td>
<td>0.292 x 10 m</td>
<td>0.292 x 10 m</td>
</tr>
<tr>
<td>Cloth area per bag</td>
<td>2.0 m²</td>
<td>9.0 m²</td>
<td>9.0 m²</td>
</tr>
<tr>
<td>Cage</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Pressure drop</td>
<td>2.0 kPa</td>
<td>2.0 kPa</td>
<td>2.5 kPa</td>
</tr>
<tr>
<td>Bag life</td>
<td>Up to 30 months</td>
<td>6–10 years</td>
<td>6–10 years</td>
</tr>
</tbody>
</table>

Source: [35, Germany 2002]

As a general rule, the average distance between fibres is considerably larger than the particles to be collected. The separation rates due to the screen effect are also supplemented by mass forces, obstructive effects and electrostatic forces.

Figure 2.34: Picture of an industrial bag filter

In the tubular bag filter systems, the equipment contains a round filter comprising a bank of vertical tubes mounted in a cylinder, similar in appearance to a cyclone and which does not require significant space. The airstream is passed through the filter and the fines are deposited on the surface of the individual tubular filters. The tubular filters are cleaned by means of a fully automatic pulse-like reverse flushing system, using compressed air or other pressurised gases, with the aid of a multistage injector system. The tubes are cleaned individually, which ensures continuous cleaning of the tubular filters and dust removal.
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The product cleaned off the tubular filters falls onto the outlet base, where it is conveyed by air flowing through a special perforation system, to the dust outlet. The gases cleaned in this way leave the filter as clean gas via a clean gas chamber.

**Achieved environmental benefits**
Reduced emissions of dust to air. Reduced energy consumption is also reported (no data provided). Reduced waste production, e.g. due to the separation process being dry, it may, in principle, be possible to reuse separated particulate matter in the process, or as a by-product.

**Environmental performance and operational data**
Filter separators can achieve high separation rates, e.g. > 99 %, with even very fine particles being separated very efficiently. Bag filters can be used to reduce dust emissions to < 5 mg/Nm$^3$. The techniques to consider in the determination of BAT of the FDM sectorial chapters (see Chapters 3 to 15) contain installation-specific performance data related to the application of bag filters.

Filters use significantly less energy than cyclones and produce less noise. If filtering installations suitable for CIP are used for outgoing air, it is not necessary to use cyclones allowing huge energy savings and noise reductions to be achieved. Reduced consumption of water and cleaning agents, by using CIP [35, Germany 2002].

**Cross-media effects**
Energy consumption. By-products are produced for which further treatment may be required. Bag filter material life is limited and creates another waste to dispose of.

**Technical considerations relevant to applicability**
Filters are used for the removal of solid and liquid air pollutants. They are also used for flue gas purification. Limited application for sticky emissions to air. Bag filters may be less effective in applications with waste gas temperatures over 240 °C. Depending on the flowrate design parameters, they can reach significant volumes and require considerable space.

**Economics**
Although the investment costs of bag filters are quite low, maintenance costs are high, as the filter material has to be changed every two to five years. Equipment associated with bag filters is more complex than cyclones and requires additional maintenance time. The minimum expense associated with a filter change is approximately 10 % of the investment cost. Precipitated material is generally easy to recycle and has some economic value.

**Driving force for implementation**
- Legislation is the main driving force.
- For those installations where the separated ash can be reused, economics is also a driver.

**Example plants**
Bag filters are used in almost all the FDM sectors, see Table 2.8.

**Reference literature**
[35, Germany 2002], [193, TWG 2015], [256, COM 2016]

**Tubular filter**

**Technical description**
The gas flows from inside to outside or vice versa, depending on the cleaning method.
The individual cleaning of the tubular filters reduces the quantity of dust cleaned from the filter at any given time, which means the potentially explosive dust-air volume in the filter chamber is correspondingly smaller compared with conventional filter systems. CIP filters have been used successfully in the food industries since 1995. If used in the dairy industry, the filter product is comparable to the spray drier tower product. Tubular filters may be used without a preliminary cyclone separator.

The cleaning system for the round filters is similar to that used for cleaning the tubular filters installed as a CIP system. A stream of air is passed through the CIP nozzles in the base of the tubular filter and the other nozzles within the filter, during operation, but not during CIP cleaning. This prevents the CIP nozzles from being blocked with dust from the process air.

Another important advantage is that the tubular filter base in the zone where the airstream is laden with dust is kept clean by air flushing. This means that even with very hygroscopic products the base is kept free of heavy deposits. This is a substantial advantage compared with other filter designs and extends the operational time between cleaning phases. The clean gas and dirty gas zones, the tubular filters, the filter wall and the other internal parts are intensively sprayed via carefully arranged nozzle groups.

Figure shows a tubular dust filter used to remove fines, downstream of a spray drier in a large dairy.

**Figure:** Tubular filter system of a large dairy
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Achieved environmental benefits
Reduced emissions of dust to air. Reduced energy consumption is also reported (no data provided).

Reduced waste production, e.g. due to the separation process being dry, it may, in principle, be possible to reuse separated particulate matter in the process, or as a by-product.

Filters use significantly less energy than cyclones and produce less noise. If filtering installations suitable for CIP are used for outgoing air, it is not necessary to use cyclones, allowing huge energy savings and noise reductions to be achieved. Reduced consumption of water and cleaning agents, by using CIP.

Environmental performance and operational data
Filter separators can achieve high separation rates, e.g. >99%, with even very fine particles being separated very efficiently.

In the example dairy described in Section 0, dust emissions from the drying totalled 534 kg/yr dust after filtering, giving 28 mg dust/t dried product. It is also reported that an emission level of 10 mg/Nm\(^3\) is achievable. In the same dairy, it was specified that an interval of 3 to 4 minutes should be allowed between cleaning operations, to allow the water to drain from the pipes. It is important to ensure complete drainage, to prevent subsequent dripping at the nozzles. At the end of the entire cleaning programme, the relevant flaps and valves in the return line have to be left open to allow the water in the tubular filters to drain away. Drying of the system needs to be started about 1 to 2 hours after the end of the cleaning procedure. The tubular filters need to be dried with warm air, with the tubular filter cleaning system switched off, to prevent operational problems due to moisture when it is used again.

Technical considerations relevant to applicability
Tubular filters are widely applied in the FDM sector. They are used for the removal of solid and liquid air pollutants.

Example plants
A milk powder manufacturer in Germany.

Reference literature
[5, German Dairy Association 1999], [35, Germany 2002]

2.3.7.2.3 Cyclone

Description
Dust control system based on centrifugal force, whereby particles are separated from the carrier gas.

Technical description
Cyclones use inertia to remove particles from the gas stream by using centrifugal forces, usually within a conical chamber. They operate by creating a double vortex inside the cyclone body. The incoming gas is forced into circular motion down the cyclone near the inner surface of the cyclone tube. A high-speed rotating flow is established within a cylindrical or conical container called a cyclone. Larger (denser) particles in the rotating stream have too much inertia to follow the tight curve of the stream, and strike the outside wall, then fall to the bottom of the cyclone where they can be removed. At the bottom, the gas turns and spirals up through the centre of the tube and out of the top of the cyclone. Particles in the gas airstream are forced toward the cyclone walls by the centrifugal force of the spinning gas but are opposed by the fluid drag force of the gas travelling through and out of the cyclone. Large particles reach the cyclone wall and are collected in a bottom hopper, whereas small particles leave the cyclone with the exiting
Some cyclones larger and more elongated than normal cyclones. The efficiency of the cyclone mainly depends on the cyclone separators’ geometric features (height) and the centrifugal force used (speed). The smaller the cyclone separators’ radius, the greater the centrifugal acceleration and thus the better the separation. The particles are crushed against the walls of the cone while the gas is expelled from the cyclone. This shape allows the improvement of the rotational speed, so, as the diameter decreases, theoretically even the smallest particles of dust are separated from the air flow inside the cyclone.

It is important to observe the air flow for which the cyclone is dimensioned (flow and temperature). A product that is too dry is more volatile and does not stick to the walls of the cone properly. The humidity instructions of output air are observed as much as possible.

The cyclone is sensitive to the incoming air flow (humidity, dimension and kind of product) and the watertightness of the locks that prevent the air from entering the cyclone from below, in vacuum cyclones. The average lifetime of a cyclone (replacement) is from 10 to 20 years.

Figure 2.35 shows the operational principle of a cyclone.

![Cyclone Diagram](image)

**Source:** [267, FEFAC 2015]

Cyclones are normally used to control particulate material of primarily >10 μm. There are, however, high-performance efficiency cyclones designed to be effective even for particles as small as 2.5 μm.

For high-performance cyclones, the working principle is the same kind as that of cyclones. The differences compared with traditional cyclones are the size and the proportion between width and length. High-performance cyclones have a more elongated shape. This shape allows the improvement of the rotational speed, so, as the diameter decreases, even the smallest particles of dust are separated from the air flow inside the cyclone. Additionally, a more accurate dimensioning of the cyclone related to the air flow can be achieved. The main controllable operating parameters are: pressure (mbar) and air flow (kg/h); their balance according to the given efficiency curve allows the best performance to be achieved.

**Achieved environmental benefits**
Reduction of dust emissions to air pollutants. Potential reuse of airborne materials.
Environmental performance and operational data
Cyclones are characterised by a simple and robust design, small space requirements and high operating reliability. Generally the removed dust is sent back to the production process. Cyclones achieve better separation results than separators (see Section 2.3.7.2.1). Table 2.10 shows performance data of a cyclone, compared to other separation techniques.

Cyclones are used to remove small particles in the exhaust air of the drier, during the production of distillers dried grains and the efficiency of the cyclones can reach up to 99.97% (see Section) depending on process conditions and particle sizes.

More environmental performance and operational data are presented in the related FDM sectorial chapters.

Cross-media effects
By-products are produced for which further treatment may be required. Electrical energy is used to overcome the pressure drop in the cyclones. Also, the operation of cyclones is a source of significant noise.

Technical considerations relevant to applicability
Applicable in new and existing installations. Only a small amount of space should be available to install the cyclone together with the air inlet and outlet ducts.

Cyclones used without other abatement techniques are generally not adequate to meet air pollution regulations, but they serve a purpose as precleaners for more expensive final control devices such as fabric filters (see Section 2.1.6.2.2) or ESPs (see Section 2.3.7.2.4). They are extensively used after spray drying operations and after crushing, grinding and calcining operations. Fossil fuel-fired industrial fuel combustion units commonly use multiple cyclones which operate with greater efficiency than a single cyclone and can separate particles <2.5 μm.

Cyclones are used for the removal of solid and liquid air pollutants. They are mainly used for separation of large particles only, i.e. >10 μm. They are suitable for use where:

- there are high levels of dust in the untreated gas
- there is no great requirement for the removal of fine particles
- there is a need for preliminary separation and/or protection and relief of downstream systems
- pressures are high, e.g. high pressure dedusting
- temperatures are high, e.g. high temperature dedusting.

A minimum airflow is required to maintain operational performance. Regular inspection is performed to ensure that the interior of the cyclone is dry and that there is no accumulation of material which could affect the efficiency of the cyclone's operation.

Economics
Low-cost technique. Operating costs include the energy necessary for the pneumatic or hydraulic removal of the collected ash and electric power to compensate the waste gas pressure loss of the equipment. Maintenance costs are low given the durability of all of the components.

For a cyclone applied in the extrusion unit of an animal feed installation, an investment cost of EUR 26 000 was reported (purchase of cyclone and fan). Its annual operating cost was around EUR 51 000, related to 341 000 kW/yr of electricity consumption [193, TWG 2015].

Driving force for implementation
Legislation is the main driving force.

Example plants
Cyclones are used in almost all the FDM sectors, see Table 2.8.
Cyclones are used during the production of animal feed; dried milk; dried soup; cake mixes; custard; distillers dried grains; dried sugar beet pulp; starch; ice cream mixes; coffee roasting, drying and blending; tea blending and malt blending, generally, cyclones are used as an integral part of the process to recover dust from the extracted air for reprocessing. They are used in the vegetable oil sector to remove fine impurities such as plant residues, dust, sand and wet dust emissions from raw oilseeds (see Section 11.4.2.2.1).

Reference literature
[35, Germany 2002], [92, Gergely E. 2003], [193, TWG 2015], [256, COM 2016]

2.3.7.2.4 Electrostatic precipitator (ESP)

Description
Electrostatic precipitators operate such that particles are charged and separated under the influence of an electrical field. Electrostatic precipitators are capable of operating under a wide range of conditions. In a dry ESP, the collected material is mechanically removed (e.g. by shaking, vibration, compressed air), while in a wet ESP it is flushed with a suitable liquid, usually water.

Technical description
ESPs are used to separate solid or liquid particles from waste gases. The particles distributed in the gas are electrostatically charged so that they stick to collection plates. The main components of an ESP are the filter housing, the discharge and collecting electrodes, the power supply, the gas guides or baffles and a rapping system for cleaning the collecting plates. The separation process can be divided into the following individual stages:

- charging of the particles in the ion field;
- transport of the charged particles to the collecting plate;
- collection and film formation on the collecting plate;
- removal of the dust film from the collecting plate.

A distinction is made between dry and wet ESPs. These may have a horizontal or vertical gas flow. Dry ESPs are mostly built with collecting electrodes in plate form; they are also called plate ESPs. In wet ESPs, the collecting electrodes frequently take the form of tubes, here the gas flow is usually vertical; they are also called tube ESPs.

Figure 2.36 shows the typical arrangement of an electrostatic precipitator.
Figure 2.36: Typical arrangement of an electrostatic precipitator (only two zones shown)

Achieved environmental benefits
Reduction of dust emissions to air.

Reduction of emissions to air. Low energy requirements compared to other separation techniques.

Environmental performance and operational data
Electrostatic precipitators permit separation rates of up to 99.9%, effective separation of particles even lower than 0.1 µm, and treatment of waste gas volumes higher than 1 000 000 m$^3$/h [35, Germany 2002]. Table 2.10 shows performance data of this technique, compared to other separation techniques.

Table 2.66 shows installation-specific performance data related to the application of ESPs.

Electrostatic precipitators have comparatively low pressure losses, e.g. from 0.001–0.004 bar; low energy requirements, e.g. 0.05 to 2 kWh/1000 m$^3$ and a long service life. Wet ESPs can achieve better separation rates than dry ESPs. In particular, they can separate fine dusts, aerosols and to some extent, heavy metals and gaseous substances.
Table 2.66: Average values of periodic measurements of dust in dryer emissions after treatment in an electrostatic precipitator [193, TWG 2015]

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>FDM sector</th>
<th>Dust (mg/Nm$^3$)</th>
<th>O$_2$ content (%)</th>
<th>Monitoring standard</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>303-2 OI</td>
<td>11.80</td>
<td>16.00</td>
<td>EN 13284</td>
<td>• Sunflower seed, grapeseed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Combustion gases from steam generator and direct contact pomace dryer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Cyclone step before</td>
<td></td>
</tr>
<tr>
<td>303-1 OI</td>
<td>26.99</td>
<td>15.20</td>
<td>EN 13284</td>
<td>• Sunflower seed, grapeseed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Combustion gases from steam generator and direct contact seed dryer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Cyclone step before</td>
<td></td>
</tr>
</tbody>
</table>

Cross-media effects
Residue (fly ash) or liquid effluent (only in the case of wet ESPs) is produced which may require further treatment. Electricity is consumed. The high voltage of an ESP can introduce a new hazard.

Waste water produced, when wet ESPs are used.

Technical considerations relevant to applicability
Used for the removal of solid and liquid air pollutants, especially for fine dust. ESPs are used in large systems for cleaning large quantities of waste gas at high temperatures. Wet ESPs are used for cleaning liquid-saturated gases, for acid and tar mists, or if there is a risk of explosion.

Economics
The cost of electrostatic precipitators includes costs due to electricity consumption, maintenance expenses and the transfer of the precipitated ash, but generally they are cost-effective devices for reducing dust emissions [256, COM 2016].

Driving force for implementation
Legislative demands for reduced emissions of fine particulate matter.

Example plants
This technique has been reported in an oilseed installation (#303) [193, TWG 2015].

Reference literature
[35, Germany 2002], [193, TWG 2015], [256, COM 2016]

2.3.7.2.5 Packed bed filter

Description
Dust particles become attached to a granulated layer of gravel, sand, limestone or coke.

Technical description
The filter medium used in packed bed filters is typically a granular layer of gravel, sand, limestone or coke in the 0.3 to around 5 mm particle size range. During filtration, the dust particles become attached to the granulated layer. A dust layer which supports the separation
process is formed at the surface of the bed. Penetration of the separated dust can be prevented by using fine particles (<0.5 mm) and low flow speeds (<0.1 m/s). However, there is a risk of bridge formation, which can result in reduced separation rates.

The packed bed may be up to several metres high. Cleaning is carried out by counterflow rinsing, mechanical shaking in conjunction with flushing air, or by movable nozzles while cleaning is taking place. Use of a multi-compartment filter design ensures continuous cleaning.

Packed bed filters can be used to achieve the simultaneous separation of dust and gases. Packed bed filters satisfy an essential requirement for high temperature or hot gas dedusting, namely utilisation of the thermal energy of the cleaned gas streams at a high temperature level.

**Achieved environmental benefits**

Reduced dust emissions to air. Reduced energy consumption is also reported (no data provided). Filters use significantly less energy than cyclones and produce less noise. If filtering installations suitable for CIP are used for outgoing air, it is not necessary to use cyclones allowing huge energy savings and noise reductions to be achieved. There is reduced consumption of water and cleaning agents by using CIP.

**Environmental performance and operational data**

Filter separators can achieve high separation rates, e.g. >99%, with even very fine particles being separated very efficiently. Clean gas figures of around 10 mg/Nm$^3$ for dust have been achieved in trials using packed bed filters, with an average dust content of 18 g/Nm$^3$ in the dirty gas and a mean particle size of 0.5 µm.

The separation rate of packed bed filters is not as good as that of fibre layer filters. Packed bed filters are, therefore, used for separating problematical dust particles or separation at higher waste gas temperatures. Packed bed filters are frequently used in conjunction with preliminary separators, e.g. cyclones.

As a general rule, the average distance between fibres is considerably larger than the particles to be collected. The separation rates due to the screen effect are also supplemented by mass forces, obstructive effects and electrostatic forces.

**Technical considerations relevant to applicability**

Packed bed filters are suitable for the removal of dusts which are:

- hard and abrasive
- at temperatures of up to 1000 ºC
- mixed with chemically aggressive gases
- combustible and where there is a risk of sparks
- mixed with mists
- mixed with some gaseous pollutants, e.g. SO$_2$, HCl and HF, when simultaneous separation can be achieved with suitable packing.

**Economics**

TWG, please provide information.

**Driving force for implementation**

Legislation is the main driving force.

**Example plants**

TWG, please provide information.

**Reference literature**

[35, Germany 2002]
Packed bed absorber

Technical description
Packed bed systems are the most commonly used type of absorbers, offering the advantages of maximised surface area per unit volume and relatively low pressure drop. A packed bed absorber system layout is shown in Figure.

![Diagram of Packed Bed Reactor Layout](image)

Figure: Packed bed reactor layout

The airstream to be treated is directed in a countercurrent fashion to the recirculated liquid stream. The packed bed area comprises a large number of packing pieces, usually made of plastic, which allow a considerable surface area for the gas and liquid to come into contact with each other. The liquid system can comprise anything from a simple recirculation pump assembly to a sophisticated chemical dosing station together with pH control dosing/control facilities. The liquid distribution is reported to be most effectively achieved by a series of nozzles situated symmetrically over the surface area of the unit. The treated airstream is discharged through a mist eliminator to remove any entrained droplets prior to discharge.

Achieved environmental benefits
Removal of odours, gases and dust from air.

Environmental performance and operational data
Absorbers are reported to be more effective for the removal of specific components rather than overall removal and they have a reported efficiency of typically 70–80%.
The use of one central nozzle to distribute the liquid is decreasing because it gives poorer liquid distribution. Depending upon the vertical length of the packing within the absorber, there may be a need to incorporate liquid redistribution systems.

The equipment is compact, so absorbers do not take up much space, but they may require space for the safe storage of chemicals.

Cross-media effects
Waste water is generated. Likely to generate a visible plume at the flue gas outlet.

Technical considerations relevant to applicability
In general terms, absorbers are suitable for a wide range of volumetric airflows which contain gases and/or odours in relatively low concentrations.

Economics
Relatively inexpensive, compared to other end-of-pipe odour control techniques. Relatively low capital and operating costs. Their cost effectiveness is reduced if the exhaust gas to be treated has a high moisture content, due to their preferential absorption of water vapour.

Example plants
Used extensively to control odour.

Reference literature
[16. Willey et al. 2001]

2.3.7.3 Techniques mainly used to reduce organic/odour emissions

2.3.7.3.1 Wet scrubber

Description
Gaseous compounds are dissolved in a scrubbing solution (e.g. an alkaline solution containing lime, NaOH, or H₂O₂). Downstream of the wet scrubber, the off-gases are saturated with water and a separation of the droplets is carried out before discharging the off-gases. The resulting liquid is further treated by a waste water process and the insoluble matter is collected by sedimentation or filtration.

Technical description
In dynamic separation techniques, the effective mass forces, i.e. gravity, inertia and centrifugal forces, all fall off sharply with increasing particle size. Wet cyclones are high-efficiency units, spraying water into the waste gas stream to increase the weight of the particulate material and hence also removing fine material and increasing the separation efficiency. Although, generally speaking, this merely shifts the pollutants from the air into the water. Wet separators may be chosen for particular applications, e.g. when there is an explosion risk associated with a dust.

Wet scrubbing (or absorption) is a mass transfer between a soluble gas and a solvent—often water— in contact with each other. Physical scrubbing is preferred for chemical recovery, whereas chemical scrubbing is restricted to removing and abating gaseous compounds. Physico-chemical scrubbing takes an intermediate position. The component is dissolved in the absorbing liquid and involved in a reversible chemical reaction, which enables the recovery of the gaseous component. Scrubbing or absorption is widely used as a raw material and/or product recovery technique for the separation and purification of gaseous streams which contain high concentrations of VOCs, especially compounds soluble in water such as alcohols, acetone or formaldehyde. The use of absorption as the primary control technique for organic vapours is subject to the availability of a suitable solvent, with a high solubility for the gas, low vapour pressure and low viscosity.
Wet dust scrubbing is a variation of wet gas scrubbing using the same or equivalent techniques to abate or recover dust in addition to gaseous compounds. A type of scrubber widely operated for dust abatement is the venturi scrubber.

Different types of wet scrubbers can be distinguished by classifying them in terms of their design features. Some examples are:

- absorption techniques such as scrubber towers, spray scrubbers, packed bed absorber (see Sections 2.1.7.2.6–2.1.6.2.3 and Table 2.67);
- injection scrubbers, e.g. high pressure/dual substance injection scrubbers;
- jet scrubbers;
- vortex scrubbers;
- rotary scrubbers, disintegrators (high performance);
- venturi scrubbers (high performance).

A spray scrubber simply comprises a liquid spray which comes into contact with an upward rising airstream within a vessel. The vessel contains no packing or plates or any device used to enhance gas-liquid contact. A typical spray tower configuration is shown in Figure 2.37.

Regarding the venturi scrubber, the characteristic feature is the constriction of the duct—venturi throat—causing an increase in gas velocity. Liquid is introduced into the scrubber and forms a
film on the walls, which is atomised by the gas stream in the venturi throat. Alternatively, with ejector venturi scrubbers, the liquid is sprayed into the venturi throat.

An example of design standards for wet scrubbers used in Germany according to DIN standards is shown in Table 2.67.
<table>
<thead>
<tr>
<th>Description</th>
<th>Scrubber tower</th>
<th>Injection scrubber (high pressure or dual-substance injection scrubber)</th>
<th>Jet scrubber</th>
<th>Vortex scrubber</th>
<th>Rotary scrubber, disintegrator</th>
<th>Venturi scrubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbols according to DIN 30600/28004</td>
<td>![Diagram]</td>
<td>![Diagram]</td>
<td>![Diagram]</td>
<td>![Diagram]</td>
<td>![Diagram]</td>
<td>![Diagram]</td>
</tr>
<tr>
<td>Gas speed in contact zone in relation to free cross-section (m/s)*</td>
<td>1–5</td>
<td>20–60</td>
<td>5–15</td>
<td>0–20</td>
<td>25–70</td>
<td>40–150</td>
</tr>
<tr>
<td>Pressure difference over entire separator (bar)*</td>
<td>1–25</td>
<td>5–25</td>
<td>Pressure recovery of approximately 10</td>
<td>15–30</td>
<td>2–10⁻¹¹</td>
<td>30–200</td>
</tr>
<tr>
<td>Energy requirements (kWh/1000 m³)</td>
<td>0.2–3</td>
<td>0.4–2</td>
<td>1.2–3</td>
<td>1–2</td>
<td>4–15⁻¹¹</td>
<td>5–15</td>
</tr>
<tr>
<td>Collecting liquid/gas ratio (l/m³)*</td>
<td>1–5</td>
<td>0.5–5</td>
<td>5–50</td>
<td>No data possible due to process principle</td>
<td>1–3 per stage</td>
<td>0.5–5</td>
</tr>
<tr>
<td>Separation limit (µm)*</td>
<td>0.7–1.4</td>
<td>0.1–1</td>
<td>0.8–0.9</td>
<td>0.6–0.9</td>
<td>0.1–0.6</td>
<td>0.05–0.5</td>
</tr>
<tr>
<td>Dust separation rate (%)*</td>
<td>50–85</td>
<td>90–95</td>
<td>90–95</td>
<td>90–95</td>
<td>92–96</td>
<td>96–98</td>
</tr>
</tbody>
</table>

NB:
* Approximate values, higher or lower variations are possible
1) In disintegrators, the energy consumption is often considerably higher depending on the efficiency and the volume of gas handled. A pressure recovery of up to 25 bar is possible.
2) The separation rate shown in the table merely gives a rough idea of the possible working range. Although the separation rate is easy to measure, it only permits limited conclusions about the efficiency of a separator. For example, it is directly dependent on the particle size distribution of the input material. If the particle size distribution changes, so does the separation rate, even if the other parameters remain constant. A knowledge of the separation rate does, however, become important in the specific application. The fraction separation rate is a much more suitable parameter for assessing the efficiency of a separator.

Source: [136, Deutsches Institut für Normung p.v. 2005]

Table 2.67: Dust removal from air – overview of wet scrubbers separators
Achieved environmental benefits
The major environmental benefits of the application of wet scrubbers are:

- reduction of gaseous pollutants, such as SO₂, ammonia, or volatile organic compounds and reduction of odour emissions;
- reduction of dust emissions;
- recovery of the product, e.g. in vegetable oil processing, the collected dust is recovered and can be added back to the meal;
- prevention of fire risk.

Reduction of emissions to air, e.g. dust. Potential reuse of airborne materials. It can be advantageous if there is an in-plant opportunity to reuse the laden collecting liquid.

Environmental performance and operational data
Using wet separation scrubbers, it is possible to achieve dust separation rates of 80–99%.

The techniques to consider in the determination of BAT of the FDM sectorial chapters (see Chapters 3 to 15) contain installation-specific performance data related to the application of wet scrubbers.

When using cyclones, wet dust emission concentrations of <50 mg/Nm³ can be achieved. Table 2.10 shows current performance data of this technique, compared to other separation techniques.

Dust particles present in the untreated gas are brought into contact with, and become attached to, the considerably larger droplets of the collecting liquid and can then be removed together with the droplets. The relatively large dust-laden droplets, which have a diameter of 50–200 µm, are usually removed from the gas stream by means of cyclones or lamellar separators. Cyclones are used for heavy solids loads and small gas streams. Better separation rates and lower pressure losses are achieved by using lamellar separators in high performance separation units. These consist of vertically arranged metal or plastic plates. These can separate particles larger than 10 µm.

Waste water is produced. The dust-laden collecting liquid can be treated and returned to the process, or concentrated by evaporation. Drying plants, in particular, give off vapours laden with water vapour which may contain not only particulate pollutants, but also odours and gaseous pollutants.

Cross-media effects
Energy consumption. Waste water production.

Technical considerations relevant to applicability
The technique is applied throughout the FDM sector.

Scrubbers are used in the FDM sector, e.g. to treat VOCs, FFA and odours from vegetable oil refining.

Economics
The cost of waste water treatment may be considerable, in some cases even higher than for measures to control dust emissions.

Driving force for implementation
Wet separators scrubbers are used for the removal of solid and liquid air pollutants, e.g. particularly in cases:

- of flammable or sticky dust;
- where there is a risk of explosion;
- for the simultaneous separation, or preliminary separation of solid, liquid and gaseous pollutants;
- for small dust particles (< 0.1 µm).
Example plants
Widely used in the FDM sector, see Table 2.8.

Reference literature
[35, Germany 2002], [16, Willey et al. 2001], [193, TWG 2015], [251, COM 2015]

2.3.7.3.2 Plate absorber

Technical description
Plate absorbers consist of a vertical tower with several horizontal perforated trays or sieve plates stacked in it. Baffles are situated a short distance above the apertures in the plates. Scrubbing liquid enters the top of the tower and successively flows along each of the trays. The airstream to be treated enters the bottom of the tower and flows upwards, passing through perforations in the plates. The velocity of the airstream is sufficient to prevent liquid seeping through the perforations. The airstream to be treated is directed through the falling curtains of liquid overflowing the trays. There are many variations in the plate design and positioning of the liquid nozzles. The plate absorber system is shown in Figure 2.38.

![Plate absorber layout](image)

Source: [16, Willey et al. 2001]

Figure 2.38: Plate absorber layout

Achieved environmental benefits
Removal of odours, gaseous components and dust from air.
Environmental performance and operational data
Absorbers, in general, are reported to have the advantage of having a relatively low pressure drop. They are reported to be more effective for the removal of specific components rather than overall removal and they have a reported efficiency of typically 70–80%.

The equipment is compact, so absorbers do not take up much space, but they may require space for the safe storage of chemicals.

Cross-media effects
Waste water is generated. Likely to generate a visible plume at the flue-gas outlet.

Technical considerations relevant to applicability
In general terms, absorbers are suitable for a wide range of volumetric airflows which contain gases and/or odours in relatively low concentrations.

Economics
Relatively inexpensive, compared to other end-of-pipe odour control techniques. Relatively low capital and operating costs. Their cost-effectiveness is reduced, if the exhaust gas to be treated has a high moisture content, due to their preferential absorption of water vapour.

Example plants
TWG, please provide information.

Reference literature
[16, Willey et al. 2001]

Spray scrubber

Achieved environmental benefits
Removal of condensable vapours and dust from air.

Environmental performance and operational data
The equipment is compact, so it does not take up much space, but it may require space for the safe storage of chemicals.

Where the presence of dust or condensable is a potential problem and gaseous pollution or odour removal is required in the same piece of equipment, this can give rise to considerable operational problems and downtime whilst the absorber is cleaned and put back into action. In this respect, it may be suitable to install a wave plate absorber. Here, the airstream entering the unit is forced through a series of wave bank plates, with a liquid spray positioned in front of each wave plate assembly. The wave plate assembly can be designed to be removed in situ, cleaned and replaced into the unit without the need to switch off the plant.

Cross-media effects
Waste water is generated. Likely to generate a visible plume at the flue-gas outlet.

Technical considerations relevant to applicability
A spray chamber is not generally suitable for the control of odour or gaseous substances, due to the limitations in mass transfer. However, where the airstream to be treated contains a significant level of dust or condensable material, then a simple spray tower may be used to remove these, prior to treatment with an increased gas-liquid contact, such as a plate or packed bed absorber.

Economics
Relatively low capital and operating costs.
2.3.7.3 Carbon Adsorption

Description
A technique for removing compounds from a waste gas stream by retention on a solid surface (typically activated carbon).

Technical description
Adsorption is a unit process involving the capture of airborne components onto a fine particulate active surface. There are a number of possible active materials that are used for general applications, including zeolites, silicas, polymeric resins and activated carbon. Currently, activated carbon is the most frequently chosen absorbent within the FDM sector and hence the term carbon adsorption is commonly used.

Carbon adsorption is a dynamic process in which vapour molecules impinge on the surface of the solid and remain there for a period of time before desorbing again into the vapour phase. An equilibrium is established between adsorption and desorption, i.e. a particular concentration of a compound on the carbon surface corresponds to a concentration or partial pressure of that compound in the gas phase.

The adsorption process can be either physical, in which case the adsorbed molecules are held to the surface by Van der Waals forces, or chemical, where chemical bonds are formed between the adsorbed molecules and the surface. Both of these processes release heat, the latter rather more than the former.

Activated carbon can be made from a variety of carbonaceous materials, including wood, coal, peat, nut shells, lignite, bone and petroleum residues. Shell and coal based products are usually used in vapour phase applications. The manufacturing process consists of the dehydration and carbonisation of the raw material, which drives off the volatile matter and produces a rudimentary pore structure. This is followed by thermal or chemical activation. Activated carbon used in odour control applications has the typical properties shown in Table 2.68.

Table 2.68: Properties of activated carbon

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size</td>
<td>mm</td>
<td>1.4–2.0</td>
</tr>
<tr>
<td>Bulk density</td>
<td>kg/m³</td>
<td>400–500</td>
</tr>
<tr>
<td>Surface area</td>
<td>m²/g</td>
<td>750–1 500</td>
</tr>
<tr>
<td>Pore volume</td>
<td>cm³/g</td>
<td>0.8–1.2</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

Carbon beds can either be once used and disposed of, or regenerated. Regenerative systems are typically used in installations where the recovery of the material being captured is economically attractive. It is more common to use a single fixed bed adsorber system. Regenerative systems are usually designed with multiple beds so that adsorption and desorption can be conducted simultaneously. It is usually necessary to raise the temperature of the adsorbent bed to release the adsorbate, with steam being the most commonly used medium. A regenerative system, therefore requires an additional capture mechanism for materials desorbed during the regenerative process.

The fixed bed system comprises a bed of activated carbon through which the gas stream to be treated is passed. The carbon is in either a simple packed bed arrangement or in the form of carbon filters. The filters are essentially paper or cardboard cartridges containing powdered activated carbon. In general, the cartridge arrangement is used for general room ventilation whilst the packed bed system is used for odour control from process exhausts. Once the activated carbon has expired, e.g. as judged by an increased outlet odour level, the carbon or cartridge arrangement needs to be replaced. The packed bed system has the advantage that, in
most cases, it can be returned to the supplier for regeneration at his premises whilst the cartridge filters are usually disposed of by the user.

The design basis for room ventilation using cartridge filters is significantly different from that for process odour control using packed beds. In general, cartridge filters are employed for small vent flows of intermittent or infrequent nature with very low sorbent concentration. Conversely, the packed bed system is used where the concentration of components in the airstream to be treated is significantly higher than typical room or factory floor concentrations. The major difference in the design basis of each system is the residence time; with room ventilation requiring only 0.1 to 0.2 seconds, and process exhaust treatment requiring between 1 and 3 seconds. The choice of residence time is essentially a compromise between the physical volume of the designed bed and the time between renewals. Table 2.69 shows the principles of operation of the three major types of adsorbers.

<table>
<thead>
<tr>
<th>Table 2.69: Principle of operation of the main types of adsorbers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adsorber</strong></td>
</tr>
<tr>
<td>Fixed bed unsteady state adsorber</td>
</tr>
<tr>
<td>Fluidised bed adsorber</td>
</tr>
<tr>
<td>Continuous moving bed adsorber</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

In general, the lower the temperature, the greater the amount adsorbed and, therefore, the longer the penetration time or bed life. As a guideline, carbon adsorption is not applicable at a temperature above 40 °C. Furthermore, the efficiency of activated carbon is reduced at a relative humidity above 75 %, except for water soluble compounds such as the lower amines and hydrogen sulphide. This preferential adsorbance of water can lead to condensation within the bed, so making the carbon inactive. The bed would then require drying out before it could be reused.

**Achieved environmental benefits**
- **Removal** Reduction of TVOC and odour, gases emissions to air.

**Environmental performance and operational data**
The installation of a carbon adsorption system is fairly simple, comprising a fan and vessel to hold the carbon bed. Carbon adsorption can give odour removal efficiencies of 80–99 % [16, Willey et al. 2001].

The absorptive capacity of activated carbon is expressed as weight-% in terms of the amount of the specified material that can be adsorbed per unit mass of carbon. These figures vary considerably from as low as zero to as high as 110 % and are fairly meaningless for a malodorous exhaust potentially containing a wide variety of individual components. In this sense, as a general guideline, a value of 30 % can be used to estimate the expected lifetime of a carbon bed used in the FDM sector.

The expected life of the carbon bed can then be estimated based on a knowledge of the design residence time, the organic load and the airflow to be treated. This is illustrated in the following example. First, the organic load is calculated by the following equation:

\[
\text{Load} = \text{airflow} \times \text{concentration}
\]

Considering an airflow of 10,000 m³/h with an organic concentration of 50 mg carbon/m³ and a carbon bed designed with a residence time of 1 second, then the organic load is 0.5 kg/h. A residence time of 1 second implies a carbon bed volume of 2.78 m³. Based on a carbon bulk density of 500 kg/m³, the carbon would be able to absorb 30 % of 1,390 kg which is equivalent.
to 2,780 hours of operation. Thus, the bed would require replacement at a frequency of approximately three times per year.

Cross-media effects
Energy consumption. Waste is produced when the activated carbon needs to be disposed of.

Technical considerations relevant to applicability
Carbon adsorption is generally suitable for low air throughputs of less than 10,000 m³/h and where the contaminant to be removed is present in a low concentration of, e.g., less than 50 mg/Nm³. In terms of odour control, the major applications of carbon adsorption are the cleaning of ventilated air and the treatment of malodorous process emissions.

The presence of dust in the gas stream to be treated can seriously interfere with the efficiency of a carbon bed, as well as increase the operating pressure drop. Carbon adsorption is, therefore, not applicable where dust or even condensable material is present. The dust and condensables can be removed in a pre-filter arrangement, although this will add to the complexity and cost of the unit as well as adding operational problems in cleaning requirements and dust breakthrough.

Economics
This technique has relatively low capital costs. The operational cost is high, e.g., carbon costs approximately EUR 2,400/t. Regeneration is not normally economical, so the carbon bed has to be totally renewed when its adsorption efficiency begins to fall, which might be after only a short period of time depending on the odour emission rate and odorant concentration [16, Willey et al. 2001].

Example plants
This technique has been reported in a meat processing installation (#331) [193, TWG 2015].

Reference literature
[16, Willey et al. 2001], [193, TWG 2015]

2.3.7.3.4 Biofilter

Description
The waste gas stream is passed through a bed of organic material (such as peat, heather, compost, root, tree bark, compost, softwood and different kinds of combinations) or some inert material (such as clay, activated carbon, and polyurethane), where it is biologically oxidised by naturally occurring microorganisms into carbon dioxide, water, other metabolites and biomass.

Technical description
In biofilters, the pollutants are absorbed onto the filter material and degraded by the microorganisms located on a fixed filter medium. The filter material is arranged in the form of a packed bed and is permeated by the waste gases. For waste gases with high dust emission levels, the gas needs to be passed through a dust remover, before the biofilter.

Biofilters can be operated in either downflow or upflow fashion. The relative merits of each mode are uncertain and it is most likely that operational efficiency is the same in each case. The pressure drop over a biofilter is low, typically in the range of 10 to 25 mm/m of packed height. This low pressure drop infers that proper design of the air distribution for either downflow or upflow installations is a critical design parameter. A typical layout of a biofilter is illustrated in Figure 2.39.
The waste gas to be treated is directed initially into a humidifier, where it is countercurrently put into contact with recirculating water. The air exiting the humidifier is subsequently directed to the biofilter.

It is not normal practice to operate the humidifier with a continuous fresh supply of make-up water as this would lead to a waste water discharge requirement.

Periodic irrigation of the top of the bed allows the system to maintain the required moisture content in the filter material of 40–60%. Any water falling through the bed, via irrigation or rainfall, can be recycled to the humidifier to avoid a waste water discharge from the system.

There is a wide variety of filter materials that have been used in biofilters. The major requisites of the filter material are a high specific surface area, e.g. 300–1000 m$^2$/m$^3$, a high water bearing capacity, limited compaction characteristics and a limited resistance to flow. Traditionally, fibrous peat mixed with heather in a 50% proportion has been used. The microbial activity occurs within the peat whilst the heather provides a stiffening agent to prevent compaction, thereby extending the operating life of the bed.

A variation of the peat/heather mixture is mushroom compost mixed with 5 mm diameter polystyrene spheres for support, in a 50% proportion. Rootwood is typically comprised of tree roots, branches and loose twigs. The rootwood is split into lengths of typically 15 cm by a tearing apart action rather than straight cuts. This action effectively exposes the maximum surface area and does not require supporting material. These filter media have all been proven in full scale installations. Specific operating experience may be sought if any other materials are proposed.

Biofilters can be further subdivided into soil and non-soil based biofilters. The soil based biofilter or soil bed, comprises a layer of porous soil under which is a network of pipes through which the airstream to be treated is passed. An open structured soil is required to keep the pressure drop across the bed to a minimum.

In general, the residence time required for a biofilter depends upon the level and type of contaminants present in the airstream to be treated. Components that are aromatic in nature will require a longer residence time than more simple organic chemicals. As a general guideline, a minimum residence time of 20 seconds is chosen, extended up to 40 seconds where contaminants with reduced biological degradability are present.
The velocity through the filter bed is typically between 0.02 and 0.05 m/s. The surface loading rate, which is often used to characterise a design, is typically within the range of 100 to 250 m³ gas/m² filter area/h.

Due to reasons of potential compaction, the maximum height of the filter media is restricted to approximately 1.0 to 1.5 metres. Where a greater height is required due to limited land availability. Then some form of intermediate support would be required within the vertical cross-section of the bed.

The distribution of air through the biofilter is an important consideration and a plenum chamber design is recommended. In this respect, the vertical height of the plenum chamber is at least 50% that of the height of the filter material.

The pH of the filter material in a biofilter is typically maintained between 6.5 and 7.5, a range preferred by most bacteria. In some cases, the biodegradation of exhaust gas components can generate acidic by-products so dosing with alkali may be undertaken.

Important characteristics of the filter material include a low pressure loss, a high buffering capacity and a wide spectrum of microorganisms present. Approximately 40 to 60% moisture content of the filter bed is needed to ensure good efficiency. The filter bed needs regular maintenance, e.g. to be kept free of plant growth, settled material and gas breakthroughs, to ensure its optimal effectiveness.

A typical lifetime of a filter bed of 3 to 5 years is often quoted, however, for most filter materials, and particularly for peat/heather, the bed will require topping up within the first 18 months of operation. A complete replacement of the material is only necessary if the degradation of the organic matter has proceeded to such an extent that the required air flowrate can no longer be achieved. To enable replacement of the filter material, the equipment has to be designed and constructed such that the grid is accessible for vehicles or the filter can be maintained with a mobile gripper. If the biofilter is divided into several segments, the entire production does not need to shut down for maintenance work.

Depending on the nature of the upstream process, an emergency gas vent to the air can be installed linked to a temperature sensor located at the inlet to the biofilter. The control mechanism is set such that if the biofilter inlet temperature exceeds 45 °C over a predetermined period of time, say 4 hours, the exhaust gases are discharged directly to the air thereby bypassing the biofilter. The use of such a system will mean that the waste gases are emitted untreated, so the conditions leading to such a bypass need to be prevented. Local temperature and bed pressure drop indicators are also recommended.

Dust and fats may need to be removed upstream of the filter to avoid potential clogging, leading to a rise in filter pressure drop and a reduction in operational efficiency.

Soil beds are normally constructed below ground, so care needs to be taken to ensure that the base of the soil filter is above the water table. The major disadvantage with the soil biofilter is the excessive residence time required for the biological process, which is in the region of 5 minutes. This results in very large open structures requiring significant land area.

Biofilters have also been used to treat frying exhaust gases. The vapour of the deep-fryer is condensed in a condensation unit. This leads to a reduction of the odour and a reduction of the vapour volume. Afterwards, the vapour is sent through a biofilter. Oil and fat will be removed by bio-organisms. The temperatures in these new-generation filters are up to 60 °C. At these temperatures, thermophilic bacteria are active. The removal rate is higher in these biofilters, which leads to a smaller design, reduced growth of bio-organisms and lower pressure drop. However, the filter is replaced more frequently than in cases where mesophilic bacteria are used (operating at 20–40 °C). The filter is kept wet enough for the bio-organisms.
Achieved environmental benefits
Reduced emissions to air, mainly odour/VOCs.

Environmental performance and operational data
A correctly operating biofilter will exhibit an outlet odour concentration of typically 150 to 200 OU/m³. The characteristic smell associated with the treated discharge is a musty, moist forest type with very little resemblance to the inlet odour. Odour removal efficiencies of up to 99.5% can be achieved, although the percentage removal is very dependent upon the inlet concentration. It is unlikely that an outlet odour level of less than 150 OU/m³ can be achieved so an inlet odour level of 5 000 OU/m³ would represent a maximum efficiency of 97% [35, Germany 2002 ].

Abatement VOC efficiencies of 80–90% have been reported.

The use of specially composted organic material, leca (expanded clay) or moler (expanded clay) leads to odour abatement efficiencies > 95% and increased biofilter lifetimes (in some cases more than 10 years) [224, Denmark 2015].

More environmental performance and operational data are presented in the related FDM sectorial chapters.

Cross-media effects
Generation of acidic by-products, e.g. from the biodegradation of exhaust gas components. Disposal of the filter material. In some cases, used material is composted to reduce the organic pollution and then sent for landspreading. Condensation water is recycled, otherwise it requires treatment. Energy consumption is required for the pump to overcome the resistance of the filter media.

The use of biofilters in FDM installations producing ready-meals and ice cream may increase hygiene risks, due to the bacterial population in the filter material.

Technical considerations relevant to applicability
Used to eliminate biodegradable gaseous air pollutants, especially organic pollutants and odours, e.g. in the fish sector, coffee processing and WWTPs. Other areas of application are the purification of room and process air in beer yeast drying and in oil mills; cleaning of roasting gases in cocoa production and cleaning of cooling air in animal feed production.

The biofiltration process is suitable for a wide range of airflows, up to and exceeding 100 000 m³/h, providing there is sufficient land space available. A limit to the maximum concentration of contaminants in the inlet airstream is generally documented as less than 5 000 mg/Nm³, although a concentration limit of 1 000 mg/Nm³ may be used as a guideline when assessing the suitability of biofiltration.

As exhaust gases from industrial sources generally contain a variety of components, pilot plant testing is recommended to ensure that the biofilter is adequately sized.

Biofilters are suitable for ventilation systems where a constant airflow is extracted from a vessel or process room. Periodic heavily contaminated airstreams are avoided unless there is a sufficient dilution from other sources being treated.

This technique is not applicable for airborne temperatures in excess of 40 °C. If temperatures above 40 °C are prevalent for significant periods of time, i.e. greater than 4 hours, then the microorganisms present in the filter become sterilised and the bed requires reseeding. At temperatures below 10 °C, the rate of biological degradation falls dramatically. This technique is not applicable for humidities lower than 95%.
Chapter 2

Economics
Relatively high odour removal efficiency at relatively low cost compared with alternative treatment techniques. The capital cost of the downflow system is higher than for the upflow system as it will require an airtight top seal. This would be emphasised for a larger biofilter.

The specific investment costs for biofilters of modular construction, depend on the size of the plant and the construction standard. For smaller plants, i.e. 200–500 m³/h, the cost is about EUR 45–50/m³ of exhaust air. In larger plants, costs may go down to EUR 10–15/m³. These costs do not include exhaust air interception and the necessary construction costs [35, Germany 2002].

The operating costs are largely made up of the energy costs for running ventilators and humidifier pumps. There are also costs associated with the water required for humidification, the maintenance of the biofilter and the replacement of filter material at the end of its service life. The energy costs amount to EUR 0.15–0.225/1 000 m³ of exhaust air, calculating electricity costs at EUR 0.15/kWh. Including the above listed additional costs, the price for the treatment of 1 000 m³/h exhaust air then amounts to EUR 0.225–0.30 [35, Germany 2002].

Soil beds have a potentially high odour removal efficiency at a relatively low cost when compared with alternative treatment techniques.

Driving force for implementation
To prevent complaints about odours and to meet legal requirements.

Example plants
This technique has been reported in several installations from the dairy, meat processing and oilseed sectors, as shown in Table 2.8 [193, TWG 2015].

Widely used in the FDM sector (an example from the coffee sector is shown in Section).

Reference literature
[35, Germany 2002], [193, TWG 2015], [224, Denmark 2015], [229, Belgium 2015], [251, COM 2015]

2.3.7.3.5 Bioscrubber

Description
A packed tower filter with inert packing material which is normally continuously moistened by sprinkling water. Air pollutants are absorbed in the liquid phase and subsequently degraded by microorganisms settling on the filter elements.

Technical description
Bioscrubbers (or biotrickling filters) are absorbers in which an intensive exchange of substances takes place between the polluted gas and the absorbent. The microorganisms are either finely divided in the collecting liquid or applied as a layer to the absorber structures or trickling filter. The absorber is followed by a mist collector to separate the gaseous and liquid phases. In the subsequent absorbent regeneration step, the waste gas constituents absorbed in the liquid phase are removed from the absorbent. For waste gases with high particulate emission levels, the gas needs to be passed through a dust remover before the bioscrubber.

The technique essentially comprises a packed bed absorber containing a bacterial population within the packing and the sump. The contaminated gas is passed up the tower against a flow of water containing a population of bacteria. The bacteria attaches itself to the packing in a similar manner to a trickling filter used for waste water treatment (see Section 2.3.6.2.1.5). Nutrients, required for bacterial growth and synthesis, are added to the absorber sump on a periodic basis.
The speed of biodegradation is relatively slow, thus operating conditions may have a crucial role. A bioscrubber operates at a typical residence time of 5–15 seconds, depending on the airstream to be treated. Bioscrubbers require a much smaller land area than biofilters. A typical layout of a bioscrubber installation is shown in Figure 2.40.

![Figure 2.40: Bioscrubber layout](image)

**Achieved environmental benefits**
Reduced emissions to air, mainly odour, VOCs, SO$_2$ and dust.

**Environmental performance and operational data**
The size of a bioscrubber is not restricted by the airflow to be treated, although the resultant size of a single packed tower may necessitate two parallel systems. A limit to the maximum concentration of contaminants in the inlet airstream is generally documented as less than 5 000 mg/Nm$^3$, although a concentration limit of 1 000 mg/Nm$^3$ may be used as a guideline when assessing the suitability of bioscrubbing [35, Germany 2002].

More environmental performance and operational data are presented in the related FDM sectorial chapters.

**Cross-media effects**
The bioscrubber is more energy intensive than the biofilter as water is being recirculated in addition to the air movement. Disposal of the filter material.
Technical considerations relevant to applicability

Used to eliminate biodegradable gaseous air pollutants, especially organic pollutants and odours. In theory, a bioscrubber can be used wherever bio-oxidation is an appropriate solution to an emission problem and its applications are, therefore, similar to that for biofilters, however, biofilters are more widely applied. This technique is not applicable for airborne temperatures in excess of 40 ºC.

Economics

A relatively high odour removal efficiency at relatively low cost when compared with alternative treatment techniques.

Driving force for implementation

- Reduction of odour emissions.
- Meeting H₂S emission requirements.

Example plants

See Table 2.8.

Reference literature

[ 16, Willey A R and Williams D A 2001 ], [ 35, Germany 2002 ], [ 193, TWG 2015 ]

2.3.7.3.6 Thermal oxidation of waste gases

Description

The oxidation of combustible gases and odors in a waste gas stream by heating the mixture of contaminants with air or oxygen to above its auto-ignition point in a combustion chamber and maintaining it at a high temperature long enough to complete its combustion to carbon dioxide and water.

Technical description

For complete oxidation of the compounds to be degraded in the airstream, it is necessary for them to be in contact with sufficient oxygen for a long enough time and at a high enough temperature. Rapid oxidation of organic compounds will occur if the gas temperature in the thermal oxidiser can be maintained at 200–400 ºC higher than the auto-ignition temperature of the chemical species present. In thermal oxidation, the pollutant conversion takes place at high temperatures, e.g. >600 ºC. Thermal oxidisers do not operate effectively until they reach the combustion temperatures of the pollutants they are used to destroy, so they need to be started up before they are actually required.

In addition to considering the applicability of thermal oxidation to the components to be destroyed, it is important to consider the recovery of heat from the thermal oxidation process to reduce fuel costs. As FDM emissions to air seldom have organic concentrations in the region of the lower explosive levels, the conventional type of thermal oxidisers, which have direct flame contact with the airstream to be treated, are mostly used. In cases where there is a high concentration of organics above the relevant explosive limits, then a flameless type of system may be required. These systems use a heating medium to heat the airstream and, thus, avoid direct contact of the airstream with the flame.

Direct flame thermal oxidisers usually operate at temperatures of between 700 and 900 ºC. The reaction temperature depends on the nature of the pollutant; it may be lower, but for less readily oxidisable substances such as organohalogen compounds it may be in excess of 1 000 ºC. For malodorous compounds, a temperature of 750–800 ºC is generally adopted. The conditions of the equipment stages of a thermal oxidiser are illustrated in Table 2.70. A typical layout of a thermal oxidiser is shown in Figure 2.41.
Table 2.70: Conditions at different stages of thermal oxidation

<table>
<thead>
<tr>
<th>Equipment stages</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burning</td>
<td>The fuel is burned with clean air or with a proportion of the contaminated air to produce a flame at a temperature of typically 1 350–1 500 °C</td>
</tr>
<tr>
<td>Mixing</td>
<td>To ensure adequate turbulence and hence mixing of the process gas to bring it to uniform temperature</td>
</tr>
<tr>
<td>Combustion</td>
<td>The gases are held at the combustion temperature until oxidation has been completed, typically 0.5 to 1.0 seconds</td>
</tr>
<tr>
<td>Heat recovery</td>
<td>Reduces operating costs and fuel consumption</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

Figure 2.41: Thermal oxidiser layout

Burners can be divided into those with a single flame and those in which the fuel is distributed between a large number of jets. With regard to the shape, laminar-flow, nozzle and vortex burners are possible. In special cases, the burner may be replaced by an electric heating system. The oxygen required for combustion can be taken from the air, the airstream to be treated, or alternatively from a proportion of each. Possible supplementary fuels include light heating oil, natural gas or LPG. Care needs to be taken and due vigilance paid to the potential for any water vapour present in the airstream to quench the flame, thereby resulting in poor combustion.

The burner also may be of the pre-mix type where the fuel is mixed with the combustion air prior to passing through the nozzles, or a diffusion type where the fuel is mixed with the combustion air downstream of the nozzles. Most burners are of the diffusion type.
The mixing of the gas stream may be achieved in a variety of ways; by natural diffusion, impingement mechanisms, or by the inclusion of baffles to induce flow changes. Suppliers offering low NO\textsubscript{X} systems often incorporate various backmixing sections, with the intention of reducing temperature increases significantly above the mixed temperature.

The combustion chamber in which the oxidation reaction takes place is designed for high thermal stresses. Some combustion chambers are made of heat resistant metal and chambers with a metal jacket and refractory lining. The dimensions of the combustion chamber are sufficient to achieve the desired residence time and to accommodate the physical length of the flame without quenching.

Some form of heat recovery is nearly always warranted to reduce operating costs and fuel consumption. Heat recovery is conventionally conducted in a shell and tube heat exchanger, which allows heat to be continuously transferred to preheat the incoming gas stream. This type of system is termed a recuperative system, with 70–80% heat recovery being a typical design level.

Heat recovery can also be achieved in a regenerative system, which uses two sets of ceramic bed heat exchangers. There, one bed is heated by direct contact with the exhaust gas while the other is used to preheat the incoming gases. The system is operated so that the beds alternate between heating and cooling. The heat recovery potential of this system is higher than the recuperative system, with 80–90% heat recovery being a typical design basis. The use of thermal fluids is an alternative to this type of system.

Heat can also be recovered using a waste heat boiler where the treated exhaust gases are used to produce steam for use in other parts of the installation or site. The operation of the thermal oxidiser may not always coincide with the demand for steam, so integration may be complex.

There is also a potential for secondary heat recovery, using the treated exhaust from the first stage heat recovery to heat water or for space heating.

It is reported that the heat from the combustion can be recovered in a cross heat exchanger and used for the cooking process instead of steam. It is reported that combustion of smoke gases from cooking/smoking kilns will eliminate all odour problems in the close environment.

Further information about this technique, its actual performance and how this compares with other air abatement techniques is given in the “Waste water and waste gas treatment BREF” [217, EC, 2003]

**Achieved environmental benefits**
Reduced TVOC gas and odour emissions.

**Environmental performance and operational data**
A properly designed and operated thermal oxidiser can achieve odour removal efficiencies approaching 100%. The performance of this technique is independent of the intensity of the odour emissions. Thermal oxidation of waste gases can achieve VOC emission levels of <1–20 mg/m\textsuperscript{3} [242, COM 2016].

More environmental performance and operational data are presented in the related FDM sectorial chapters.

**Cross-media effects**
There is a potential of the oxidation process to generate unwanted by-products of combustion, e.g. high emission levels of NO\textsubscript{X} and CO\textsubscript{2}. Essentially, the higher the reaction temperature then the greater the potential for the generation of increased emission levels of NO\textsubscript{X}. It is usually beneficial to opt for a low NO\textsubscript{X} burner.
Any compounds containing sulphur present in the malodorous gas stream will generate SO$_2$ emissions and the potential for minimising this should be considered. The presence of chlorides in the malodorous airstream may need to be reviewed due to the potential formation of acidic gases such as HCl. As well as leading to emissions, there could be potential corrosion problems within the equipment. When halogenated VOCs are present, special conditions to suppress the formation of dioxins may be required, though normally there is negligible dioxin formation during the combustion of waste gas streams [242, COM 2016].

Energy consumption, e.g. consumption of fuel for operating the oxidiser.

**Technical considerations relevant to applicability**

*Used for the removal of VOCs/odour.* Thermal oxidation has the advantage of being almost universally applicable as a method of odour control because most malodorous components can be oxidised to non-malodorous products at a high temperature, whereas the application of other methods are more restrictive.

Thermal oxidation is generally used for the treatment of air volumes of less than 10,000 Nm$^3$/h, having increased costs for heating greater volumetric airflows. It is suitable for malodorous streams with variable contaminant concentrations and is capable of treating a variable volumetric throughput.

If alkali metals are present from the soil in vegetable drying installations, they may cause premature degradation of the ceramic media used for regenerative heat recovery.

Malodorous airstreams containing significant quantities of particulate material generally require pretreatment prior to the thermal oxidation process. This is particularly relevant if a heat recovery system is installed, due to a potential fouling of the heat exchanger.

Whilst the presence of high levels of water vapour in an airstream is not considered a process problem, the fuel requirements are greater than for heating dry air. In practice, the removal of water vapour from an airstream is usually not undertaken and additional fuel requirements are usually included in the overall economic consideration of thermal oxidation as a technique.

**Economics**

This technique requires high capital investment, but the major consideration when assessing the suitability of thermal oxidation is the operating cost in terms of the fuel requirements. The use of recuperative or regenerative heat recovery systems can improve the efficiency of the technique and reduce the running costs. Retrofitting is possible for all types of smoking kilns, at varying cost. Smoking kilns are available with integrated thermal oxidation equipment.

**Driving force for implementation**

To prevent complaints about odours and to meet legal requirements.

**Example plants**

See Table 2.8.

**Reference literature**

[16, Willey A R and Williams D A 2001], [20, Nordic Council of Ministers 2001], [35, Germany 2002], [193, TWG 2015], [242, COM 2016]

**2.3.7.3.7 Catalytic oxidation of waste gases**

**Description**

Catalytic oxidation is a process similar to thermal oxidation with the fundamental difference being that the oxidation reaction takes place in the presence of a catalyst rather than in free air.
Technical description
Catalytic oxidation is a process similar to thermal oxidation with the fundamental difference being that the oxidation reaction takes place in the presence of a catalyst rather than in free air. The main advantage of catalytic oxidation is that significantly lower operating temperatures are required, e.g. 250 to 500 °C. Catalytic oxidisers do not operate effectively until they reach the combustion temperatures of the pollutants they are used to destroy, so they need to be started up before they are actually required.

As with adsorption, the reactants for the heterogeneous gas reaction are first transported to the inner surfaces of the generally porous catalysts. As there is a general lack of adequate substance data, such as the reaction speed constant and the diffusion coefficient, reactors are usually designed on the basis of empirical data.

The main components of a catalytic combustion system are auxiliary firing equipment, a heat exchanger and a reactor with a catalyst. A typical layout of a catalytic incinerator is shown in Figure 2.42.

![Figure 2.42: Catalytic incineration layout](image)

The airstream enters the unit and is preheated in a conventional shell and tube heat exchanger. The preheated inlet stream is then further heated via a burner to the desired oxidation temperature, before passing onto the catalyst. The contaminants present in the malodorous airstream, together with oxygen, diffuse onto the surface of the catalyst. Oxidation takes place and the products of oxidation are desorbed back into the gas stream. These transfer processes require a finite time within the catalyst, with the rate of reaction being strongly influenced by the operating temperature. The treated gas stream then passes through the heat exchanger, warming the incoming malodorous airstream.
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The most important aspect of a catalyst bed is the ratio of surface area to volume and hence the available area for the reaction. Active components commonly used include metals of the platinum group and oxides of the metals Co, Cr, Cu, Fe, Mo, Ni, Ti, V, and W. The support materials are usually metals, in the form of plates, woven fabrics or nets, metal oxides, e.g. Al₂O₃, SiO₂ and MgO, and minerals, e.g. pumice and zeolite, in moulded shapes.

The following design pointers are considered when evaluating the potential of catalytic incineration as a possible abatement solution: space velocity, pressure drop and temperature.

The space velocity is defined as the reciprocal of the residence time of the gas within the catalyst block, with the volumetric airflow expressed at 0 ºC. A typical range of space velocities used in industrial applications is between 20 000 and 45 000 m/h. This corresponds to a residence time range of 0.03 to 0.1 seconds at typical operating temperatures. Essentially, there is a trade-off between the amount of catalyst incorporated into the design and the operational temperature. The more catalyst and, hence, operation towards a space velocity of 20 000 m/h, then the lower the operational temperature required to achieve a given performance. If the airflow to be treated is large, then there is scope to incorporate an additional catalyst to reduce fuel costs by heating to a lower operational temperature. However, an increased catalyst charge will create an increased pressure drop, thereby requiring additional extraction fan power.

The catalyst exhibits a linear relationship between flowrate and pressure drop due to the laminar flow within the catalyst. A typical design would allow for a total system pressure drop of approximately 500 mm. The configuration of the catalyst block plays an important role in minimising the pressure drop and hence the operating costs.

Catalytic oxidation is an exothermic reaction. There are installations where the temperature increases to a sufficient magnitude to enable the catalytic oxidiser to operate in a self-sustaining mode without the addition of fuel after the operating conditions are reached.

Heat recovery is an essential part of the process, and is usually integrated within the design, by using the treated gases to preheat the incoming gases. Heat exchangers are typically designed with an 80 ºC heat recovery, which effectively results in a final discharge temperature of between 150 and 200 ºC for typical oxidation temperatures.

Achieved environmental benefits
Reduced TVOC gas and odour emissions.

Environmental performance and operational data
Catalytic incineration of waste gases can achieve VOC emission levels of <1–20 mg/Nm³ [242, COM 2016]. Carbon monoxide emission levels of <100 mg/Nm³ have been reported. In contrast, the NOₓ emission levels can reach extremely high values, e.g. emission levels of around 1 000 mg/Nm³ have been reported during catalytic incineration.

Legal requirements in Germany are largely met by using catalytic incineration, but are completely met by using incineration.

Compared to incineration, catalytic incineration requires a lower operating temperature and has no need for special construction materials. The likely odour removal performance of a catalytic incinerator is in the region of greater than 95 %, which is less than the approaching 100 % reported for incineration.

Compounds such as sulphur, halogens, zinc and organic solids tend to coat the catalyst surface. Fortunately, this process is reversible with the catalyst activity re-achievable by the application of a high temperature. Inert particulate material will also result in a gradual decrease in catalyst activity, although the application of a high temperature, approximately 500 ºC, will return the catalyst activity.
The honeycomb structure is more effective than other structures in minimising problems of attrition, mechanical stability, excessive pressure drop and chemical stability in oxidising atmospheres.

The effective lifetime of the catalyst is largely dependent upon the nature of the airstream being treated. Lifetimes reported vary considerably over a range of two to ten years, although they are more typically between three and five years.

Smokehouse waste gases are often treated using catalytic oxidation, at temperatures of between 350–450 °C. Precious metals (platinum, palladium) or certain metal oxides (copper, chromium) deposited on ceramic surfaces are used as catalysts. They are sensitive to dust, fat aerosols and catalyst poisons such as lead and other metals. The efficiency is reported to be high and heat can be recuperated.

**Cross-media effects**

There is a potential of the incineration process to generate unwanted by-products of combustion, e.g. high emission levels of NO\textsubscript{X} and CO\textsubscript{2}. Essentially, the higher the reaction temperature then the greater the potential for the generation of increased emission levels of NO\textsubscript{X}. It is usually beneficial to opt for a low NO\textsubscript{X} burner. There is a relatively low formation of NO\textsubscript{X} at operating temperatures and emission levels of 15 mg/Nm\textsuperscript{3} can be achieved.

Any compounds containing sulphur present in the malodorous gas stream will generate SO\textsubscript{2} emissions and the potential for minimising this should be considered. The presence of chlorides in the malodorous airstream may need to be reviewed due to the potential formation of acidic gases such as HCl. As well as leading to potential emissions, there could be potential corrosion problems within the incinerator. When halogenated VOCs are present, special conditions to suppress the formation of dioxins may be required, though normally there is negligible dioxin formation during the combustion of waste gas streams [242, COM 2016].

Energy consumption, e.g. consumption of fuel for operating the incinerator.

**Technical considerations relevant to applicability**

Used to reduce emissions of gaseous pollutants and odour at low dust concentrations. They can operate with airstreams of variable temperature and odour load.

The presence of dust in the gas stream tends to accumulate at the front edge of the catalyst, resulting in a gradual increase in the catalyst pressure drop. Whilst the literature would suggest that dust concentrations of up to 115 mg/Nm\textsuperscript{3} are possible, in practice a maximum concentration of 50 mg/Nm\textsuperscript{3} is mentioned as a guideline.

Catalytic incinerators occupy less space than waste gas incinerators.

**Economics**

Lower fuel costs compared to incineration. The catalyst replacement cost, at approximately GBP 50 000/m\textsuperscript{3} (2001), is an important parameter in the calculation of operating costs.

**Driving force for implementation**

Compliance with legislation on odour control.

**Example plants**

Used in the coffee sector in Germany and to treat smokehouse waste gases. See also Table 2.8 in the Nordic countries.

**Reference literature**

[16, Willey A R and Williams D A 2001], [20, Nordic Council of Ministers 2001], [35, Germany 2002], [193, TWG 2015], [242, COM 2016]
2.3.7.3.8 Non-thermal plasma treatment

Description
Abatement technique based on creating a plasma (i.e. an ionised gas consisting of positive ions and free electrons in proportions resulting in more or less no overall electric charge) in the waste gases in which organic and inorganic compounds are oxidised.

Technical description
Non-thermal plasma treatment is an odour abatement technique based on creating a highly reactive treatment zone in the waste gases in which the malodorous molecules are broken down. The way in which this reactive zone is created may vary.

The general principles used in the non-thermal plasma technology are to accelerate the natural destruction of the chemical composition in the process emission. Hence, there are no by-products created from the process.

Plasma is a gas state in which the gas component molecules are separated into a collection of ions, electrons, charge-neutral gas molecules and other species in varying degrees of excitation. Depending on the amount of energy added, the resulting plasma could be characterised as thermal or non-thermal.

In thermal plasma, the plasma constituents are in a thermal equilibrium. The ions and electrons are, on average, at the same temperature corresponding to approximately 1–2 eV (where 1 eV corresponds to a temperature of 11 327 ºC). The electric arc in an electric arc furnace is an example of thermal plasma.

In non-thermal plasma, the electron energy levels, or speeds, are considerably higher than those of the bulk gas molecules (i.e. they are not in a thermodynamic equilibrium). Because energy is added to the electrons only, these can attain energies from 1–10 eV, while the background gas remains at the equivalent of ambient temperature. The high electron energies generate plasma in which free electrons, ions and radicals coexist. Due to changes in waste gas conductivity, non-thermal plasma technology is less effective at waste gas temperatures exceeding 80 ºC.

Non-thermal plasma can be used to treat malodorous waste gases at ambient pressure and temperature. The radicals in the plasma react with the pollutants, which are broken down and oxidised to produce less malodorous components. The most active radicals in this process are nitrogen-, oxygen-, and hydroxyl-based. These species originate from nitrogen, oxygen and water in the waste gas. Industrial treatment systems are based on electrical discharge, where high voltages (up to 40 kV) are used to create plasma within the waste gases. Figure 2.43 shows a proprietary design of an industrial non-thermal plasma treatment system.
Figure 2.43: Industrial non-thermal plasma treatment equipment

Equipment for the non-thermal plasma treatment of odours is of modular design with a light and compact construction. One module treats air volumes in the range of 20,000–25,000 Nm$^3$/h. When larger treatment capacities are required, multiple modules can be installed in parallel. The technique requires no process additives and no consumables for the operation, apart from power. It has a low pressure drop, in the range 30–180 Pa. It can be installed both on the suction side and the pressure side of the main air extraction fan.

Achieved environmental benefits
Reduced TVOC and odour emissions to air.

Environmental performance and operational data
The technique has been proven to reduce the odour emissions by 75–96 %, depending on the design, process conditions and odour characteristics.

The power consumption is reported to be 6–12 kW (1.67–3.33 J/h) for a treated volume of 20,000–25,000 Nm$^3$/h (one module). This includes the energy used by the high voltage generation unit, but excludes increased energy consumption in the main exhaust fan to overcome the pressure drop (30–180 Pa) of the unit and the energy required for any extra air. Extra air may be needed to maintain a sufficient level of radicals in the gas mixture and possibly for cooling the gases to the temperature where the technique is most efficient, i.e. between 45 and 80 °C, or to condense water upstream of the treatment unit. The need for additional air can be up to 20 % of the treated volume and is normally supplied by a dedicated fan. Table 2.71 shows some data reported from various industries in the FDM sector.
Like many end-of-pipe techniques, the technique performs better when treating a highly concentrated flow than a flow with a low concentration of pollutants. Field tests on specific odour compositions determine the design of the installation and the guarantees that are given. If the full-scale installation has to treat significantly different odour molecules, e.g. due to changes in raw materials or concentrations, this may influence the performance. This is normally solved by introducing different system settings for different products/recipes, controlled automatically from the plant’s central control system.

The technique is reported to operate well with up to 100 % humidity. One installation reports that when the waste gas was oversaturated with water (>100 % humidity) this caused raining inside the reactor. The water droplets in the reaction chamber led to frequent spark-over in the reaction zone, resulting in a reduced power input to the airstream and consequently a reduced cleaning efficiency. In situations like this, the power setting of the system can be reduced to limit the amount of spark-over to an acceptable level, i.e. ≤20 sparks/min. In the reported case, the achieved cleaning efficiency was still high enough to meet the authority requirements for total allowed odour emission, so the customer accepted the system performance without modification. This type of problem is normally solved by admixing up to 20 % cold air, to stimulate condensation and installing a mist filter prior to the plasma treatment unit. This has been carried out in several installations.

Above 80 °C, the performance of the technique drops significantly, due to the electrochemical characteristics of the waste gas, so a maximum input temperature of 70 °C is specified. Airstreams at higher temperatures can be cooled by adding air at ambient temperatures.

The equipment is engineered to treat a specified volume of air and built as modular units, normally to handle 20 000 m$^3$/h/module. For higher volumes, several modules can be installed in parallel. However, if the actual flow is significantly different from the design parameters, there might be an effect on the performance.

In addition to odour destruction, the plasma reactor also acts like an electrostatic precipitator. For a dust-laden airstream, there will, therefore, be a build-up of dust over time in the reaction chamber and on the corona wire. The speed of this build-up will depend on the dust load and the dust characteristics. Experience has shown that the plasma technique works well with dust loads of <25 mg/Nm$^3$. In such circumstances, the reactor can be in continuous operation for up to
several months, after which cleaning is normally required. For this reason, many of the industrial applications are equipped with a wet cleaning system that operates (semi)automatically during production stops and flushes the collected dust to a WWTP. At very high dust loads, there is a risk of clogging the equipment and frequent cleaning is required. In addition, high dust concentrations in the waste gas will increase the frequency of spark-over and may reduce the odour cleaning efficiency. Normally such high concentrations will only occur during failure of upstream dust abatement equipment.

Cross-media effects
Energy is required to create the plasma and to transfer air to the gas mixture for the process and for cooling and water condensation. Ozone is generated. Waste water, contaminated with, e.g. dust is produced.

Ozone is generated in the plasma reactor and emitted to the air. In industrial applications, ozone emission levels are kept well below 1 ppm by volume, although this is generally not monitored after commissioning. NOx and SOx are not generated in detectable quantities, due to inorganic compounds like NH3 and H2S, not being effectively destroyed.

Technical considerations relevant to applicability
Non-thermal plasma treatment can be installed as an end-of-pipe solution to malodorous waste gases in the FDM industry. This includes, e.g. the emissions from extruders, dryers, coolers and hammer mills. The technique is applied to various types of waste gas, including those containing dust, although upstream dust abatement may be required. The most odorous waste gases contain a mixture of organic and inorganic components. The plasma process has a high performance for organic components, but is less efficient at removing some inorganic components, e.g. NH3 and H2S. This is due to the fact that the energy densities currently achievable have insufficient power to break down these compounds. The technique has to be protected from significant amounts of water condensing on the equipment.

There are some outstanding concerns about the reliability and performance of this technique and possible safety concerns when the technique is used to treat airstreams which may cause a fire and explosion hazard. At the time of writing, its application and performance in the FDM sector is still being evaluated.

Economics
According to the technology supplier, one module (treating between 20 000 and 25 000 Nm3/h) will cost around NOK 1 million, which corresponds to around EUR 117 000 (March 2004). This includes the necessary equipment, electromechanical service and commissioning from the supplier, but excludes mechanical installation. Annual maintenance costs are approximately 3 to 5 % of the investment costs. Consumables include power and minor quantities of rinsing water.

Driving force for implementation
To prevent complaints about odours and to meet legal requirements.

Example plants
In the FDM industry, the technique has reportedly been applied on an industrial scale in several fish-meal factories and in the production of pea products, pet food, proteins, oil extraction and animal feed. It has also been applied in at least one waste sorting installation in Denmark, a manure processing installation in Norway and a pharmaceuticals installation in Norway. It has been applied for its electrostatic cleaning effect in at least one silicon carbide installation in Norway.

Reference literature
2.3.7.3.9 Extending the height of the discharge stack

Description
Height extension of the discharge stack.

Technical description
The effect of buildings or structures within the vicinity of the stack discharge can often cause poor dispersion and, in some cases, the phenomenon known as plume grounding, where the exhaust is pulled downwards under the influence of nearby structures. Air dispersion models can take account of the potential influence of these structures.

Achieved environmental benefits
Reduced perception of odour problems in the vicinity of the odour source.

Environmental performance and operational data
This process is typically carried out using a correlation taking into account the height, width and length of the building. For example, in the breeze computer model as validated by the Environmental Protection Agency in the United States, a correlation is used that incorporates the height and maximum projected width of nearby buildings. The maximum projected width is defined as the diagonal distance \( L \) between extreme corners of the building at the maximum building elevation. The procedure is then to draw a radius of \( 5 \times L \) from the building/structure. If the stack discharge falls within \( 5 \times L \) of the nearby building/structure, then the presence of that building will likely have a negative impact on the dispersion from the nearby stack. Similarly, if the stack discharge is outside of the \( 5 \times L \) radius then the building/structure will have no effect on the dispersion.

The procedure subsequently allows the user to determine the required stack height such that the stack is at a sufficient elevation not to be influenced by the building/structure. The procedure involves comparing the diagonal distance \( L \) with the building/structure height and the lesser of these two measurements is used in the following equation to determine the stack height required so as not to be influenced by the building/structure.

\[
h_e = h_b = 1.5 \times L
\]

Where:
\( h_e \) = required stack height
\( h_b \) = height of the building/structure
L = diagonal distance

This procedure can be used as a simple check to ascertain whether an existing stack discharge would be influenced by a nearby building/structure. The analysis indicates whether or not extensions to the stack height would be a viable option. In this respect, reference to any planning restrictions, in terms of maximum elevations, would need to be considered in addition to the need for, e.g. increased supporting structures.

Cross-media effects
Reduced visual amenity due to the presence of the chimney(s). The production and emission of the malodorous substance(s) has not been prevented or abated.

Technical considerations relevant to applicability
Applicable in all FDM installations with malodorous emissions which are not considered to be harmful to the environment, only offensive.

Economics
Low-cost technique.
Example plants
TWG, please provide information.

Reference literature
[ 16, Willey et al. 2001 ]

2.3.7.3.10 Increasing stack discharge velocity

Description
Increase of stack discharge velocity.

Technical description
The magnitude of the discharge velocity applied to a final emission to the air can have a significant effect on the resultant ground level impact of a malodorous emission. An increased discharge velocity will result in an increased momentum or buoyancy of the emission. This implies that the discharge will attain an increased elevation thereby allowing more potential for dispersion in the air and hence lower ground level concentrations.

Achieved environmental benefits
Reduced odour emissions.

Environmental performance and operational data
A typical design range for final discharge velocities from stacks is between 10 and 20 m/s, with an industry standard of 15 m/s. Design velocities of less than 10 m/s are likely to suffer from poor dispersion, whilst velocities above 20 m/s can prove expensive in terms of extraction fan power and operating costs. Furthermore, discharge velocities greater than 20 m/s can result in significant noise as the discharge generates a whistling phenomenon.

There may also be restrictions on the design velocity that can be applied to certain installations. In guidance documents, it is common for the discharge from a wet separation plant such as a water scrubber to be limited to no greater than 9 m/s. This restriction is designed to prevent the carryover of a significant quantity of water droplets resulting in a fountain effect.

The stack discharge velocity can be reduced significantly if there are physical restrictions in the discharge flowpath. Restrictions reduce the momentum of the plume during discharge. Many discharge stacks have a cone fixed over the outlet, designed to prevent rainfall entering the process via the discharge stack. The discharging process air is thus forced outwards through 90º rather than upwards, resulting in a considerable loss of available momentum. If the use of rainfall protectors is avoided, the stack design then needs to take account of rainfall and its collection.

Cross-media effects
Energy consumption.

Technical considerations relevant to applicability
Applicable in all FDM installations.

Economics
Low-cost technique.

Example plants
TWG, please provide information.

Reference literature
[ 16, Willey et al. 2001 ]
2.3.7.3.11  Odour management plan (OMP)

Description
An odour management plan (OMP) is compatible with the concept of the environmental management system (EMS) approach as described in Section 2.3.1.1. The OMP can be a part of the EMS of the installation.

As odour arises from different operational areas, it is good practice for the odour management plan to include all potential odour sources of farm operation (housing, manure storage and spreading) and seek to control them in an integrated way.

An odour management plan includes the following elements:

- a protocol containing appropriate actions and timelines;
- a protocol for conducting odour monitoring;
- a protocol for response to identified odour nuisance;
- an odour prevention and elimination programme designed to e.g. identify the source(s), to monitor odour emissions (see Section 4.18.4), to characterise the contributions of the sources and to implement elimination and/or reduction measures;
- a review of historical odour incidents and remedies and the dissemination of odour incident knowledge.

The approved OMP may be made available to the public.

Achieved environmental benefits
The minimisation of odorous emissions is the achieved environmental benefit. Many of the management techniques to reduce odour will also simultaneously reduce other emissions to air.

Cross-media effects
There are no cross-media effects associated with the implementation of this technique.

Environmental performance and operational data
TWG, please provide information.

Technical considerations relevant to applicability
The technique is applicable to new and existing installations provided that an odour nuisance at sensitive receptors is expected and/or has been substantiated.

Economics
TWG, please provide information.

Driving force for implementation
Management systems are likely to be less of a cost burden, or may even improve financial returns for producers, and often have lower capital costs and require less resources (energy, water, chemicals etc.) than end-of-pipe treatments.

Example plants
TWG, please provide information.

Reference literature
No information provided.
2.3.7.4 Techniques to reduce NO\textsubscript{X} emissions

2.3.7.4.1 Low-NO\textsubscript{X} burners

For more information please consult the LCP BREF [256, COM 2016].

**Description**
The technique is based on the principles of reducing peak flame temperatures; boiler burners are designed to delay but improve the combustion and increase the length of the flames, allowing the heat radiated during combustion to reduce peak temperatures. The air/fuel mixing reduces the availability of oxygen and reduces the peak flame temperature, thus retarding the conversion of fuel-bound nitrogen to NO\textsubscript{X} and the formation of thermal NO\textsubscript{X}, while maintaining high combustion efficiency. This may be associated with a modified design of the furnace combustion chamber.

**Technical description**
Low-NO\textsubscript{X} burners have reached a mature stage of development, but further improvements are ongoing and a considerable amount of research work is still devoted to the enhancement of existing low-NO\textsubscript{X} burner systems. Since design details of low-NO\textsubscript{X} burners differ significantly from manufacturer to manufacturer, only the general principle is referred to here.

In a classical combustion installation, the combined fuel and air/oxygen mix is entirely injected at the same place. The resulting flame is then composed of a hot and oxidising primary zone located at the flame root and a colder secondary zone located at the flame tip. The primary zone generates most of the NO, which increases exponentially with temperature, whereas the contribution of the secondary zone is more modest.

Low-NO\textsubscript{X} burners modify the means of introducing air and fuel to delay the mixing, reduce the availability of oxygen, and reduce the peak flame temperature.

According to the different principles to reduce the formation of NO\textsubscript{X}, low-NO\textsubscript{X} burners have been developed as air-staged burners, flue-gas recirculation burners and fuel-staged burners.

**Achieved environmental benefits**
Reduced NO\textsubscript{X} emissions to air.

**Economics**
For new installations, the additional investment for a low-NO\textsubscript{X} burner compared to a classical burner can be considered negligible. For retrofits, possible modifications to the installation have to be taken into account, which are very often plant-specific and thus not quantifiable in general terms.

**Driving force for implementation**
Reduction of NO\textsubscript{X} emissions.

**Example plants**
TWG, please provide information.

**Reference literature**
[256, COM 2016]

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**Optimal use of air abatement equipment**

**Technical description**
The requirement for abatement equipment to run may vary depending on the recipe, e.g. in the case of odour. If there are processes or recipes which do not require air abatement equipment to
be used all of the time, its use can be managed to ensure that it is available and at the required operating condition when it is required.

It can be installed in such a way that it cannot be bypassed by the individual operating it, but when the conditions which require the abatement do not apply, then managers can bypass it. For example, the manager can keep control of the keys which give access to the controls which enable the equipment to be bypassed and they can also ensure that it is switched on again in time to have reached its optimum operating condition as soon as it is required.

**Achieved environmental benefits**

Reduced emissions to air.

**Environmental performance and operational data**

When an example wet petfood canning installation, which had been operating without emitting malodorous substances, started to make another product, odour became a significant problem, because the existing odour control measures were not suitable for the new recipe. Recipe changes have also led to fluctuating odour problems at animal feed mills, where on a batch basis, fish oils or molasses are added. These examples demonstrate the varying need for abatement, even within some individual installations.

As well as ensuring that the abatement equipment is switched on, for the efficient prevention of emissions to air, the operating conditions need to be correct. For example, at smokehouses for meat or fish, and at coffee roasting installations using thermal oxidation to destroy odours, these thermal oxidisers do not operate effectively until they reach the combustion temperatures of the pollutants, so they need to be started up in time for these temperatures to be reached in the combustion chamber (see Sections 2.3.7.3.6 and 2.3.7.3.7).

**Technical considerations relevant to applicability**

Applicable where air abatement equipment is used.

**Driving force for implementation**

Prevention of emissions to air.

**Reference literature**


### 2.3.8 Techniques to reduce noise and vibrations

#### 2.3.8.1 Selection of efficient and quiet fans

**Description**

Efficient and quiet fan selection.

**Technical description**

The principal cause of fan noise is turbulence and local slowing of flowrates due to vortex shedding. Vortex shedding is the periodic detachment of vortices from an object in a fluid flow, causing a varying force to be experienced by the object.

The most efficient and the quietest fans are usually the ones with the lowest blade tip speed, i.e. those with a large diameter and a low speed. For a given duty, a backward-curved or backward-inclined fan working at peak efficiency is quieter than a radial tipped fan.

Additional noise reduction measures include using flexible connections between fans and ducts to minimise the transmission of vibration and mounting fans on vibration isolators to prevent transmission of vibration to supporting structures. Fan noises are transmitted over long distances. The higher frequencies, from fans with many blades, tend to dissipate over shorter
distances than the lower frequencies emitted from fans with fewer blades. Figure 2.44 shows the effect of modifying a roof-mounted fan to produce a higher frequency noise.

![Figure 2.44](image)

**Figure 2.44:** The effect of the number of fan blades on the distance of noise transmission

**Achieved environmental benefits**
Reduced noise emissions.

**Environmental performance and operational data**
In an example spray dryer, a fixed speed 2500 rpm fan delivering approximately 45000 m$^3$/h was replaced with two smaller fans running at 1500 rpm and delivering the same total air volume. Control of the new fans was obtained by reducing their speed, rather than using a damper. The net reduction in noise was approximately 8 dB(A). Table 2.72 shows the noise reduction that can be expected from reducing the fan speed. Every 3 dB(A) reduction is equivalent to halving the noise level.

<table>
<thead>
<tr>
<th>Fan speed reduction</th>
<th>Noise reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 %</td>
<td>2 dB(A)</td>
</tr>
<tr>
<td>20 %</td>
<td>5 dB(A)</td>
</tr>
<tr>
<td>30 %</td>
<td>8 dB(A)</td>
</tr>
<tr>
<td>40 %</td>
<td>11 dB(A)</td>
</tr>
<tr>
<td>50 %</td>
<td>15 dB(A)</td>
</tr>
</tbody>
</table>

**Technical considerations relevant to applicability**
Applicable where fans are used, e.g. for air conditioning, ventilation and refrigeration.

**Economics**
The cheapest fans are usually those with the smallest diameter, but these tend to be the noisiest. The cost of a fan is, however, usually a relatively small proportion of any overall project and the cost is, therefore, not used as the governing factor.

**Driving force for implementation**
Reduced complaints about noise emissions from outside the installation.

**Reference literature**
[35, Germany 2002], [147, Lewis D. N. 2003], [192, COM 2006]
Selection of fans with low numbers of blades
Achieved environmental benefits
Reduced noise emissions.

Technical considerations relevant to applicability
Applicable where fans are used, e.g. for air conditioning, ventilation and refrigeration.

Driving force for implementation
Reduced complaints about noise emissions from outside the installation.

2.3.8.2 Designing pipework to minimise noise emissions

Description
Pipework design to minimise noise emissions.

Technical description
Pipes can be enclosed within walls or laid in special ducts to reduce noise immission levels. Optimum results are achieved by either lining or filling cavities with sound absorbing material. Sound insulation can be improved by:

- selecting pipe material with sound insulating properties, e.g. cast iron instead of plastic
- increasing the thickness of the pipe wall
- insulating the pipe.

The material and the geometry of the pipe wall determine the propagation of the airborne noise. Damping the vibrations in the pipe wall that give rise to airborne noise causes a reduction in sound energy by absorption, as the sound spreads through the fluid. This damping effect is not important at low frequencies, but increases as the frequency rises. The damping effect decreases as the pipe diameter increases. Irregularities in the surface of the pipe also increase the damping effect. If pipes have a sound-absorbing inner lining, then at higher flow speeds the damping is considerably reduced for sound propagation in the direction of flow and increased for sound propagation against the direction of flow.

When dimensioning pipes, it is important to ensure that the principal excitation frequency of the sound level entering the pipe is sufficiently far from the natural frequencies and pass frequencies of the pipes. All natural frequencies are influenced by the way the pipes are mounted, the route taken by the pipe, e.g. the number and position of bends and any internal baffles.

Achieved environmental benefits
Reduced noise emissions.

Environmental performance and operational data
Pipes are used to transport gases, vapours, liquids and solids with a carrier fluid. The noise emissions arising from pipes include noise transmitted by the fluids and solids, as well as airborne noise transmission. Virtually no noise results from laminar flows, but increasing turbulence leads to increased noise emission levels within pipes.

Cavitation causes intensive noise. Cavitation occurs when the static pressure is locally equal to or less than the vapour pressure, and occurs, e.g. where the direction of flow is changed.

When solids are transported with the aid of carrier fluids, additional noise results from contact of the solid particles with each other and with the walls of the pipe, particularly when hard particles are transported using a gaseous fluid. The sound pressure level depends on the flowrate, the material of the pipe, and the type of solid. Sound pressure levels may reach
between 85 and 100 dB(A) at a distance of 1 metre from straight pipe elements. This can be expected to increase by a further 10–15 dB(A) near bends.

**Technical considerations relevant to applicability**
Applicable where pipes are used to transport gases, vapours, liquids and solids with a carrier fluid.

**Driving force for implementation**
Prevention of occupational noise induced hearing loss and reduced complaints about noise emissions from outside the installation.

**Reference literature**
[ 35, Germany 2002 ]

### 2.3.8.3 Sound insulation of equipment

**Description**
An insulating enclosure usually consists of a metal jacket lined with absorbing material which wholly or partially encloses the sound source.

**Technical description**
Sound insulating enclosures can be built around sources of noise pollution. An insulating enclosure usually consists of a metal jacket lined with absorbing material which wholly or partially encloses the sound source. The noise level reduction that can be achieved depends on the insulation of airborne sound by the walls and the absorption capacity of the internal lining. The size, shape and materials for the screen can be determined by acoustic design calculations to ensure that particular design targets, i.e. noise emission levels, are met. Connecting fans and the ducts or housings using elastic linkages and placing noisy equipment on noise absorbing bases can also reduce noise emission levels.

**Achieved environmental benefits**
Reduced noise emissions.

**Environmental performance and operational data**
Some examples of uses of sound insulation materials in the FDM sector include:

- for glass bottling lines, enclosing glass bottle conveyors and cap feeder hoppers
- lining insides of hoppers with impact deadening material and lining outsides of hoppers and guard panels
- at packing machines, lining cover panels and enclosing bagging lines
- in the meat sector, fitting noise dampening hoods over bowl choppers
- in the dairy sector, enclosing homogenisers (e.g. in sound insulated rooms which require infrequent access)
- enclosing spray dryers (e.g. in sound insulated rooms which require infrequent access)
- in milling operations, enclosing hammer mills, roller mills and mixers
- in freezers and coldstores, enclosing the refrigeration machinery allowing for the ventilation of motors and fans
- enclosing vapour compressors.

For some applications it may be necessary to allow the entry or release of air from an acoustic enclosure. This reduces the noise reduction potential, but the effect of this may be reduced by designing bends in the airways to abate the noise emissions. For example, fans can be enclosed in sound insulating enclosures designed to minimise the build-up of reflected noise inside the enclosure and adequate ventilation for cooling of the fan needs to be provided.
For ductwork, instead of fitting silencers, it is often possible to achieve a 10–20 dB(A) reduction in airborne noise from a duct or opening by lining the last bend in the ductwork with a noise absorbing material or by constructing a simple absorbent lined right-angled bend to fit on the opening. It is reported that either side of the bend should be lined along a length equivalent to twice the duct diameter.

Technical considerations relevant to applicability
A variety of equipment used in the FDM sector, e.g. fans, compressors, pumps and blowers.

Driving force for implementation
Prevention of occupational noise induced hearing loss and reduced complaints about noise emissions from outside the installation.

Example plants
Insulation of noisy equipment is widely applied in the FDM sector, e.g. at glass bottling lines; at hoppers where there is noisy product impact; during packing, e.g. while wrapping, cutting and bagging; at bowl choppers used in the meat sector; in grain milling, e.g. in the manufacture of flour and animal feed and in freezing and cold storage.

Reference literature
[110, CIAA 2003], [147, Lewis D. N. 2003]

2.3.8.4 Position equipment to direct noise away from neighbours

Description
Equipment is positioned in order to minimise the noise impact for neighbours.

Technical description
Some equipment emits different noise emission levels in different directions. For example, any equipment which has a fan inlet or outlet on one side will have its maximum noise level on that side. Positioning the equipment so that the noisiest side faces away from a sensitive location could, therefore, reduce the immission levels there. This cannot be guaranteed to always be effective because the direction that sound is carried varies with weather conditions.

Achieved environmental benefits
Reduced noise emission levels at receptor sites away from the noisy side of the equipment.

Cross-media effects
The emission of noise is not prevented or reduced at all and there may the risk of occupational noise induced hearing loss or complaints may remain.

Technical considerations relevant to applicability
Applicable to cooling towers, condensers, compressors, pumps and blowers.

Driving force for implementation
Reduced noise emission levels at sensitive receptor sites.

Reference literature
[35, Germany 2002], [110, CIAA 2003], [147, Lewis D. N. 2003]
2.3.8.5  Sound insulation of buildings

Description
Sound insulation of buildings.

Technical description
The acoustic output of machines and the acoustic properties of the rooms determine the sound pressure levels inside a building. These internal sound pressure levels and the sound insulation provided by the external shell, i.e. walls, roofs, windows, doors and openings result in the airborne sound power, i.e. the emission level. This can be a particular problem when equipment is inside steel frame buildings with relatively lightweight profiled cladding. The acoustic power of a source is related to its surface area. Large building facades can, therefore, radiate significant acoustic power.

Buildings can be insulated against airborne noise. It is much easier to insulate against high frequency noise than low frequency noise. Either single-shell or double-shell insulation can be provided. The sound insulation of components of a more or less homogeneous structure depends largely on their weight per unit area. The nature of the material is also important.

Double-shell buildings consist of two dense shells separated by an air gap or a resilient insulating layer. Under certain conditions, the sound insulation provided by such elements is greater than that of single-shell elements of the same weight. The most important requirement for better sound insulation is that the air gap between the shells is sufficiently large or that any insulating layer between the shells is sufficiently resilient and open textured. The insulating effect of the cavity is achieved by filling it with sound absorbing materials, e.g. mineral fibre panels. Rigid connections between the double shells have an adverse effect on sound insulation.

The sound insulation of any wall is only as good as the weakest link. The sound insulation of windows, doors, roofs and louvres has to be considered so that sound insulation of the composite structure can be calculated. If the sound reduction index of windows and doors matches or approaches that of the wall, then the overall performance will be maintained. If a poor fitting door and a light window is installed in a block wall, this will significantly reduce the noise reduction possible.

If particular design targets are to be met, the size, shape and materials for the screen should be determined by acoustic design calculations.

Achieved environmental benefits
Reduced noise emissions.

Technical considerations relevant to applicability
Applicable to all FDM installations, e.g. where fans are used for air conditioning, ventilation and refrigeration.

Driving force for implementation
Reduced complaints about noise emissions from outside the installation.

Reference literature
[ 35, Germany 2002 ], [ 110, CIAA 2003 ], [ 147, Lewis D. N. 2003 ]

2.3.8.6  Shielding buildings from noise immission sites

Description
Shielding buildings from noise immission sites.
Chapter 2

**Technical description**
Shielding buildings from immission sites has the effect of reducing the sound pressure level at those sites. Other buildings in the vicinity may provide the shielding effect, or this can be manufactured by constructing barriers such as walls or embankments. It is reported that these can achieve a shielding effect of more than 5 dB(A) if they at least interrupt the line-of-sight connection. The higher the barrier and the closer it is to the noise source and/or immission site, the greater the shielding effect.

**Achieved environmental benefits**
Reduced noise emissions.

**Cross-media effects**
The emission of noise is not prevented or reduced at all and there may the risk of occupational noise induced hearing loss or complaints may remain.

**Technical considerations relevant to applicability**
Applicable to all FDM installations, e.g. where fans, cooling towers and condensers are used.

**Driving force for implementation**
Reduced complaints about noise emissions from outside the installation.

**Reference literature**
[35, Germany 2002]

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**2.3.8.7 Application of a spiral turbulence generator to a chimney to minimise noise emissions**

**Description**
Application of a spiral turbulence generator to a chimney.

**Technical description**
Air flowing past towers and chimneys creates noise, due to eddies and also excites vibrations in the chimney. Applying a spiral turbulence generator interferes with the eddy formation. The gradient of the turbulence generator is not constant. The technique is shown in Figure 2.45.

![Figure 2.45: Reduction in noise emissions from a chimney](source: [35, Germany 2002])

**Figure 2.45: Reduction in noise emissions from a chimney**
Achieved environmental benefits
Reduced noise emissions.

Technical considerations relevant to applicability
Applicable where fans are used, e.g. for air conditioning, ventilation and refrigeration.

Driving force for implementation
Reduced complaints about noise emissions from outside the installation.

Reference literature
[ 35, Germany 2002 ]

2.3.8.8 Fit silencers to air inlets and exhausts

Description
Application of fit silencers to the compressor air inlet or exhaust.

Technical description
Fit silencers to the compressor air inlet or exhaust. Silencers can be absorptive or reactive. Absorptive silencers absorb the noise. Reactive silencers contain chambers and baffles and their size and position determine the silencer’s sound attenuation characteristics. Reactive silencers may be more effective for compressors, which generate significant emission levels of low frequency tonal noise.

Achieved environmental benefits
Reduced noise emission levels.

Cross-media effects
If the silencer is not well designed, there may be increased energy consumption, due to back pressure or blockage.

Environmental performance and operational data
It is reported that a well-designed silencer will not increase system back pressure. If the silencer is not well designed, increased attenuation may increase pressure loss and consequently increase energy consumption. Back pressure can be minimised by increasing the size of the silencer and the coupling between the silencer and the compressor. Fitting a straight-through silencer can prevent both back pressure and blocking.

It is reported that multiple exhausts can be attached to a manifold leading to a single, larger diameter pipe. It is reported that the rear silencer from virtually any make of car can be used to achieve a typical reduction of 25 dB(A).

Technical considerations relevant to applicability
Applicable where compressed air is used. The air should be filtered within the compressor area. Filters should be cleaned (cleaning frequency to be set depending on the season) to prevent dirty exchangers.

Economics
Low cost.

Driving force for implementation
Prevention of occupational noise induced hearing loss and reduced complaints about noise emissions from outside the installation.

Example plants
Widely applied.
2.3.8.9 Manage on-site vehicle movements

Description
The times when vehicles enter and leave the installation and the location and times of on-site vehicle movements are controlled.

Technical description
By controlling the times when vehicles enter and leave the installation and the location and times of on-site vehicle movements, noise emissions off-site can be reduced at sensitive times, e.g. at night during the hours when neighbours, in residential areas, normally wish to sleep.

This may be optimised further by the selection of quiet vehicles, including those that are well maintained and providing road surfaces with low noise transmission qualities.

Achieved environmental benefits
Reduced noise emissions at night.

Cross-media effects
Increased noise and vehicle emission levels during the daytime.

Environmental performance and operational data
For some FDM processes which practice 24 hour processing, the importance of receiving materials fresh for rapid processing may limit the possibilities to restrict deliveries to daytime. This restriction may apply to, e.g. fruit and vegetable processing when harvesting and processing of, e.g. tomatoes and peas is undertaken during 24 hours/day, to ensure ripeness and taste.

It may be difficult to limit the arrival and departure times of shift workers to avoid times when noise may cause a nuisance to residential neighbours.

Noise emission levels were measured in the neighbourhood of an example large brewery operating for a full 24 hours a day on working days. Noise emission levels attributed to the brewery were measured at identified nearest immission detection sites. In addition, calculations were made of the noise emission levels at the nearest immission detection sites caused by traffic to and from the brewery, such as incoming raw materials, e.g. malt and outgoing products; by-products and waste, e.g. bottled and canned beer; yeast and brewery residues; and within the installation, e.g. forklift trucks and cars. Traffic to and from the brewery is limited to daytime hours.

Six parcels of land were considered as immission detection sites. With the exception of one site which contained storage and workshop buildings, the parcels of land were not built on.

The measurements of the immissions attributed to the brewery at the nearest immission detection sites are shown in Table 2.73. The noise sources used were the fans and compressors and brief blow-off noises from valves.
Table 2.73: Noise measurements (mean of three independent measurements) from a German brewery

<table>
<thead>
<tr>
<th>Measuring site*</th>
<th>$L_{A_{FM}}$ (dB(A))</th>
<th>$L_{A_{95}}$ (dB(A))</th>
<th>Noise source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (distance of 100 m)</td>
<td>43.3</td>
<td>42.0</td>
<td>Fans of waste water system</td>
</tr>
<tr>
<td>2 (distance of 110 m)</td>
<td>48.0</td>
<td>46.5</td>
<td>Fans of CIP system, roof fans</td>
</tr>
<tr>
<td>3 (distance of 75 m)</td>
<td>49.7</td>
<td>48.0</td>
<td>Fans of CIP system, roof fans</td>
</tr>
<tr>
<td>4 (distance of 120 m)</td>
<td>48.6</td>
<td>46.0</td>
<td>Fans of CIP system, compressor unit</td>
</tr>
<tr>
<td>5 (distance of 110 m)</td>
<td>45.8</td>
<td>44.5</td>
<td>Compressor unit</td>
</tr>
<tr>
<td>6 (distance of 110 m)</td>
<td>46.9</td>
<td>45.5</td>
<td>Compressor unit</td>
</tr>
</tbody>
</table>

$L_{A_{FM}}$ = the maximum noise level measured/read on the noise meter, during the time under consideration
$L_{A_{95}}$ = the noise level measured in dB(A), exceeded for 95% of the time under consideration

*The measurement period was 1.5–10 minutes. The values are an average from 3 measurements

The measurements in Table 2.74 show the noise emissions calculated for daytime and night operation from internal site traffic and supplier traffic.

Table 2.74: Calculated partial rating levels for materials transport and transhipment processes

<table>
<thead>
<tr>
<th>Site</th>
<th>Partial rating level--night (dB(A))</th>
<th>Partial rating level--day (dB(A))</th>
<th>Rating level (dB(A))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Day</td>
<td>Night</td>
</tr>
<tr>
<td>1</td>
<td>43.5</td>
<td>52.9</td>
<td>53.7</td>
</tr>
<tr>
<td>2</td>
<td>41.2</td>
<td>51.0</td>
<td>53.7</td>
</tr>
<tr>
<td>3</td>
<td>30.9</td>
<td>44.3</td>
<td>52.8</td>
</tr>
<tr>
<td>4</td>
<td>24.4</td>
<td>37.3</td>
<td>51.2</td>
</tr>
<tr>
<td>5</td>
<td>31.7</td>
<td>41.7</td>
<td>49.1</td>
</tr>
<tr>
<td>6</td>
<td>38.9</td>
<td>44.9</td>
<td>50.1</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

When calculating the daytime rating levels, the values in Table 2.74 were raised by a rest period (06.00h–07.00h and 20.00h–22.00h) mark-up of 2.4 dB(A). The measured values at all six sites were well below the local immission guide value during the day and also complied with the immission guide value during the night.

The concentration of vehicle movements during the day can have mixed occupational safety implications. During the day visibility may be better, but there may be more people on the site and together with the additional concentration of vehicles, the management of vehicle movements and the segregation of vehicles from people is a very high priority.

There may be off-site implications in terms of traffic congestion by limiting the hours of reception and dispatch from any site.

Technical considerations relevant to applicability
Applicable in virtually all FDM installations.

Driving force for implementation
Good relations with neighbours and the elimination of complaints about off-site noise emission levels.

Example plants
At least one brewery in Germany.
2.3.8.10 Switch off the engine and refrigerator unit of a vehicle during loading/unloading and when parked

Description
The running engines and the refrigeration units of vehicles are switched off during loading, unloading and when the vehicle is parked.

Technical description
The running engines and the refrigeration units of vehicles can cause noise nuisance. This can be avoided by switching them off during loading, unloading and when the vehicle is parked. If it is necessary to maintain chilled or frozen storage conditions in a vehicle this can be done by using the power supply from the installation.

Achieved environmental benefits
Reduced noise emissions.

Technical considerations relevant to applicability
Applicable during loading and unloading of vehicles whether refrigerated or not.

Driving force for implementation
Reduced noise emissions.

Reference literature
[14, VITO et al. 2001]
2.4 Emerging techniques across the FDM sector

This chapter includes novel pollution prevention and control techniques that are reported to be under development and may provide future cost or environmental benefits. If available, the information includes the potential efficiency of the techniques, a preliminary cost estimate, and an indication of the time-scale before the techniques might be commercially available. Established techniques in other sectors that are emerging in practice within the FDM sector are not included.

2.4.1 Use of UV/ozone in absorption for odour abatement

Description
Ozone has been used historically as an oxidant in only a limited number of odour control applications. This is primarily because, although it is extremely reactive in the liquid phase, its reactivity in the gaseous phase is lower. A process was developed during the 1980s that enhanced the activity of ozone by the incorporation of UV light. The process uses a conventional packed bed system and a liquid recycle system. Ozone is bubbled into the sump of the absorber and the ozonated water is passed through a bank of UV lamps. Ozone in the presence of UV light produces hydroxyl radicals which are far more reactive than ozone alone. Dissolved organic compounds in the liquid phase are oxidised to carbon dioxide and water and thus the absorber liquor discharged from the system is relatively clean.

Achieved environmental benefits
Reduced odour emissions.

Technical considerations relevant to applicability
Ozone systems have not been effective when applied to hot and humid airflows, e.g. when applied to a poultry processor scald tank vent.

Reference literature
[16, Willey et al. 2001]

2.4.2 Electrochemical activation

Description
Electrochemical activation for cleaning.

Technical description
This technique refers to cleaning and disinfection of equipment within the food industry. The cleaning and disinfection agents are produced at the site through an electrochemical process from sodium chloride (table salt) solution. On the cathode side OH\(^-\) ions are formed, which are used for the cleaning. On the anode side Cl\(_2\) is formed. OH\(^-\) ions and Cl\(_2\) can react and form hypochlorous acid (HClO), which acts as a disinfectant. Cleaning and disinfection take place with the use of a cold solution.

Savings on energy consumption, chemicals and possibly water consumption are achieved. The technique has not yet been operating long enough to allow the full documentation of this new BAT candidate. One brewery has indicated that the annual energy consumption may be reduced by approximately 100 000 KWh per production line. The cost of chemicals will certainly be significantly reduced.

Achieved environmental benefits
Reduced energy, chemical and water consumption.

Reference literature
[241, Nordic Council of Ministers 2011]
2.4.3 Waste activated sludge reduction and generation of carbon source for denitrification

Technical description
OpenCEL uses electrical pulses to disrupt the waste activated sludge (WAS) cell structure causing the cells to lyse. OpenCEL focused pulse (FP) technology uses high-frequency micro-pulses of between 20 kV and 60 kV for no more than 0.1 second to cause the cell membrane to swell and rupture. Once ruptured, the WAS is more readily degradable by the active microorganisms. Bench-scale research shows that the semi-soluble COD of WAS increased by more than 26 times after OpenCEL treatment compared with untreated WAS. If the WAS treated with OpenCEL is fed to a digester, it degrades more completely, giving higher volatile solids destruction (therefore less biosolids yield) and generating more digester gas (if anaerobic). If fed to an anoxic zone, the ruptured cells become a source of readily biodegradable carbon for denitrification. The denitrification rate using OpenCEL treated WAS has been shown to be approximately equal to the rate when using methanol as the carbon source but does not include the dangers of methanol handling.

Other research shows that full FP pretreatment should increase biogas production and biosolids removal by 60 % and 40 %, respectively. Note that WAS is approximately 6–10 % nitrogen and 1–2 % phosphorus (more if biological phosphorus removal is practiced).

Achieved environmental benefits
Enhanced nitrogen removal.

Reference literature
[266, EPA 2013]

2.4.4 Integrated fixed-film activated sludge systems with biological phosphorus removal

Technical description
The integrated fixed-film activated sludge (IFAS) hybrid processes includes any activated sludge system that has some type of fixed-film media in a suspended growth reactor to increase the amount of biomass available for treatment. The IFAS media can be retrofitted into existing activated sludge systems and lagoons. There are two major types of IFAS: (1) Submerged Mobile Media IFAS and (2) Submerged Fixed Media IFAS. The media material varies but is usually a plastic carrier, sponge carrier, or knitted matrix. Mobile media are retained by screened baffle walls and can be allowed to migrate over the entire basin volume or can be retained in specific zones by multiple baffle walls.

An important feature of the IFAS process is that it provides the capability to decouple the solids retention time (SRT) of the suspended biomass from the SRT of the biomass attached to the IFAS media. This feature is especially useful with processes that must nitrify and perform enhanced biological phosphorus removal (EBPR) because the optimal SRT for EBPR is short (< 5 days) while the optimal SRT for nitrification is generally longer (> 8 days) depending on the waste water temperature.

Research has shown that the majority (> 90 %) of the EBPR capability is associated with the suspended biomass, but most of the nitrifying capability (> 70 %) is associated with the biomass attached to the IFAS media. This segregation of EBPR and nitrifying organisms allows the suspended phase to be controlled to a short SRT without the concern that the nitrifying capability of the system will decline or that nitrifier washout will occur. It also retains the bulk of the nitrifier population in the aerobic zone(s) thereby reducing the nitrifier fraction in the anaerobic and anoxic zones where the nitrifiers are ineffective.
Achieved environmental benefits
Enhanced phosphorus and nitrogen removal.

Reference literature
[ 266, EPA 2013 ]

2.4.5 Microbial fuel cell-based treatment system

Technical description
A microbial fuel cell (MFC) is a device that generates electricity from the bacterial metabolism of organic matter (which is measured as chemical oxygen demand in waste water). During the final stage of bacterial metabolism, electrons are passed along the cell membrane and deposited onto a terminal electron acceptor, usually oxygen. Under anaerobic conditions, bacteria must use an alternative electron acceptor like sulphate, nitrate, or –as is the case with an MFC– an electrode. In an MFC, bacteria are grown under anaerobic conditions and they transfer their electrons externally to an anode.

Electrons flow from the anode to a positively charged cathode through an external circuit; this flow of electrons represents an electrical current. The cathode is exposed to oxygen and protons (H\(^+\)) that chemically react with the incoming electrons to form water. MFC research is focused on the design of the fuel cell including the number of chambers and their layout; electrode size (surface area), spacing, materials, and quantity; alternatives to and composition of proton exchange membranes; and affordable cathode catalysts.

Biological research is being done to identify bacterial species that optimise the process and to better understand how they transfer electrons externally. A modified MFC that generates pure hydrogen gas for use with hydrogen fuel cells is also being studied. In this approach, no oxygen is supplied at the cathode. Instead, a low voltage is applied to the circuit to facilitate the chemical formation of hydrogen gas (instead of water). Recent advances in MFC research have achieved substantial increases in MFC power production compared to previous designs. While still an emerging technology that is being studied at the laboratory level, in the future MFCs might be capable of producing enough electricity to operate a waste water treatment plant and perhaps even an excess that could be sold back to the grid.

Integrated Fixed-film Activated Sludge (IFAS) Systems with Biological Phosphorus Removal

Reference literature
[ 266, EPA 2013 ]
3 ANIMAL FEED

Feed is defined (Regulation (EC) No 178/2002) as 'any substance or product, including additives, whether processed, partially processed or unprocessed, intended to be used for oral feeding to animals'. The feed chain is represented in Figure 3.1.

This chapter covers the production of the following types of feed:

- compound feed and premixtures for food-producing animals;
- pet food;
- feed for fur animals;
- dehydrated forage.

Operations consisting of the processing of by-products from food industries with a view to their use as animal feed (such as drying of sugar beet pulp) are covered in the corresponding sectorial chapters of this document.
3.1 General information about the sector

3.1.1 Compound feed and premixtures for food-producing animals

Farm animals in the EU-28 consume an estimated 475 million tonnes of feed a year (see Figure 3.2), of which 153 million tonnes are produced by compound feed manufacturers.

Compound animal feeds are based upon core formulations of cereals (such as wheat and barley), soya, rapeseed and sugar beet, liquid ingredients (such as water, molasses and vegetable oils) and specific additives such as mineral and medicinal supplements.

The purpose of compound feed manufacturing is to supply farmers with a product whose nutritional composition (vitamins, energy, proteins, amino acids, etc.) meets the requirements of the animals as much as possible to achieve predefined animal production criteria (e.g. amount of milk/day, daily live weight gain) at the lowest cost. Considering that the nutritional requirements of the animals depend on many parameters (e.g. species, sex, breed, age, physiological stage, production system), compound feed manufacturers may produce feed meeting up to 150 different predefined specifications at the same location. The vast majority of compound feed is produced in a dry form from raw materials in solid and dry form, with exceptions such as molasses or vegetable oils.

The non-exhaustive EU Catalogue of Feed Materials (Regulation (EU) No 68/2013) lists more than 600 feed materials. Volume-wise, cereals represent just less than half of the feed materials used. The European feed industry is also exploiting a significant amount of co-products from the food industries. Of an average compound feed formula, 40% is made up of these co-products (co-products from the food industry, cakes and meals) (see Figure 3.3). Regarding protein, the most important feed materials are soybean meal, mainly imported from third countries, and rapeseed meal, from the European crushing industry. The industry also uses protein-rich co-products from the starch and ethanol industries and digestible fibre-rich co-products from beet sugar industry plus numerous liquid feeds. A large part of the feed ingredients used to feed food-producing animals is of vegetable origin. However, dairy by-products are used significantly in milk replacers for young animals, in particular calves.
Products of marine origin such as fish meal, fish oil, krill, etc. are incorporated in fish feed, especially for carnivorous species. Due to the limited marine resources, fish meal is increasingly replaced by proteins of vegetable origin and still, to a limited extent, processed animal proteins from poultry and/or pigs.

Figure 3.3: Use of feed materials by the EU-27 feed industry in 2011

The European compound feed industry is a growing industry and turnover is estimated at EUR 45 billion. It offers direct employment for approximately 110 000 people in approximately 4 500 installations. Many of these installations are situated in rural areas, which offer few employment opportunities. Most (85%) of the (compound) feed installations are SMEs, with in 2012 an average annual production of 38 000 tonnes of compound feed per installation. The number of production installations falling under the scope of the FDM BREF is estimated to be around 450 [202, FEFAC 2015].

The manufacturing of compound feed for food-producing animals is characterised by the fact that it is performed in a dry environment: the feed manufacturing process does not involve water (except for steam production during pelleting or thermal treatment) and cleaning is performed in a dry environment. This means that there is no water release into the environment.

The following list identifies key environmental impacts of manufacturing of compound feed for food-producing animals:

- air/particulates: particulates from processing (cooling), loading and unloading of materials, failure of arrestment equipment;
- energy: use of energy in feed processing;
- noise: vehicles and process operations may cause noise disturbance, especially if close to the site boundary;
- air/odours: odour (for feed containing a minimum of 5% animal proteins) from processing (pelleting, cooling), loading and unloading of materials.
Noise and odours are mainly incidental and tend to be relevant to the relatively few compound feed installations occupying inhabited areas. These emissions can be minimised by good management practice and can be legitimately considered at local level [225, FEFAC 2015].

### 3.1.2 Pet food

Pet food contributes significantly to the economy and to society. Throughout Europe, an estimated 50,000 direct and 700,000 indirect jobs are generated by the pet food industry. A total number of about 650 pet food installations are spread all over Europe. The pet food industry and related supply and services represent a combined annual turnover of over EUR 30 billion. Pet food products serve approximately 75 million pet-owning households with annual pet food production of over 9 million tonnes [203, FEFAC 2015].

In order to define their formulations as precisely as possible, manufacturers rely on the analysis of nutritional requirements of pets. In R&D centres, manufacturers, nutritionists, biochemists, microbiologists and veterinarians study animal nutrition. They also measure the nutritional value, palatability and digestibility of feed materials used in the formula which constitutes the basis of production.

The nutrients that enter into the composition of products are found in animal-based ingredients, cereals and vegetables or are supplied in the form of supplements. The industry therefore uses animal by-products or leftovers from the fish filleting industry that are mixed with vegetable materials (e.g. cereals, legumes).

There are two major processes for producing pet food. The majority of produced foods are complete feeds, whether in dry or wet form. The typical characteristic of a wet food is a moisture content of 60% or more. This requires specific technical preparations and procedures for stabilising and securing the final product in cans, pouches and metal trays. Dry pet food has up to 14% moisture and is therefore, in terms of handling, packaging and transport, closer to some agricultural products in bags (paper/plastic) or boxes [203, FEFAC 2015].

The following list identifies key environmental impacts of pet food processing [203, FEFAC 2015]:

- emissions to air: particulates and odour from processing (grinding, heating, cooling), loading and unloading of materials, failure of arrestment equipment;
- energy: use of energy in pet food processing;
- noise: vehicles and process operations may cause noise disturbance, especially if close to the site boundary;
- water and waste water: as raw material and for process cleaning.

### 3.1.3 Feed for fur animals

TWG, please provide more information.

### 3.1.4 Dehydrated forage

The industry producing green fodder operates in rural areas with market demand. Spain is the leading European producer of dehydrated alfalfa, the main product in the sector, ahead of France and Italy. The French sites stand out for their high combustion capacities and the weather limiting the drying potential for the fodder in the fields before it is processed in the installations [247, Copa-Cogeca 2016].

Direct flame combustion is used to directly process incoming material. The choice of these hot-air generators is historical and most of these installations were set up in the 1960s under the legal form of farming cooperatives. They are therefore owned by their member farmers who
manufacture a large number of products: alfalfa, other leguminous plants, grasses, other green fodder, corn, poppy seeds, carrots, straw, unripe hay, etc. Most of the sites also handle by-products from nearby industries in order to extend the campaign for longer and make better use of their production tools: sugar beet pulp with the sugar industry, grape marc with distilleries, pomace with cider producers, mustard bran with mustard producers, and so on. Some even operate during the winter campaign, using sawdust, miscanthus, and short-rotation bushes to manufacture agro-fuels.
3.2 Applied processes and techniques

The compound feed industry consists of two distinct sectors, i.e. animal feed and petfood. Animal feeds are predominantly dry, while petfoods often have a significant moisture content. In both sectors, the manufacturing process involves the blending of a range of ingredients such as cereals, protein sources, vitamins, minerals, fats and oils, to produce nutritionally balanced foods.

By far the most important moist petfood ranges are those for dogs and cats. These foods are classified according to moisture, packaging and processing systems, and include moist foods and semi-moist foods. In the UK, although moist foods currently comprise a major portion of the market, semi-moist foods are becoming increasingly popular. Moist foods have a moisture content of 60 to 85% and are usually preserved by heating. Heat treatment may be applied before or after packaging. Moist foods can be subdivided into canned foods, premium moist foods, brawns and frozen meats.

Animal feed and dry petfood

The main animal feed types are compound feeds. These consist of a variety of blended ingredients. The composition is varied depending on the type and age of the animal to be fed, but typically includes ingredients such as cereals, animal and vegetable proteins, fibre sources, minerals and supplements such as vitamins, antibiotics and other additives. Some of the ingredients are co-products and by-products of the FDM sector.

The raw materials are received at the feed mill and may be pneumatically conveyed or mechanically transferred to bulk storage silos. Some small ingredients which may be mixed in during the process, such as supplements, may be sent pre-bagged in appropriate quantities. Ingredients are weighed automatically in modern installations and transferred to holding bins prior to grinding, typically using hammer mills. After grinding, the ingredients are thoroughly mixed and any supplements are added. The blend may then be drawn off as meal or mash feed, or pressed to produce pelleted feed. More commonly, the blend goes on to be manufactured into feed pellets. Steam is injected into the feed in a process known as conditioning before being forced through holes in the pelletising die. The resulting pellets vary in size depending on the intended use. After this stage of manufacture, the pellets are dried and then cooled, typically in coolers in which the pellets enter from the top and cool air is blown in from the bottom. To account for moisture loss during pelleting, drying and cooling, water may be added to some feeds at the blending stage. The pellets are then either stored in bulk or packed. Some feeds may be coated in fat prior to packing.

Moist petfood

The raw materials used in moist petfoods are typically co-products of the FDM sector. These co-products must be fit for human consumption, although they would not typically be used for this purpose. Ingredients used include meat processing co-products, whole grain, ground cereals, flavourings and vitamin and mineral supplements. Petfoods are designed to be nutritionally balanced to meet the needs of a particular type of animal.

Semi-moist petfood

The raw materials used in moist petfoods are typically co-products of the FDM sector. Ingredients commonly used include dry cereal sources, vitamin and mineral supplements and some meat slurries. The ingredients are blended, conditioned and extruded into small shaped pieces. The pieces are dried and fat or meat extracts may be sprayed onto the surface. This type of feed is often multi-component. After drying, various fractions manufactured in a similar way are blended to produce the finished feed. The feed is then packaged.
3.2.1 Compound feed and premixtures for food-producing animals

3.2.1.1 General

Generic steps in the manufacture of compound animal feeds are as follows:

- reception and storage of raw materials;
- size reduction of raw materials;
- processing of materials;
- product storage and dispatch;
- cleaning activities.

Equipment common to this sector includes:

- storage silos, hoppers and tanks for the containment of stored materials;
- grinders for the size reduction of material prior to processing;
- conveyance systems for the contained transportation of material;
- mixers to allow the creation of batches of feed mixtures with preset formulations;
- conditioning units in which the feed mixture undergoes steam treatment;
- press lines in which the conditioned feed materials are pelleted through dies to achieve the desired product conformation (pelleting is also known in certain countries as extrusion);
- coolers which utilise air to cool the product materials prior to storage;
- storage silos and bins for the storage of processed materials;
- boilers for the production of steam;
- dust abatement systems.

A generic schematic of the activities undertaken in the manufacture of compound animal feeds is provided in Figure 3.4.
3.2.1.2 Receipt and storage of raw materials

The methods used for the storage and handling of the raw materials are specific to the individual materials [204, FEFAC 2015]:

- Bulk solid raw materials (e.g. cereals) are generally delivered to the site in covered vehicles and tipped into reception hoppers prior to conveyance to silos or bulk bins for storage. Other bulk powders (e.g. amino acids) are delivered by tanker and are blown directly, by tube, into dedicated storage silos.
- Bulk liquid raw materials (e.g. molasses, soya oil and vegetable oil) are delivered by road tankers and are pumped into designated, bunded storage tanks.
- Packed solid and liquid raw materials (such as vitamins and enzymes) are stored internally within a warehouse facility in the supplier’s primary packaging plant prior to use.

3.2.1.3 Size reduction of raw materials

In order to ensure the homogeneity of the finished product and to produce the physical attributes required, the raw materials are ground and sieved prior to inclusion in the product mixture. Typically, electrically driven grinders are used to grind the material to a uniform particle size. Once ground, the raw material is conveyed to the processing plant by means of enclosed conveyors [204, FEFAC 2015].
3.2.1.4 Processing of raw materials

Weighing and mixing
Raw materials are fed via load cells into a batch mixer. A typical site will have a number of mixers which are dedicated to specific product types to prevent cross-contamination. At this stage of the process, the low-dose ingredients, such as feed additives or premixtures of feed additives, are added directly into the mixer. Depending upon the recipe, liquid additives and water can also be weighed and added into the mix via dedicated lines at this stage.

Mixing is typically performed within a horizontal enclosed continuous mixer. The residence time for the mixing process is recipe-specific and, when the mixing cycle is complete, the homogeneous batch is conveyed for further processing in the press plant. However, if a meal product is being produced, the batch will be transferred directly from the mixer to a finished product bin, ready for dispatch [204, FEFAC 2015].

Steam treatment
Steam treatment or conditioning is the process of adding steam directly into the mix to raise its temperature so that any bacteria present (such as salmonella) are eliminated. The steam also improves the physical characteristics of the mix in preparation for the subsequent pelleting process. At this stage, further liquid materials (such as molasses) may be added as required. The length of the conditioning process is determined by the requirements of the feed being produced [204, FEFAC 2015].

Installations operate a dedicated boiler plant to provide the steam to the production process.

Pelleting or extrusion
After conditioning, the hot mix is conveyed to a press line; a typical installation will have a number of press lines dedicated to the production of a specific compound feed. A screw feed is used to force the mix into a press whereupon it is extruded through a rotating ring die to form a pellet product. Different die dimensions and press rotation speeds facilitate the production of different pellet sizes, to meet specific product requirements [204, FEFAC 2015].

Cooling
After pelleting, the hot product is then passed through a counterflow air cooler to reduce its temperature, causing it to harden and become durable. The cooling process involves air at ambient temperature being passed directly over the pellets.

Additional processing steps may be utilised after cooling to produce specific products. The pellets may be crushed to produce feeds for poultry, or undergo fat coating prior to storage [204, FEFAC 2015].

3.2.1.5 Product storage and dispatch

Once cool, the finished product is conveyed to dedicated finished product silos or tote bins, prior to dispatch. Silos are fitted with high level alarms to prevent overfilling.

The product is typically dispatched in bulk, although some installations also operate bagging stations to facilitate the creation of packaged products to meet small-scale demand. Bulk product is loaded onto dedicated delivery lorries prior to dispatch to customers. Typically, loading activities are undertaken in enclosed bays to limit the potential for the fugitive release of dust and odour [204, FEFAC 2015].
3.2.1.6 Cleaning

Cleaning and housekeeping activities are essential at compound animal feed manufacturing installations to guarantee food hygiene and to ensure that cross-contamination of different feeding stuffs cannot occur. Cleaning of the installation and processing equipment generally does not involve wet cleaning; typically involving dry, mechanical processes only (sweeping and vacuuming). Most installations also operate a dedicated on-site vehicle washing facility to clean the lorries used for bulk deliveries to customers [204, FEFAC 2015].

3.2.2 Pet food

3.2.2.1 General

Generic steps in the manufacture of pet foods are as follows:

- reception and storage of raw materials;
- size reduction of raw materials;
- processing of raw materials;
- product storage and dispatch;
- cleaning activities.

Equipment common to this sector includes:

- silos, hoppers, freezing/cooling equipment (wet products) and tanks for the containment of stored materials;
- grinders for the size reduction of material prior to processing;
- conveyance systems for the contained transportation of material;
- mixers to allow the creation of batches of feed mixtures with preset formulations;
- processing units;
  - wet food: preparation of solid and liquid parts for final products (product shape; pieces in gravy, pieces in jelly mousse, pate), containers filling machines, steriliser;
  - dry food: extruders (product shape; kibbles, in different dimensions), dryers spray coating.
- coolers;
- storage facilities for the intermediate storage of processed material (pallets);
- boilers for the production of steam;
- dust abatement systems;
- waste water treatment facilities;
- odour treatment.

A generic schematic of the activities undertaken in the manufacture of pet food is provided in Figure 3.5.
3.2.2.2 Receipt and storage of raw materials

Pet food is based upon core formulations of cereals (such as wheat and barley), animal by-products as protein source (Category 3 materials; fresh, frozen, dried; from animals passed as fit for human consumption), vegetables, liquid ingredients (such as water, and oils) and specific additives such as mineral supplements. The methods used for the storage and handling of raw materials, are specific to the individual materials [203, FEFAC 2015]:

- bulk solid raw materials (e.g. cereals) are generally delivered to site in covered vehicles and tipped into reception hoppers prior to conveyance to silos or bulk bins for storage. Other bulk powders (e.g. minerals,) are delivered in big bags, or by tanker and blown directly into dedicated storage silos;
- bulk liquid raw materials (e.g. animal and vegetable oil) are delivered by road tankers and are pumped into designated storage tanks;
- packed solid and liquid raw materials (such as vitamins and enzymes) are stored internally within a warehouse facility in the supplier’s primary packaging prior to use.

3.2.2.3 Size reduction

In order to ensure the homogeneity of the finished product and to produce the physical attributes required, the raw materials are ground and sieved prior to inclusion in the product mixture. Typically, electrically driven grinders and/or cutters are used to grind the material to a uniform particle size. Once ground, the raw material is conveyed to the processing plant by means of enclosed conveyors [203, FEFAC 2015].
3.2.2.4 Processing of raw materials

**Weighing and mixing**

Raw materials are fed via load cells into a batch mixer. A typical site will have a number of mixers which are dedicated to specific product types to prevent cross-contamination. At this stage of the process, the low-dose ingredients, such as feed additives or premixtures of feed additives, are added directly into the mixer. Depending upon the recipe, liquid additives and water can also be weighed and added into the mix via dedicated lines at this stage [203, FEFAC 2015].

For dry products, mixing is typically performed within a horizontal enclosed continuous mixer. The residence time for the mixing process is typically three to four minutes and, when the mixing cycle is complete, the homogeneous batch is conveyed for further processing.

For wet products, mixing is typically performed in a vertical mixer in batches. The ready mixed mixture will be poured directly into the final containers.

**Extrusion (dry pet food)**

This process has become the most common for dry pet foods. An extruder consists of a tightly fitting screw rotating within a stationary barrel. Pre-ground and conditioned ingredients enter the screw where they are conveyed, mixed and heated by a variety of processes. The product exits the extruder through a die where it usually changes texture due to the release of steam and normal forces. A variety of food extruder designs have been developed [203, FEFAC 2015].

The extrusion is a high-temperature, short-time process which minimises losses in vitamins and amino acids. Colour, flavour, and product shape and texture are also affected by the extrusion process. Extrusion has been widely applied in the production of nutritious foods. Emphasis is placed on the improvement of protein quality and digestibility. This process makes the product highly digestible as it ensures the complete cooking of the starch.

After the extruder, the product goes into the dryer in order to reach the target moisture, and then continues into the cooler. Dry foods may then be sprayed with liquids in order to complete their composition and increase palatability without degradation during extrusion.

Figure 3.6 shows a typical scheme of the manufacture of dry pet food.
Figure 3.6: Manufacture of dry pet food

Sterilisation (wet pet food)
After conditioning and mixing the different ingredients (texture, size, density, liquid, solid, etcetera), the final containers are filled, closed and finally sterilised.

Figure 3.7 shows a typical scheme of the manufacture of wet pet food.
Cooling

After processing, the hot product is then passed through a counterflow air cooler or a cooling tower to reduce its temperature [203, FEFAC 2015]:

- dry pet food: cooling/drying enables pellets to harden and become durable;
- wet pet food: cooling towers, using water, are used to cool down sterilisers or products after sterilisation.

Additional processing steps may be utilised after cooling to produce specific product characteristics (e.g. fat coating of pellets) prior to packaging and storage.

3.2.2.5 Product storage and dispatch

Finished, packed and labelled products are stored on pallets.

3.2.2.6 Cleaning

Cleaning and housekeeping activities are essential at pet food production sites to guarantee food hygiene and to prevent cross-contamination. Most installations also operate a dedicated on-site vehicle-washing facility to clean the lorries used for bulk deliveries to customers.

3.2.3 Feed for fur animals

TWG, please provide information.

3.2.4 Dehydrated forages

3.2.4.1 First stages

The improvement of operating stand-alone dehydration units involves controlling their supplies. In order to ensure the unit operates as regularly as possible and to reduce the number of incidents or stoppages, which are always costly, harvesting in the alfalfa fields takes place during the periods in which the units are operating, in other words round the clock.

The first stage on a field site is mowing the alfalfa. Until recently, rakes were used and the alfalfa was gathered afterwards to conserve product quality, the average humidity rate of which was hence reduced from 80% to 75% when entering the unit. Apart from the harvesting constraint this implied, such practice reduced the drying capacity of sun-dried products. Therefore an intermediary stage has been included in the process in the form of flat pre-wilting that requires maintenance of the farming machinery used for this purpose, i.e. rakes. The mown alfalfa is lifted up from underneath by rakes that spread it over a rolling belt that expels it out of the machine to the sides. The alfalfa is then spread flat over the field, where it dries better due to the larger surface specifically exposed to the sun. The silage is then carried out 24 to 48 hours after the cutting process, depending on the weather conditions and the unit needs for supplies. This flat pre-wilting technique does not lower the quality of the finished product and enables up to 30% energy savings to be achieved by the unit due to the lower humidity level of the input products [247, Copa-Cogeca 2016].

3.2.4.2 Dehydration by dry process at high temperature

The high-temperature drying process consists of producing dehydrated alfalfa pellets or bales with 10% to 12% humidity using raw material with humidity that varies from 25% to 85%,
depending on the treatment it is given in the fields and the humidity conditions at the time of harvesting. It is also used for other kinds of fodder. The alfalfa, pre-wilted or not in the field, is dried at a high temperature in single- or three-pass rotary furnaces. The shorter three-pass rotary drums (see Figure 3.8) are adapted to high humidity levels because the passes through the drum are more frequent, the exchange volumes being greater. They are fed with heat from the grill burners. The fuel used is coal, lignite, gas or, more recently, some kinds of biomass such as wood chip, sawdust or miscanthus [247, Copa-Cogeca 2016].

![Three-pass drying drum](image)

**Figure 3.8:** Three-pass drying drum

The furnace pipe temperatures vary according to the humidity of the incoming products and vary between 300 °C and 950 °C depending on the product in question. When exiting the drum, the temperature of the output fumes is about 120 °C. Fodder is dehydrated with surplus air, in particular for the purpose of creating a flow to allow its correct circulation in the dryer. The air contains water vapour when exiting the dryer. The products are separated from this humid gas by high-performance cyclone separation. When leaving the cyclone, the humid gas from the drum can be directly expelled into the atmosphere or be partially used in various recycling processes in order to reduce energy consumption [247, Copa-Cogeca 2016]:

- partial recycling upstream to be injected into the air burner that is already hot;
- recycling to a fodder pre-dryer through a condenser scrubber;
- recycling in a wet process using vacuum evaporators.

The dehydrated alfalfa husks are either pressed into bales or processed in pellets. In order to manufacture pellets, the alfalfa from the cyclone is normally crushed in hammer mills. The outgoing product is transported by suction, then separated by cyclones and the waste is passed through bag filters or treated in the wet process. The desired moisture of the output alfalfa from the furnace is about 15 % in order to obtain a moisture content of about 12 % for the pellets from the presses, and 12 % to ensure the best preservation of bales.

Due to the risk of fire, ongoing monitoring of input and output product temperatures is conducted in the dryer, with detection of sparks and engine rotation. Alarms, a circuit sprinkler and automatic stoppage of the drying line are implemented.

Optimising the operation of the production line, in particular adjustment of the required temperatures (input and output) of the dryer to the humidity rate of the alfalfa, enables the optimisation of the energy consumption. The direct flame drying process does not cause a loss of heat.
3.2.4.3 Dehydration by the wet process

There is a twofold objective for using the wet process: to produce protein-concentrated pellets and xanthophyl and carotenoid pigments and to save energy. The freshly cut alfalfa is harvested without pre-wilting, crushed and pressed to extract the protein-rich sap, called green juice. The cake, a by-product from the pressing stage, is transferred to the dry process. The juice is heated by steam at 85 °C in order to coagulate the proteins into coagulum, proteins that are then separated from the serum by centrifugation (see Figure 3.9).

![Figure 3.9: Centrifuge system in a dehydration site](source: [247, Copa-Cogeca 2016])

The coagulum, rich in proteins and pigments, is dried in a fluidised bed dryer and then compacted into pellets in the presses. After cooling, the pellets are stored at a cold temperature (5 °C) or rendered inert with nitrogen in order to preserve the pigments. The serum is concentrated by vacuum evaporation. Once concentrated, when the serum reaches 45 % dry content, it is returned to the cake which is returned to the high-temperature dryers in the dry process [247, Copa-Cogeca 2016].
3.3 Current consumption and emission levels

3.3.1 Energy consumption

Table 3.1 shows reported data on specific energy consumption (MWh/tonne of raw materials). Among the related techniques reported, heat recovery from condensation of flue gases, boiler economisers, use of variable speed drivers on motors and insulation of pipes are reported.

Table 3.1: Specific energy consumption in animal feed production

<table>
<thead>
<tr>
<th>Type of animal feed</th>
<th>Specific energy consumption (MWh/tonne of raw materials)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compound feed production</td>
<td>&lt; 0.003–0.11</td>
</tr>
<tr>
<td>Dry pet food production</td>
<td>0.39–0.45</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

3.3.2 Water consumption

Table 3.2 shows reported data on specific water consumption (m³/tonne of raw material). Generally, low specific water consumption values have been reported for compound feed production.

Table 3.2: Specific water consumption in animal feed production

<table>
<thead>
<tr>
<th>Type of animal feed</th>
<th>Specific water consumption (m³/tonne of raw materials)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compound feed production</td>
<td>0.012–0.087</td>
</tr>
<tr>
<td>Dry pet food production</td>
<td>0.29–0.46</td>
</tr>
<tr>
<td>Wet pet food production</td>
<td>6.8–8.4</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

3.3.3 Emissions to water

Figure 3.10 shows reported data on specific waste water discharges (m³/tonne of raw materials) from animal feed installations. Higher specific waste water discharge values are generally reported in the case of wet pet food production.
3.3.4 Emissions to air

3.3.4.1 Dust emissions from green fodder drying

The reported data related to dust emissions from green fodder drying are shown in Table 3.3.

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm$^3$)</th>
<th>$\text{O}_2$ (%)</th>
<th>Frequentcy of monitoring</th>
<th>Monitoring standard</th>
<th>Sampling duration (h)</th>
<th>Abatement technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>291-1</td>
<td>116.25</td>
<td>17.45</td>
<td>Monthly</td>
<td>NA</td>
<td>0.50</td>
<td>Cyclones and wet scrubbers</td>
</tr>
<tr>
<td>264-1</td>
<td>151.02</td>
<td>17.50</td>
<td>Monthly</td>
<td>EN 13284-1</td>
<td>0.33</td>
<td>Cyclones</td>
</tr>
<tr>
<td>265-1</td>
<td>184.25</td>
<td>16.40</td>
<td>Monthly</td>
<td>EN 13284-1</td>
<td>0.50</td>
<td>Cyclones</td>
</tr>
</tbody>
</table>

NB: NA = no information provided.

Source: [193, TWG 2015]

3.3.4.2 Dust emissions from processing of grain-based feed

A general overview of the data received for dust emissions from processing of grain-based feed is shown in Table 3.4. It should be noted that the predominant abatement technique reported for this type of emission was a bag filter. In a few cases, cyclones were used as a first treatment step before the bag filters. In a few cases, no information about the abatement technique implemented was provided. The predominant monitoring standard reported was EN 13284-1 and the majority of concentrations were reported at atmospheric $\text{O}_2$ levels.
Table 3.4: Total dust emissions to air from processing of grain-based feed

<table>
<thead>
<tr>
<th>Number of release points involved</th>
<th>Range of dust emission levels (mg/Nm³)</th>
<th>Abatement technique implemented</th>
<th>Typical processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>&lt; 1.0–60.64</td>
<td>Bag filters, cyclones</td>
<td>Raw material loading/unloading, transportation and preparation</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

The majority of release points reported dust emission levels below 10 mg/Nm³. In only five cases were dust emission levels higher than 20 mg/Nm³.

3.3.4.3 Dust emissions from extrusion (compound feed)

A general overview of the data received for dust emission from extrusion is shown in Figure 3.11.

![Figure 3.11: Total dust emissions to air from extrusion](image)

Source: [193, TWG 2015]

The meaning of the symbols used in Figure 3.11 is indicated in Table 3.5.

Table 3.5: Symbols used in the graphs for emissions to air

<table>
<thead>
<tr>
<th>Average emission levels</th>
<th>Symbol</th>
<th>Type of monitoring regime</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Less frequent monitoring (less than 12 measurements per year)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequent monitoring (at least 1 measurement per month)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Continuous monitoring</td>
</tr>
</tbody>
</table>

It should be noted that the most common final abatement techniques implemented for abatement of dust emissions from extrusion are bag filters and cyclones.
Chapter 3

3.4 Techniques to consider in the determination of BAT

3.4.1 Techniques to increase energy efficiency

3.4.1.1 Flat pre-wilting

Description
Spreading the mown fodder flat on the mowing site to allow it to dry in the open air before harvesting it.

Technical description
Flat pre-wilting consists of spreading the fodder flat after mowing to dry in the open air before harvesting it. This enables the humidity level of the input material in the dryer to be reduced more quickly than when using rakes, hence improving the proportion of the product surface exposed to the sun. Flat pre-wilting is more efficient than pre-wilting using rakes. It is carried out with mowers and hay rakes specifically used for this purpose.

Flat pre-wilting requires traditional mowers to be adapted so that the mown alfalfa is placed flat on the field and not collected with rakes. Raking requires specific machinery and is only practical at the time of harvesting, therefore it is not used with mowing. This implies an additional use of machinery and thus extra costs (staff, specific machinery and fuel).

The variability of weather conditions has an impact on the continuity of the harvesting sites. As the raking stage is carried out after mowing, the most reliable weather forecasts are required in order to adapt the work in the event of rainy periods.

Apart from the weather conditions mentioned above, flat pre-wilting also depends on the following:

- the fodder humidity at the time of the mowing and raking work (e.g. flat pre-wilting is rarely carried out early in the morning (dew));
- the kind of equipment used (mower or adapted mower, which has an impact on the quality of the product harvested: the machinery will crush the product to a greater or lesser extent).

Achieved environmental benefits
Flat pre-wilting enables the humidity of the alfalfa entering the plant to be reduced compared with pre-wilting using rakes, to achieve an average fodder humidity of 60–70 %, which implies energy savings of about 30 %. Moreover, the following benefits are achieved [193, TWG 2015]:

- reduction in fuel consumption in the dryers of about 20–30 % (see Figure 3.12);
- reduction in emissions related to the reduction in the fuel combustion;
- reduction in NMVOC emissions (biogenic) to air of about 30 %.
Specific NMVOC emissions tend to be lower when the level of dry content in the fodder is higher. The NMVOC emissions are about 1.8 kg per tonne of product obtained from normally pre-wilted alfalfa (using rakes), compared with 1.2 kg NMVOC emissions per tonne of product obtained from flat pre-wilted alfalfa, which is equivalent to a reduction of more than 30% in NMVOC emissions.

**Cross-media effects**
Extra resources are required for spreading the fodder flat (staff, specific machinery and fuel).

**Technical considerations relevant to applicability**
Flat pre-wilting can be used in installations equipped with a high-temperature dryer and integral low-temperature dryer. The wet extraction process, which enables alfalfa protein concentrate to be obtained, needs high water content, which is incompatible with flat pre-wilting.

Flat pre-wilting is sensitive to the moisture of the fodder during the mowing and raking work; however, it is rarely carried out early in the morning because of the dew. The kind of equipment used, a mower or mower-conditioner, crushes the product more or less, which affects its quality. A high number of stones on the land the alfalfa is to be collected from causes serious wear or even breakage of the harvesters, cyclones, hammers and drying equipment.

**Economics**
The costs incurred by this technique are partly related to the adaptation of equipment, fuel consumption and staff. One tractor-raking machine pair should be estimated to cover an area of 1,600 hectares of alfalfa. In terms of investment, the costs are as follows [247, Copa-Cogeca 2016]:

- raking machine purchase: about EUR 85 000, excluding taxes;
- tractor purchase: about EUR 78 000, excluding taxes;
- installation modifications: EUR 10 000–50 000, excluding taxes.

The cost of adaptation of the installation, mainly relating to its equipment with stone removers, depends on the initial situation before implementing flat pre-wilting and the gap to be bridged in order to adapt it to the use of this technique. The annual operating costs are as follows [247, Copa-Cogeca 2016]:

![Figure 3.12: Tonnes of water to be evaporated depending on the humidity of the fodder for one tonne of pellets](source)
for a tractor: EUR 2 000, excluding taxes, for operational expenses (i.e. insurance, spare parts) and EUR 7 000, excluding taxes, for fuel (i.e. diesel); 
for a raking machine: EUR 7 000, excluding taxes, for upkeep and maintenance costs and EUR 20 000, excluding taxes, for employing a driver for the season; 
additional diesel to operate the rake: 11.8 l/hectare/year.

Driving force for implementation
Reduction in fossil fuel consumption.

Example plants
Installations #264, #265, #292. [193, TWG 2015]

Reference literature
[193, TWG 2015], [247, Copa-Cogeca 2016]

3.4.1.2 Recycling of humid air from the dryer

Description
Injection of the outgoing warm air from the cyclonic separation (about 120 °C) into the burner of the dryer.

Technical description
The volume of the primary air is less than the air needed in the drying drum. Therefore, additional air needs to be injected. Rather than injecting outdoor air, it is better to inject the outgoing warm air from the cyclonic separation (about 120 °C), in order to save energy.

Recycling of air increases dust emission levels expressed in concentrations. However, the pollution load remains the same. When the required temperature for the burner is lower, in the case of flat pre-wilted fodder, recycling of air must be optimised by ensuring that no over-pressure is created in the burner. Using flat pre-wilting reduces the need for recycling on small plants.

Achieved environmental benefits
This technique reduces energy consumption by decreasing the need for outdoor cold air supplies.

Environmental performance and operational data
When operating at high temperature with wet fodder, the recycling of 20% of the gas volume from the hot drying process means an energy saving of 7%.

Cross-media effects
Increased electricity consumption to feed the dedicated ventilator of the system. Recycling the air modifies the acidity of the fumes and the pipes must be made of stainless steel instead of grey steel.

Technical considerations relevant to applicability
For safety reasons, special attention must be paid to the minimum circulation speed of the recycled gas to avoid the accumulation of the dust and fire risk.

Economics
Recycling part of the gas from the dryer requires a high investment since the whole recycling line, including the cyclone, must be heat insulated. The investment in the insulated recycling system is about EUR 300 000 (excluding taxes), for a dryer with a capacity of 40 000 l/h.
Driving force from implementation
The related energy savings and reduction of emissions from combustion are the main motivations for using this technique.

Example plants
TWG, please provide information.

Reference literature
[247, Copa-Cogeca 2016]

3.4.1.3 Use of waste heat for pre-drying

Description
The outgoing steam from the high-temperature dryers is used for pre-drying part or all of the green fodder.

Technical description
A part of the fumes emitted by the dryers, at a temperature of about 120 °C, is directed to a wet scrubber (saturator gas scrubber), after separation in the main cyclones. This wet scrubber washes the steam with water until the dew point and allows the heat emitted by the water condensation to be exchanged with a coolant, normally water, to transport it to the low-temperature dryer. The heated air is applied on a bed of products of about a fifth of a centimetre thick (see Figure 3.13).

![Diagram of low-temperature pre-dryer](source: [247, Copa-Cogeca 2016])

Figure 3.13: Implementation of a low-temperature pre-dryer on a dehydration site

Achieved environmental benefits
This technique reduces energy consumption in the high-temperature dryer. Greenhouse gas and other emissions to air are also reduced.

Environmental performance and operational data
This technique applied to fodder with 80% humidity reduces energy consumption by about 20% when lowering the humidity rate of the input fodder in the rotary dryer by 5%.
Cross-media effects
The wet scrubber generates acid washing water, which may require storage before discharge (e.g. landspreading).

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique in green fodder installations.

Economics
The investment in a pre-dryer is about EUR 5 million for a line of 30 000 litres of evaporation per hour. Moreover, the high costs for treating the acid waste water must be added to this.

Example plants
TWG, please provide information.

Reference literature
[247, Copa-Cogeca 2016]

3.4.2 Techniques to reduce emissions to air
3.4.2.1 Techniques to reduce dust emissions from green fodder drying
3.4.2.1.1 Cyclone

The technique is generally described in Section 2.3.7.2.3.

Environmental performance and operational data
Cyclones allowed dust concentrations from 90 mg to 180 mg/Nm$^3$ depending on the conditions of use. The reduction in emissions of particles achieved is 70% using this equipment.

Some installation-specific performance data related to the application of cyclones for reduction of dust emissions from green fodder drying are presented in Table 3.6.

Table 3.6: Dust emission levels to air from green fodder drying after treatment in a cyclone [193, TWG 2015]

<table>
<thead>
<tr>
<th>Installation ID</th>
<th>Dust (mg/Nm$^3$)</th>
<th>O$_2$ content (% dry basis, mean value)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>264-1</td>
<td>103.7</td>
<td>151.02</td>
<td>193.1</td>
<td>EN 13284-1</td>
<td>Monthly Alfalfa. Rotary dryer/mix of coal and lignite. 99% of particles are PM$\text{<em>{10}}$. 80% of particles are PM$\text{</em>{2}}$. and 38% of particles are PM$\text{_{1}}$. 70% abatement efficiency.</td>
</tr>
</tbody>
</table>
### Economics

Investment costs of around EUR 160 000 for a 15 000 l/h dryer and around EUR 250 000 for a 40 000 l/h dryer (values excluding taxes and without heat insulation) have been reported. Additional costs of around EUR 30 000 (excluding taxes) per cyclone must be considered for their heat insulation and connection [247, Copa-Cogeca 2016].

### Example plants

Installations #264 and #265 [193, TWG 2015].

### Reference literature

[193, TWG 2015], [247, Copa-Cogeca 2016]

#### 3.4.2.1.2 Wet scrubber

The technique is generally described in Section 2.3.7.3.1.

**Environmental performance and operational data**

A wet scrubber is applied after a cyclone step in installation #292. An average value of 116.25 mg/Nm$^3$ was achieved for dust emissions (average value of four measurements), and the average $O_2$ content was 17.45%. The minimum value was 71 mg/Nm$^3$ (at 16.20% $O_2$ content) and the maximum value was 207 mg/Nm$^3$ (at 19.60% $O_2$ content). The installation uses a rotary dryer, fuelled with coal.

**Reference literature**

[193, TWG 2015]

#### 3.4.2.2 Techniques to reduce dust emissions from handling and preparation of grain-based feed

##### 3.4.2.2.1 Bag filter

The technique is generally described in Section 2.3.7.2.2.

**Environmental performance and operational data**

Table 3.7 shows some installation-specific performance data related to the application of bag filters for abating emissions to air from handling and preparation of grain-based feed.
Table 3.7: Dust emission levels to air from handling and preparation of grain-based feed after treatment in a bag filter

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm$^3$)</th>
<th>$O_2$ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>308-12</td>
<td>0.50</td>
<td>NI</td>
<td>EN ISO 16911-1</td>
<td>Yearly</td>
<td>Compound feed. Bulk loading. Tubular filter. 20.40 % cereal grains as raw material.</td>
</tr>
<tr>
<td>309-14</td>
<td>0.50</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Pet food. Raw material unloading. 41.20 % cereal grains as raw material.</td>
</tr>
<tr>
<td>424-5</td>
<td>0.56</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Biennial</td>
<td>Compound feed. 22.00 % cereal grains as raw material.</td>
</tr>
<tr>
<td>309-3</td>
<td>1.00</td>
<td>20.9</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Pet food. Raw material unloading. 41.20 % cereal grains as raw material.</td>
</tr>
<tr>
<td>309-4</td>
<td>1.30</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Pet food. Raw material transportation. 41.20 % cereal grains as raw material.</td>
</tr>
<tr>
<td>306-9</td>
<td>1.30</td>
<td>20.9</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Compound feed. Raw material preparation. 59.04 % cereal grains as raw material.</td>
</tr>
<tr>
<td>309-5</td>
<td>1.20</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Compound feed. Milling process. 41.20 % cereal grains as raw material.</td>
</tr>
<tr>
<td>309-8</td>
<td>1.80</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Pet food. Milling process. 41.20 % cereal grains as raw material.</td>
</tr>
<tr>
<td>217-6</td>
<td>1.84</td>
<td>20.9</td>
<td>NI</td>
<td>Yearly</td>
<td>Compound feed. Discharging. 72.00 % cereal grains as raw material.</td>
</tr>
<tr>
<td>308-4</td>
<td>3.40</td>
<td>NI</td>
<td>EN ISO 16911-1</td>
<td>Yearly</td>
<td>Compound feed. Pneumatic transport. Tubular filter. 20.40 % cereal grains as raw material.</td>
</tr>
<tr>
<td>217-1</td>
<td>7.00</td>
<td>20.90</td>
<td>NI</td>
<td>Yearly</td>
<td>Compound feed. Milling process. 72.00 % cereal grains as raw material.</td>
</tr>
<tr>
<td>246-7</td>
<td>18.80</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Compound feed. Mill/Grinder. 67.00 % cereal grains as raw material.</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.

Source: [193, TWG 2015]
3.4.2.2  Cyclone

The technique is generally described in Section 2.3.7.2.3.

Environmental performance and operational data
At one emission point (#363-6), cyclones are used as an end-of-pipe abatement technique for dust emissions from unloading of raw materials. Low concentrations levels (< 1 mg/Nm³) have been reported for two measurements. The reference O₂ level was 20.95 % and the measurement method EN 13284-1.

3.4.2.3  Techniques to reduce dust emissions from extrusion (compound feed)

3.4.2.3.1  Bag filter

The technique is generally described in Section 2.3.7.2.2.

Environmental performance and operational data
Table 3.8 shows some installation-specific performance data related to the application of bag filters for abating emissions to air from extrusion (in compound feed manufacture).

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>O₂ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>246-2</td>
<td>0.12</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
</tr>
<tr>
<td>246-3</td>
<td>0.19</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
</tr>
<tr>
<td>424-1</td>
<td>0.39</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Biennial</td>
</tr>
<tr>
<td>424-3</td>
<td>0.59</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Biennial</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.
Source: [193, TWG 2015]

Economics
The investment in a bag filter is about EUR 100 000 to treat 20 000 m³/h of air. In addition, this technique needs the use of additional electricity and compressed air [247, Copa-Cogeca 2016].

Reference literature
[193, TWG 2015], [247, Copa-Cogeca 2016]

2.4.2.3.2  Cyclone

The technique is generally described in Section 2.3.7.2.3.

Environmental performance and operational data
Table 3.9 shows some installation-specific performance data related to the application of bag filters for abating emissions to air after extrusion (in compound feed manufacture).
Table 3.9: Dust emission levels to air from extrusion (compound feed manufacture) after treatment in a cyclone

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm$^3$)</th>
<th>$O_2$ content (%)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>308-9</td>
<td>0.50</td>
<td>NI</td>
<td>EN ISO 16911-1</td>
<td>Yearly</td>
</tr>
<tr>
<td>425-1</td>
<td>0.59</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
</tr>
<tr>
<td>042-3</td>
<td>0.79</td>
<td>21.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
</tr>
<tr>
<td>308-10</td>
<td>0.90</td>
<td>NI</td>
<td>EN ISO 16911-1</td>
<td>Yearly</td>
</tr>
<tr>
<td>308-8</td>
<td>1.00</td>
<td>NI</td>
<td>EN ISO 16911-1</td>
<td>Yearly</td>
</tr>
<tr>
<td>308-7</td>
<td>3.40</td>
<td>20.10</td>
<td>EN ISO 16911-1</td>
<td>Yearly</td>
</tr>
<tr>
<td>422-1</td>
<td>4.30</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
</tr>
<tr>
<td>306-1</td>
<td>6.70</td>
<td>20.10</td>
<td>EN 13284-1</td>
<td>Yearly</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.

Source: [193, TWG 2015]

At one emission point (#424-6), continuous measurement of dust is performed. For the year 2014, the daily average dust concentration was 2.01 mg/Nm$^3$ and the relevant 95th percentile value was 1.92 mg/Nm$^3$.

Reference literature
[193, TWG 2015]

3.4.2.3.3 Separator

The technique is generally described in Section 2.3.7.2.1.

Environmental performance and operational data
The application of a separator resulted in a dust emission level of 11.40 mg/Nm$^3$ in installation #423 (one measurement in 2014). The monitoring standard used was EN 13284-1.

Reference literature
[193, TWG 2015]

3.4.2.4 Techniques to reduce odour

TWG, please provide more information.

3.4.2.4.1 Non-thermal plasma treatment

A general description of the technique is given in Section 2.3.7.3.8.

Environmental performance and operational data
In a pet food processing facility (#309), a non-thermal plasma system has been installed for emission volumes ranging from 10,000 m$^3$/h up to 200,000 m$^3$/h. The system has the following main properties:

- cleaning efficiency: 75–95 %;
- modular capacity: 20,000 m$^3$/h;
- power consumption: 10–12 kW per module;
- small equipment footprint and weight for its capacity and compared to alternative technologies;
• low pressure drop (approximately 40–180 Pa);
• it can be installed on both the suction side and the pressure side;
• no consumables in operation;
• no effluent release;
• simple on/off operation;
• remote control and monitoring via modem/internet.

The system is cleaned every two weeks during the maintenance shutdown of the factory. The cleaning operation takes six hours (roughly six days/year).

Economics
A total cost of around EUR 700 000 has been reported (cost for five modules to handle 100 000 Ncm/h). Very low maintenance and operating costs.

Example plants
Used in pet food processing facilities. This technique has been reported in installation #309.

Reference literature
[193, TWG 2015]

3.4.2.4.2 Biofilter

A general description of the technique is given in Section 2.3.7.3.4.

Environmental performance and operational data
In a UK pet food installation (#416), biofilters using coconut fibres have been applied to retain particles that would normally be emitted into the atmosphere, causing large volumes of odorous gases to spread across the local area, impacting on residents and other bodies. The biofilters are fitted with low air suction to extract air and the air is then passed through the filter which absorbs the odorous particles. With the application of biofilters, a 90% reduction in complaints about odour has been achieved [193, TWG 2015].
3.5 Emerging techniques

TWG, please provide more information.
4 BREWING

4.1 General information about the sector

Figure 4.1 and Figure 4.2 depict the beer production and the beer consumption, respectively, in the EU-28 in 2014.

![Beer production in the EU-28 in 2014 (in 1 000 hl)](image)

Source: [208, The Brewers of Europe 2015]

Figure 4.1: Beer production in the EU-28 in 2014 (in 1 000 hl)
Figure 4.2: Beer consumption in the EU-28 in 2014 (in 1 000 hl)

The number of active breweries in the EU-28 in 2014 is shown in Figure 4.3.
Figure 4.3: Number of active breweries in the EU-28 in 2014

Source: [208, The Brewers of Europe 2015]
4.2 Applied processes and techniques

Beer is traditionally considered to include products such as lager, e.g. Pilsner malt and Munich malt, ale, porter and stout. It is an alcoholic drink derived from malted barley, with or without other unmalted cereal grains, and flavoured with hops. Sugar may also be added. There are three basic steps in the process; mashing, fermentation, and maturation/conditioning.

Mashing
Grains are normally received in bulk at breweries and transferred to silos. The malted barley is milled before use, the aim is to crush the endosperm with minimal damage to the husk. After milling, the ground materials or grist are mashed to produce a fermentable substrate for yeast fermentation. Additives may be used as a supplementary carbohydrate source, either to the mash kettle, e.g. maize grist or rice, or to the wort kettle, e.g. sucrose or glucose/maltose syrup. The grist is mixed with hot water to produce a thick slurry. The mix is then held for a sufficient period to allow the enzymes present in the malted barley to break down starch and proteins in the cereals.

Depending on the way in which the temperature is raised, mashing processes are classified into two types, i.e. infusion or decoction mashing. With infusion mashing, the entire mash is heated up, with appropriate rests until reaching the final mashing-off temperature. In decoction mashing, the temperature is increased by removing and boiling part of the mash. By returning it back to the remainder, the temperature of the total mash is increased to the next higher rest temperature. The vessel used for mashing is known as a mash tun. The wort is separated from the brewers grain by filtration in a mash filter or by straining. This is called lautering and takes place in lauter tuns. Once the so called first wort has run off the water is sprayed over the spent grist to extract as much wort as possible. After completion of the lautering, the leached brewers grains are discharged to silos and traditionally sold to farmers for use as cattle feed.

Fermentation
The wort is boiled for for 1 to 1.5 hours in the wort kettle with hops or hop extracts, releasing bitter substances that are dissolved. The wort is boiled with a boiling intensity of 5 to 8 % evaporation of casting volume per hour. A coarse coagulum of proteinaceous precipitated material is separated from the wort. This is known as the hot trub. Synthetic additives, based on polyester, result in a compact separation of the unpleasant, coarse, and bitter tasting hot trub.

The wort is clarified in a whirlpool to remove the hops and then cooled to the pitching temperature. The hot cooling water, of about 75 to 85 ºC, is collected and used as brewing water and for cleaning. It is possible to produce stronger wort than that corresponding to the original gravity of the final beer produced and it is possible later, before or after fermentation, to dilute it with water to the desired extract content. This is called high gravity brewing. Whether dilution is performed before or after fermentation depends, among other things, on local legislation. A further aim of wort boiling is the inactivation of all enzymes, sterilisation as well as concentration of the wort.

The clear hopped wort is aerated to encourage yeast propagation prior to fermentation and yeasts are added. The particular yeasts strains used are typical for beer production. Yeasts are divided into two major groups, i.e. top and bottom fermenting yeasts. Yeasts that tend to rise to the top of the fermentation vessel are typically used for ales and have a fermentation temperature of about 15 to 25 ºC. Yeasts which tend to settle to the bottom of the vessel toward the end of fermentation are typically used in lagers, where the fermentation is normally performed at 8 to 15 ºC. To maintain the desired fermentation temperature, the tanks are cooled. At the end of fermentation, the yeast is separated from the product. A part of it is used for another batch, and the remainder is disposed of or considered to be a co-product.
Maturation/conditioning

Lagers require conditioning by chilled storage for several weeks before clarification. The beer is generally clarified in a diatomaceous earth filter, e.g., kieselguhr. After carbonation, the beer may be subjected to a number of preservation processes, such as flash pasteurisation and aseptic filling, membrane separation or in-container pasteurisation.

Before bottling, the beer is filtered through a filter cake. Proven materials for this purpose are mud-free kieselguhr; calcined and screened diatomaceous earth of various particle size distribution; and perlite from ground and calcined glassy rock of volcanic origin. Activated carbon may be used to correct a mild off-taste. For example, it is usually used in the treatment of rest beers. Shortly before filtration, hydro- and xero-silica gels may be added to contribute to the build-up of the filter cake. Fining, by the addition of, e.g., cross-linked polyvinylpyrrolidone (PVP) and polyvinylpolypyrrolidone (PVPP) is carried out to clarify the beer and, e.g., reduce the polyphenol concentration.

Cleaning agents and disinfectants are also used.

An overview of the brewing production process is shown in Figure 4.4. In the following sections, individual production steps are analysed further.

Source: [209, The Brewers of Europe 2015]
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4.2.1 Wort production

4.2.1.1 Overview

Cereal raw materials are delivered to the brewery, weighed, conveyed, cleaned, stored and made available for wort production.

Depending on the location of the brewery, the malt is delivered to the brewery by truck, rail or boat, and is stored in silos with mechanical or pneumatic conveyors. The quantity of malt grains needed for the next brew is cleaned (dust and rock removal) and then dry-milled or wet-milled [230, Germany 2013].

After the milling of the malt and preliminary treatment of the adjuncts to facilitate the extraction, the malt (and adjuncts, if within the recipe formulation) is mixed with brewing water to form a mash. Adjuncts are a supplementary carbohydrate supply added either to the mash kettle as starch (e.g. maize grits or rice) or alternatively to the wort kettle as sucrose or glucose/maltose syrup. The mash is usually heated following a preset time-temperature programme, in order to convert and dissolve substances from the malt and the adjuncts in the brewing water.

Extraction is accomplished through a combination of simple dissolution and the activity of naturally present enzymes formed during malting. The substances dissolved in the water are collectively called the extract. The solution of extract and water is called the wort.

When the mashing is completed, the insoluble solids, called the brewers’ grains (sometimes referred to as spent grain), are separated from the wort by straining. Brewers’ grains are a valuable co-product and not waste. Traditionally, brewers’ grains may be used as cattle feed. Alternative uses of the brewers’ grains may be heat production or biofuel production. The wort is boiled with hops and hop extracts, releasing bitter substances and oils, which are dissolved in the wort. During boiling, a precipitate consisting mainly of proteins is obtained (the trub) and the bitter substances are isomerised which increases their solubility. After separation of the trub, the finished wort is cooled to approximately 8–20 °C depending on the yeast strain in question and the fermentation process chosen. The cooled wort is hereafter transferred to the fermentation area [209, The Brewers of Europe 2015].

The choice of mashing methods greatly influences the energy consumption in the brewhouse or brewery. Even if, for example, the infusion mashing method consumes less energy than a decoction method, a brewery may choose the method with lower energy efficiency for quality reasons and/or in order to maintain the special character of the beer [230, Germany 2013].

The wort production process is depicted in Figure 4.5.

4.2.1.2 Raw materials handling

The malt reception department precedes the brewing process and essentially handles the cleaning and storage of the required amount of malt. The malt reception department is subdivided into several sections. The first section consists of the unloading of the bulk product, its conveyance and cleaning with subsequent storage in silos. In the second section, the malt is conveyed from the storage silos, cleaned, and, after dry milling, stored in process-specific grist cases. The individual steps involved result in the production of malt fines (dust) due to abrasion,
which are expelled and separated in filter systems. Extra machinery usually includes a stone
remover and magnets to protect the mills and also preserve the quality of brewers’ grain co-
products for their likely use in the animal food chain.

4.2.1.3 Milling

In order to obtain as high as possible a yield of extracted substances as quickly and as efficiently
as possible, the malt is first crushed before being mixed with hot water. Two major types of
milling systems are distinguished. These are wet milling, possibly with conditioning, and dry
milling which may also comprise conditioning. In the conditioning process, the malt is hydrated
by cold or hot water or by steam. As a result, the husks are made more pliable and they are left
almost intact. In these processes there will be a consequent loss of water and/or energy. When
dry milling is applied, the whole grain, including the husk, is crushed. The type of dry milling
determines how fine the grits are that are being produced and to what degree the husk is
damaged. The dry grist is usually placed in intermediate storage in grist cases before it is added
to the mash kettle. In contrast, the grist from wet milling goes directly into the mash kettle. Dry
milling may result in a release of dust. This is both a health and fire hazard [209, The Brewers
of Europe 2015].

4.2.1.4 Mashing

4.2.1.4.1 Malt mash

The purpose of mashing is to obtain a high yield of extract (of the highest possible quality) from
the malt grist and adjuncts by extraction in the brewing water. During mashing, the proteins,
starches and some other organic materials are broken down by enzymes naturally formed in the
grain during malting. The enzymatic reactions require careful control of temperature. Indeed,
sometimes reaction periods at different temperatures (least warm first) are required. This can be
achieved by intermittently warming the mash (most commonly with steam) or a decoction
process in which part of the mash is removed, raised to boiling or near-boiling temperatures and
returned to the bulk. However, it is notable that in most processes the bulked temperature of the
wort after mashing and mash filtration is typically approximately 70 °C. It is also noteworthy
that heat for the mashing liquor (water) is often recovered heat from the cooling prior to
fermentation.

4.2.1.4.2 Adjunct mash

Adjuncts are usually not pre-germinated and do not contribute significantly to the enzyme
activity in the mash. Among others, adjuncts may include maize, rice or unmalted barley.
Furthermore, their starch usually has a higher gelatinisation temperature than malt starch. The
adjunct is, therefore, mixed with water and cooked separately from the main mash at increased
and specific temperatures. The adjunct mash is then mixed with the malt mash and the malt
enzymes break down the adjunct starch. In some cases, the addition of special enzymes may be
necessary (e.g. endo-β-glucanase or proteases). It should be noted that in some cases these are
employed in the main mash.

4.2.1.5 Mash filtration

During mashing, substances in the malt and adjuncts are broken down and dissolved in the
brewing water. In addition to the soluble material (carbohydrates and protein compounds of
various complexities), the mash also contains insoluble material (brewers’ grains). The wort is
separated from the brewers’ grains by straining (filtration). This takes place in a lauter tun, mash
filter or mash tun. Once the so-called first wort has run off, the remaining brewers’ grains are leached out with sparging water.

4.2.1.6 Wort boiling

Following removal of the brewers’ grains, the wort may then be pumped into a pre-run tank, which merely serves as a buffer, and from there into the wort kettle.

The wort is heated to boiling point in the wort kettle and the hops are added. The wort is normally boiled for 0.5–1.5 h with 3–8% evaporation per hour of volume of wort cast. This has several crucial and beneficial implications for the wort and beer quality.

Energy supply is most commonly by steam but alternatives include thermal oils, pressurised hot water, electricity and burners. Sucrose and glucose/maltose syrups may also be used as adjuncts. Since no enzymatic breakdown is required, these adjuncts are added to the wort kettle in which dissolution and dispersion are fully achieved.

4.2.1.7 Separation and cooling of trub

The wort should be clear and free of particles (hop residues and heat-precipitated proteins, the so-called hot trub) before entering the fermentation vessel. The equipment most commonly used for wort clarification is the whirlpool in which the wort and trub particles are injected in a tangential direction. Secondary forces on the particles cause them to migrate and accumulate in a cone at the centre of the bottom of the vessel. Alternatives include a filtration process in a hop back or a decanter centrifuge.

After clarification, the wort is cooled to the so-called pitching temperature. This temperature depends on the type of yeast used and the fermentation process chosen. Cooling normally takes place in a heat exchanger, the so-called wort cooler. The hot water (75–85 °C) produced is collected and used as brewing water (most likely) or for cleaning for example.

4.2.1.8 High-gravity brewing

It is possible to produce stronger wort than that corresponding to the original gravity of the final beer produced by diluting it, before or mostly after fermentation, with carbonated and de-aerated water to the desired extract content.

The result is a considerable increase in the brewhouse and cellar capacity. This links in the planning stage with lower capital expenses, less space requirements, smaller diameter pipework, and to a more efficient use of existing installations. The main benefit, however, is the large energy and water saving as the water to be used later in a cold state for dilution does not have to be heated and subsequently cooled with the wort. Less pipework and fewer vessels result furthermore in smaller CIP volumes and water amounts being necessary.

4.2.2 Fermentation / Beer processing area

4.2.2.1 Overview

The cold wort is aerated and pitched, meaning that yeast is added, most commonly as a slurry of a defined consistency. Oxygen (air) is necessary to support development of the yeast to a state and amount capable of fermenting the wort efficiently. The import or production of compressed air or oxygen has a small environmental impact at this stage, although compressed air to operate air valves may be a relevant resource when moving the product. The so-called main
fermentation is an anaerobic process; the yeast metabolises the fermentable carbohydrates in the wort, forming alcohol and carbon dioxide. A large number of other compounds, such as higher alcohols, esters, aldehydes, organic acids, etc., influencing the aroma and taste of the beer, are also produced, while others are degraded by the yeast.

When this main fermentation is completed and the yeast has been cropped (harvested), the green beer matures most commonly but not always, at lower temperatures. At this stage, the yeast decomposes or reabsorbs certain undesirable constituents of the green beer, the beer is enriched with carbon dioxide, the residual extract is fermented and yeast and other particulates settle out of suspension. However, the fine clarity expected by the consumer from most beer types is still missing. This is achieved by filtering the beer. Kieselguhr is used as a filtration aid in most cases. During filtering, yeast cells still contained in the beer and other substances causing turbidity and most bacteria that may cause the beer to spoil are removed. The filtered beer is pumped to the so-called bright beer tanks [209, The Brewers of Europe 2015].

Figure 4.6 depicts the fermentation and beer processing steps.

![Figure 4.6: Fermentation / Beer processing](image)

Source: [209, The Brewers of Europe 2015]

**4.2.2.2 Fermentation**

The breakdown of simple sugars into alcohol is normally referred to as alcoholic fermentation. Yeasts, usually *Saccharomyces* sp, e.g. cerevisae or bayanus, are used to produce ethanol from carbohydrates and very small amounts of other organic compounds. This conversion can be represented by the following equation:

\[
C_{6}H_{12}O_{6} = 2C_{2}H_{5}OH + 2CO_{2}
\]

This is an anaerobic process, i.e. it does not require the presence of oxygen. The temperature of fermentation is usually in the range of 8 to 30 °C. The temperature affects the rate of fermentation, the efficiency of conversion and the flavour and the aroma of the finished product. The pH may also be adjusted. This ensures that the fermentation is efficient and produces the required flavour. The type of yeast species used affects the rate, efficiency, flavour and aroma and is, therefore carefully selected to give the desired results. Selected strains of yeasts are often used to optimise the alcohol yield and the production of aromatics as secondary components. Nitrogen, vitamins and trace elements are usually added as yeast nutrients.

In the early stages of fermentation, there is separation of the cold break, consisting mainly of protein formed during cooling of the wort. The separation is often performed by simple sedimentation in the fermentation vessel, but may also be achieved by flotation, centrifugation or filtration.

During the subsequent pitching phase, sterile air or O₂ is injected into the clarified wort and the yeast is added. Aeration is used to ensure that the yeast is supplied with an adequate amount of oxygen in order to support cell multiplication. Later on, the metabolism of the yeast changes from respiration to alcoholic fermentation; it then processes the carbohydrate molecules contained in the wort to produce ethanol, carbon dioxide and, to a lesser extent, other compounds that affect the character and quality of the beer.
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Fermentations are exothermic biochemical reactions and so heat is generated. To maintain the desired fermentation temperature, the fermentation tanks are cooled. Refrigerants used for indirect cooling (secondary refrigeration) are alcohol/water, glycol, ice-water or brine. The refrigerant for direct cooling (primary refrigeration) is usually ammonia.

Fermentation usually takes place in horizontal tanks or cylindro-conical tanks, which may be installed indoors or outdoors. The CO₂ produced during the fermentation process may be collected by a CO₂ recovery system. This will be reusable in the beer, brewing process or other products.

Once fermentation has taken place, the yeast is cropped (or harvested) and pumped to the yeast storage tanks. During the fermentation, yeast is produced in excess. A part of this yeast is usually reused for a new batch of wort, the remainder being disposed of (it has a high demand in terms of effluent disposal if that is the route) or treated as a by-product. The production yeast may be reused several times, but should be replaced due to contamination, decreasing vitality and viability.

The fermentation area has a high demand for cleaning resources. At the end of fermentation, there is a lot of soil in the vessels. Carbon dioxide needs to be displaced from the vessel or else it reacts with caustic detergents, reducing efficiency (acid detergents are an alternative). Prior to use, the fermenter vessel and associated process equipment need to be disinfected.

4.2.2.3 Yeast handling

The yeast treatment may involve the following functions:

- yeast propagation, i.e. production of new yeast, which requires process equipment and intensive cleaning;
- pitching of yeast to wort;
- inline cooling at yeast cropping via a heat exchanger;
- cleaning of yeast at cropping using a yeast sieve (optional);
- cleaning of yeast using acid washing;
- cold storage of production yeast;
- storage and discharge of surplus yeast; the surplus yeast from fermentation or tank sediment from storage is sold to companies for further processing or may be used as animal feed;
- beer (or alcohol) recovery from surplus yeast, which may entail filtration, centrifugation, sedimentation or distillation.

4.2.2.4 Maturation and storage

After fermentation, further processes are required to produce commercial quality beer. Further (secondary) fermentation (maturation) is required to remove certain off-flavours and to improve the quality of the product. Cold storage is usually then employed. This causes precipitation of particles that would otherwise form slowly in the packaging and cause the consumer to receive cloudy beer. Maturation is most rapidly performed at temperatures slightly higher than those employed in the primary fermentation. The product is rapidly put into cold storage, below 0 °C (enabled by the anti-freeze effect of alcohol and other solutes) and is usually regarded as requiring at least three days.

A clarification and stabilisation effect by enhanced precipitation may be caused by the use of finings (e.g. isinglass or wood chips). The purified form of isinglass is produced from the swim bladder of certain species of fish. It consists of 70% of the protein molecule collagen and is normally injected into the cask or occasionally dosed at the end of fermentation. Since the
molecular structure of collagen consists of positively and negatively charged areas, it is able to bind proteins and yeast cells (which possess negatively charged cell walls).

Fining is the process of clarifying liquids, i.e. removing suspended particles which give the liquid a cloudy appearance. The fining agent introduced causes the minute hazy particles to flocculate and precipitate out of solution. These particles are proteins, polysides, polyphenols, ferrous or cupreous complexes. For the fining action to take place, the electrical charges between the fining agent and the particles should be opposed, which means that it is necessary to carefully choose the fining agent depending on the effect sought. The nature and the dose of the fining agent can be determined by laboratory tests. Moreover, some other treatments can be technically classed as examples of the fining process, such as iron elimination with potassium ferrocyanide.

The fining agents used can be divided into two major groups; organic and mineral fining agents. Some organic fining agents are gelatine, ichthyocola, egg albumin, blood albumin, algein, caseins and caseinates. Some mineral fining agents are bentonites, silica gel and oenological tannins.

The beer may be chilled prior to filtration (also known as secondary cooling).

### 4.2.2.5 Filtration and stabilisation

The purpose of the filtration is to obtain a specified level of clarity and to enhance shelf life. Filtration commonly takes place in a kieselguhr (diatomaceous earth) filter using various systems such as frame, candle or mesh filters. Diatomaceous earth performs the filtration with the filter itself acting as a support for the filter cake. To prevent clogging of the filter and to achieve extended filter runs, kieselguhr is continuously dosed into the unfiltered beer as body feed, thereby constantly building up the depth of the filter cake.

At a few sites, the used kieselguhr is regenerated and reused. The regeneration process includes inter alia thermal and caustic washing procedures as well as enzymatic treatment. However, the process is expensive and the economic benefits are marginal. Also, the recycling processes result in damage to the kieselguhr so that discharge of spent kieselguhr is not completely eliminated. Spent kieselguhr may be used as a soil improver or fertiliser. Alternatively, it may be used in building materials and it may also be reprocessed. Used filter sheets may be reused, e.g. in the paper industry.

Methods to filter beer without kieselguhr are becoming more widespread. The use of kieselguhr-free filter aids (e.g. polymer-based filter aids, cellulose, perlites) and alternative filter strategies is possible.

In most cases, filtration is accompanied by stabilisation. Stabilisation is used to selectively remove beer colloids by means of adsorption, e.g. using silica gel and/or PVPP (polyvinylpolypyrrolidone), in order to counteract the beer’s tendency to become turbid after filling. Other possibilities to stabilise are ion exchange, tannic acid or enzymatic stabilisation. Another possibility (in the case of PVPP stabilisation) is to install an additional regenerative PVPP filter system in combination with the kieselguhr filtration. Regeneration hugely reduces the wastage of PVPP powder, although considerable resources are required in terms of equipment and energy and water for the hot caustic regeneration medium.

To act as a polishing filter after the kieselguhr filter, a cartridge filter or sheet filter may be installed. For polishing and sterilising filtration, several filter systems, e.g. sheet filters, module filters, cartridge filters and membrane filters, may be used. As an alternative to the sterile filter, the beer may be thermally treated (flash or tunnel pasteurisation) to increase its microbiological stability. Heat may be recycled in the pasteurisation process.
4.2.3 Beer packaging

For general information about packing and filling see Section 2.1.4.1.

4.2.3.1 Overview

From the bright beer tanks, the beer is pumped to the packaging area where most beer is bottled, canned or kegged.

During this final operation, it is important that:

- the beer is prevented from coming into contact with oxygen;
- no carbon dioxide is lost as the beer was carbonated to certain specifications during its processing;
- microbiological contamination of the product is prevented; this may require treatment of the available water and certainly requires an intense cleaning effort: new methods are emerging in the sector, for example physical treatments of surfaces with ionised air;
- the packaging is marked to obey local legal requirements concerning traceability and other laws, e.g. concerning customer information.

Packaging lines may be equipped quite differently, not only with respect to packaging material but also with respect to the level of automation and inspection. Typically, consumption of energy and water and the machinery requirements are very significant. Returnable bottles require thorough cleaning. The bottle washer consumes large quantities of energy, water and caustic. Furthermore, substantial quantities of waste water are discharged. The use of non-returnable packaging material reduces the consumption of energy, water and caustic on site, therefore reducing waste water generation.

In packaging lines using non-returnable bottles and cans, the bottles/cans are only flushed with water before filling. Alternatively, compressed air is used to blow out any solid particles. Non-returnable bottles are a loss to the brewing company but in some cases reclaiming returnable bottles is logistically very difficult. The glass in non-returnable bottles is readily recyclable if the regional infrastructure is in place. If kegs are used, they are cleaned and sterilised with steam before filling.

Packaging lines can be noisy, in particular those for glass bottles and kegs. In some cases, the brewery surroundings may mean that careful soundproofing of the packaging block is required.

4.2.3.2 Returnable bottles

Figure 4.7 shows a typical returnable bottles line. The individual steps are analysed below.

Before being filled with beer, the returned bottles are conveyed to a bottle washer that cleans the bottles both inside and outside. Impurities may be present inside the bottle, including residual
beer, mould, cigarette butts, organic solvents, etc. Outside impurities may include labels, aluminium foil and dust particles.

Bottle washing consists of soaking in caustic solution, rinsing, sterilisation and re-rinsing. To improve the cleaning effect, surfactants, sequestrants and similar agents are added to the cleaning solution. In order to guarantee the hygienic condition of the bottles, disinfectants may be added in the rinsing zones of the bottle-cleaning machine. Alternatively, high temperatures may be used.

In addition to filling bottles, the most important function of the filling machine is to prevent oxygen coming into contact with the beer. The bottles are evacuated and counter-pressurised with CO₂ (usually twice) before the actual filling with beer. Bottles are not infinitely reusable and so there will be some attrition, but failed bottles may be recycled.

If the beer has not been sterile-filtered, the beer may be pasteurised to prolong shelf life. Pasteurisation guarantees practically unlimited biological stability. Two different methods are used for the pasteurisation:

- tunnel pasteurisation, during which the beer is pasteurised in bottles (or cans);
- flash pasteurisation, employing a heat exchanger in which the beer is pasteurised before it is poured into bottles (or kegs).

The bottles are packed in crates, cartons or other forms of transport packaging and palletised. Plastic crates are reusable if they are not lost in the distribution chain. Cardboard is recyclable. The crates are washed with water and inspected for damages, colour runs, abraded logos, and so on. Sound and correct crates are sent to the packaging machine.

### 4.2.3.3 Non-returnable bottles

A typical non-returnable bottles line is depicted in Figure 4.8.

![Figure 4.8: Non-returnable bottles line](Source: [209, The Brewers of Europe 2015])

For packaging lines using non-returnable bottles, the phases are the same as described for the returnable bottles from the filling of the bottles and onwards. However, the first steps are different for non-returnable bottles as the bottles are not delivered in crates, washed and sorted. Instead, the activities described below, which are similar to the ones for cans, take place.

Non-returnable bottles are delivered on pallets from the glassworks. The bottles are pushed off the pallets in layers onto a reception table / conveyor chain. When a layer has been deposited, the spacer packaging is removed and returned to the manufacturer.

The bottles arrive clean from the glassworks but dust may have contaminated the bottles during transport. Therefore the bottles are rinsed before filling, either by spraying with water or the solids are blown out with compressed air. For rinsing, the bottles are turned so that their openings face downwards and they are then turned upright again before filling.
4.2.3.4 Cans

Cans are necessarily non-reusable, although recycling rates may be very high depending on the facilities in the geographical region. Recycling the metal saves a lot of energy by reducing the need for mining and extracting the aluminium or steel. A typical cans packaging line is presented in Figure 4.9.

![Cans line](source: [209, The Brewers of Europe 2015])

Figure 4.9: Cans line

Cans are supplied in bulk as so-called tall packs. The cans are pushed off the pallet in layers onto a conveyor chain. When a layer has been deposited, the spacer packaging is removed and returned to the manufacturer. The cans generally arrive clean from the manufacturer, but dust may have contaminated the cans during transport. Therefore the cans are rinsed before filling, either by spraying with water or the solids are blown out with compressed air. For rinsing, the cans are turned so that their openings face downwards and they are then turned the right way up again before filling.

The cans are sealed with lids immediately after filling and the filling height is checked. Sealing of cans is a two-step operation (pressing first with a pre-roller and secondly with a seaming roller) that needs to be performed exactly right to prevent pressure loss and thus beer spoilage. The cans may then be pasteurised. The cans are packaged into various types of pack including cardboard (recyclable) and plastic.

4.2.3.5 Kegs

A typical kegs packaging line is shown in Figure 4.10.

![Kegs line](source: [209, The Brewers of Europe 2015])

Figure 4.10: Kegs line

Pre-soaking, cleaning and rinsing clean the outside of the keg. The cleaning solution is recirculated. Internal cleaning and filling of kegs is performed in many stages in one or more filling aisles. First, the kegs are cleaned with water and caustic and sterilised with steam. Afterwards, the kegs are pressurised and often filled with flash pasteurised beer. Before discharge, the head is rinsed. Weighing of the kegs controls the filling volume. Protective plastic caps are put on the fittings. These are most likely not recycled from the distribution chain.

4.2.3.6 Plastic bottles

As an alternative to single-use and refillable glass bottles, different solutions for plastic bottles have emerged. Materials like PET are available to be used in beer packaging. The filling lines for these packages need a few changes compared to glass bottles, such as specific transportation for the empties, or blow-moulding machines if the bottles are to be produced on site.
For non-refillable PET bottles, recycling systems are available which may include bottle-to-bottle recycling. It is simpler to recycle to non-food-grade applications such as strapping.

### 4.2.3.7 Warehouse

Packed beer is stored in the warehouse. It is important to store bottled beer inside as sunlight affects the beer quality. Bottles are also protected against artificial light. Warehouses for glass bottles situated in a cold climate should be heated in order to prevent possible bottle breakage due to freezing.

### 4.2.4 Non-alcoholic beer production

The legal definitions of alcohol-free beer vary from country to country. For instance, this type of beer contains a maximum alcohol level of 0.5% in England, Germany and the Netherlands; 1 vol-% in Spain; and no detectable amount, i.e. less than 0.05 wt-%, in the US. The alcohol concentration of ≤ 0.05 wt-% is below the usual analytical detection limits.

There are several methods applicable for the production of non-alcoholic beers. These methods can be divided into four main categories: fermentation-free brewing, dilution, alcohol removal/dealcoholisation, and restricted alcohol fermentation. These methods are described in the following sections [211, Rezaei et al. 2010].

#### 4.2.4.1 Fermentation-free brewing

In fermentation-free brewing, no yeast is added to the wort. In other words, the fermentation stage is eliminated. However, the expected sensory characteristics of the final product are improved by using different additives. Achieving the microbalance among beer components, especially flavour compounds, is difficult and will result in a beer that has a dull flavour. Nevertheless, the method is easier to perform and more economical than other non-alcoholic procedures.

#### 4.2.4.2 Dilution

In this method, wort is initially produced with a dry matter content of several times more than the expected concentration. After separation of the yeast cells, dilution is carried out using pure potable water (demineralised and deoxygenised) up to the determined solids and alcohol concentration. The pH is then adjusted by adding organic acids (such as lactic acid). This is followed by a carbonation stage. This procedure takes advantage of the reduced fermentation time and a higher available capacity of the fermenter, resulting in a lower production cost. The dilution procedure can also be accomplished by using chilled carbonated water. The dilution method can also be performed by blending the dealcoholised beer with normal beer.

#### 4.2.4.3 Alcohol removal (dealcoholisation)

Alcohol removal (dealcoholisation) is a process in which the alcohol produced during the fermentation is removed from the beer by different methods in accordance with the standards of low-/free-alcohol beer. The alcohol removal process can include heat- and membrane-based processes, as described below.
4.2.4.3.1 Vacuum distillation

Vacuum distillation consists of two stages: evaporation under high vacuum (vacuum evaporation) and then cold condensation (e.g. 38–48 °C / 0.06–0.1 bar). This practice is also known as low-temperature/low-pressure distillation. Dealcoholisation can also be performed by distillation of the beer under vacuum, in which an ordinary beer, previously pasteurised, is degassed at a pressure of about 1 bar (with recovery of the foam and the flavour compounds) and then dealcoholised by means of a vacuum evaporator (0.05–0.12 bar), at a temperature between 30 °C and 50 °C.

The method generally suffers from the limitations that it also removes (to some extent) other volatile components such as flavour and fragrance compounds and dissolved gases such as carbon dioxide and sulphur dioxide, which are important for sensory characteristics, controlling the acidity of the beverage and for their bacteriostatic effects on destructive microorganisms.

4.2.4.3.2 Water vapour/Gas stripping under vacuum

Stripping is a practice in which water vapour or a neutral gas (nitrogen or carbon dioxide) is passed through the wort under vacuum in order to carry away ethanol from the bulk. This method is also called gaseous entrainment or the alcohol desorption method. At the end of fermentation, sudden stripping of the carbon dioxide that is produced during fermentation leads to the removal of alcohol from the beer. This is why a high pressure difference between the inside of the reactor and outside environment (about 1 bar) is required.

4.2.4.3.3 Dialysis

This process operates at low temperature and uses the selectivity of a semi-permeable membrane. Small molecules pass through the membrane into the dialysis medium. Then the medium flows to a vacuum distillation column, where the alcohol is continuously removed, and the stream of alcohol-free dialysis liquor returned to the dialysis unit. The final product may contain as little as 0.5 % alcohol.

4.2.4.3.4 Reverse osmosis

In this method, fermented wort is passed through a semipermeable membrane under high-pressure conditions. The membrane is permeable to water, alcohol and other materials that have small molecules. Large molecules including flavour agents are rejected and remain in the concentrated beer. Production of non-alcoholic beer with alcohol contents < 0.5 vol-% is possible with reverse osmosis. Addition of water is recommended for facilitating the removal of ethanol. In order to retain heat sensitive substances and to increase the rejection coefficient of volatile compounds, the temperature should be low (about 5 °C).

However, dealkoholisation of beverages by reverse osmosis removes not only volatile low molecular weight components such as water, alcohol, flavour and fragrance components, and dissolved gases such as carbon dioxide and sulphur dioxide, but it may also remove certain low molecular weight, nonvolatile, non-ionic solutes such as organic acids and simple sugars. Moreover, the current practice involves dilution of the reverse osmosis concentrate or retentate with pure water to replace the water that is removed in the permeate. This will result in undesirable changes in quality parameters such as flavour, fragrance, colour, acidity and stability. Restoration of these depleted components by their readdition to the concentrate in proper proportions to produce a high-quality product is generally difficult and costly.
4.2.4.4 **Restricted alcohol fermentation**

Restricted fermentation is a method in which the production of alcohol during the production process is reduced in the early stages of fermentation. This is achieved either using yeast that can only partially ferment the wort or by repressing or interrupting fermentation by applying different compositional and/or process procedures (interrupted fermentation technique). In other words, restricted fermentation methodology consists of using yeasts under conditions in which they are not physiologically capable of producing an alcoholic fermentation but can excrete metabolites that help to impart a beer-like taste to the solution.

Restricted fermentation processing can be classified into two subclasses, namely suspended batch and continuous immobilised processes. In the batch-type process, yeast cells are in a suspended state in the wort during the fermentation. In this procedure, it is difficult to keep the process parameters such as temperature and concentration of dissolved oxygen at precisely the desired values (at equilibrium). Even a minor deviation from the desired values may result in the formation of alcohol at a higher level than that allowed in the final product (e.g. 0.05 %). In the production of alcohol-free beer, immobilisation of yeast cells has also been practised. The immobilisation technique with the microporous sintered glass system has been successfully employed for the production of alcohol-free beer. This method provides the advantages of high controllability, flexibility, and a high biomass concentration and allows short contact times compared to the batch method. As an alternative procedure in this practice, firstly, the beer with a definite amount of alcohol is produced in a short time. Then, after 2–4 hours of flavour ageing, dilution of the beer is carried out with cooled carbonated water to achieve the desired alcohol content.

4.2.5 **Bottle cleaning**

Within the bottling department, the bottle cleaning machine is the biggest consumer of fresh water, and therefore also the source of most of the waste water.

A reduction in water consumption can be achieved by a combination of different methods for the different zones of the cleaning machine. The various process steps are grouped in a single system. The basic formula for calculating the amount of cleaning process needed is:

\[
\text{Cleaning} = \text{temperature} \times \text{time} \times \text{concentration} \times \text{mechanical force}
\]

Where:
- concentration = content of chemicals
- mechanical force = strength of mechanical cleaning, e.g. of spray nozzles.

These parameters are determined, to some extent, by the design of the cleaning machine. Other quantities such as the type and concentration of the chemicals, additives and surfactants used are optimised in co-operation with the chemicals supplier. This cleaning process, which takes place primarily in the soaking zone and the caustic bath, results in clean germ-free bottles. The interaction of chemical, thermal and mechanical effects ensures that the bottles are cleaned within a certain time.

The bottle cleaning process is shown schematically in Figure 4.12. The bottles pass through the individual zones of the bottle cleaning machine in the order shown in Figure 4.11.
Figure 4.11: Bottle cleaning and rinsing steps

Figure 4.12: A bottle cleaning process with pH control to reduce water consumption
In the caustic bath, the glass bottles are cleaned using approximately 1.8% caustic soda solution. The alkali, chemicals and small dirt particles remaining in the bottles leaving the caustic bath, then have to be washed away during the subsequent cleaning zones. The dirt particles entrained from the caustic bath can be rinsed off without difficulty in the first spray zones. It is considerably more difficult to remove any alkalinity carried into the first hot water zone (tank 1) with the bottles. As the bottles leave the main bath, they are still wet with this cleaning solution, resulting in liquor entrainment [35, Germany 2002].

The pH of the first basin after the main caustic bath is originally between 10 and 11. This high pH favours deposition of lime and magnesium salts, i.e. removal of scale, when hard drinking water is used. Neutralisation of the water may reduce scaling considerably.

Moreover, to save caustic soda and fresh water and to avoid unnecessary waste water loads, the contents of the bottle cleaning bath are settled and filtered at the end of the production period. The cleaning solution is pumped from the bottle cleaning equipment to a sedimentation tank using electrical energy. This tank also serves as a temporary storage unit. The settled particles are drawn off with a filtration unit that also requires the input of electrical energy for pumping. The water is then available again to be used for cleaning at the beginning of the next production period [35, Germany 2002].

**Waste water treatment**

During primary treatment, neutralisation (see Section 2.3.6.1.4) is essential. The dosing capacity of the neutralisation plant will depend on the operation of the brewery, especially the design and operation of the discharge of the caustic baths in the bottle washers and CIP tanks. Other alternatives are using flue gases from the boiler plant or surplus CO₂ from the fermentation to neutralise caustic in CIP plants or overflow from bottle cleaning facilities. The equipment can be a scrubber or a simpler system with venting of the gas to a sump.

Secondary treatment can include aerobic (see Section 2.3.6.2.1) and/or anaerobic (see Section 2.3.6.2.2) processes. The most common aerobic method applied for brewery waste water treatment is the activated sludge process (see Section 2.3.6.2.1.1). Nevertheless, using an anaerobic process gives the advantage that less (or no) nutrient is needed for nutrient deficient brewery waste water. The most commonly used anaerobic techniques are the UASB (see Section 2.3.6.2.2.4) and the UGSB (see Section 2.3.6.2.2.7) reactors.

The excess sludge can be a significant part of the breweries’ solid waste generation and is disposed of. The use of sludge in land application has been reported (see Section).

If waste water requirements are more stringent than a BOD of 15 mg/l and an TSS of 20–30 mg/l, tertiary treatment is necessary (see Section 2.3.6.3).
4.3 Current consumption and emission levels

Beer is a fermented drink with a relatively low alcohol content made from various types of malt and grain. Malted barley predominates but malted wheat, maize or other grains, or sugar and syrups may also be used. Although there are installations where malt is also produced at the same premises, consumption and emission levels for malt production are reported in Section 0.

Breweries use significant amounts of water and energy and produce waste water and solid residues, by-products and waste. As an indicative example, Figure 4.13 shows the typical consumption and emission levels for German breweries. Note that capacity/output of breweries is usually expressed in hectolitres (hl) of beer sold.

![Image of input and output figures for large German breweries](source: [35, Germany 2002].)

**Figure 4.13: Input and output figures for large German breweries (capacity over 1 million hl beer) per hl of beer sold.**

### 4.3.1 Energy consumption

Energy is supplied to breweries in the form of oil, gas, coal, steam, hot water and electricity. Heat is normally distributed in the brewery as steam or hot water. The actual heat consumption of a brewery depends on the process and production characteristics such as the packaging method, pasteurising technique, type of equipment, and by-product treatment. The main heat-consuming processes in a brewery are: mashing, wort boiling, generation of hot liquor, CIP/disinfection, bottle and keg washing, pasteurising and room heating (in cold climates) ([72, Brewers Europe 2002]). The largest single heat consumer will normally be the wort kettle. Heat consumption for some departments is given in Table 4.1.
Table 4.1: Heat consumption for different brewery processes

<table>
<thead>
<tr>
<th>Department/process</th>
<th>Minimum (MJ/hl beer)</th>
<th>Mean (MJ/hl beer)</th>
<th>Maximum (MJ/hl beer)</th>
<th>Literature (1)</th>
<th>Measured (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brewhouse</td>
<td>87</td>
<td>92</td>
<td>121</td>
<td>84–113</td>
<td>50–80</td>
</tr>
<tr>
<td>Bottling installation</td>
<td>58</td>
<td>86</td>
<td>94</td>
<td>25–46</td>
<td>38–58</td>
</tr>
<tr>
<td>Kegging installation</td>
<td>8</td>
<td>11</td>
<td>13</td>
<td>8–13</td>
<td>NI</td>
</tr>
<tr>
<td>Process water</td>
<td>3</td>
<td>4</td>
<td>8</td>
<td>4–8</td>
<td>NI</td>
</tr>
<tr>
<td>Service water</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>8–17</td>
<td>NI</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>33–46</td>
<td>95</td>
</tr>
<tr>
<td>Total</td>
<td>156</td>
<td>193</td>
<td>236</td>
<td>162–243</td>
<td>183–233</td>
</tr>
</tbody>
</table>

(kWh/hl beer) (kWh/hl beer)

Bottling installation 16.11 23.89 26.11 6.94–12.78 10.56–16.11
Kegging installation 2.22 3.06 3.61 2.22–3.61 NI
Process water 0.83 1.11 2.22 1.11–2.22 NI
Service water NI NI NI 2.22–4.72 NI
Miscellaneous NI NI NI 9.17–12.78 26.39
Total 43.33 53.62 65.55 44.99–67.50 24.44–64.72

NB: NI = no information provided.
(1) 20 000 to 500 000 hl beer sold/yr.
(2) 300 000 to 500 000 hl beer sold/yr.
Source: [35, Germany 2002]

The main single consumers of electricity in a brewery are: packaging area, cooling plant, compressed air plant, CO₂ recovery plant, waste water treatment plant and air conditioning. There are also many small consumers of electricity, accounting for a large part of the electricity consumption, e.g. pumps, ventilators, drives and electric lighting [72, Brewers Europe 2002].

Breweries need both electrical and heat energy. Combined heat and power generation is in use in some facilities. Depending on availability, price and legal requirements, different fuels such as coal, oil or gas are used. Table gives average energy consumption levels for German breweries with 20 or more employees.

<table>
<thead>
<tr>
<th>Year</th>
<th>Coal (x 10⁵ kWh)</th>
<th>Oil (x 10⁵ kWh)</th>
<th>Gas (x 10⁵ kWh)</th>
<th>Total (x 10⁵ kWh)</th>
<th>Beer Output (x 10⁴ hl)</th>
<th>Specific Heat (kWh/hl)</th>
<th>Specific Power (kWh/hl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>157</td>
<td>929</td>
<td>292</td>
<td>4078</td>
<td>1190</td>
<td>114.8</td>
<td>35.5</td>
</tr>
<tr>
<td>1998</td>
<td>150</td>
<td>846</td>
<td>2943</td>
<td>3939</td>
<td>1187</td>
<td>111.7</td>
<td>35.3</td>
</tr>
<tr>
<td>1999</td>
<td>162</td>
<td>789</td>
<td>2956</td>
<td>3907</td>
<td>1175</td>
<td>112.8</td>
<td>34.6</td>
</tr>
<tr>
<td>2000</td>
<td>150</td>
<td>683</td>
<td>2809</td>
<td>3642</td>
<td>1163</td>
<td>110.4</td>
<td>33.0</td>
</tr>
</tbody>
</table>

(x 10⁶ MJ) (MJ/hl)

1997 565 3345 40271 11684 127.9
1998 544 3046 40595 14182 127.0
1999 583 2841 10642 40666 124.7
2000 540 2458 10113 13111 118.7

Energy consumption of German breweries with more than 20 employees [35, Germany 2002]
A brewery without a sophisticated heat recovery system consumes about 27.78 – 55.55 kWh/hl beer (100 – 200 MJ/hl) [136, CBMC – The Brewers of Europe, 2002]. The main heat consuming process steps are mashing, wort boiling, generation of hot liquor, CIP, sterilising, bottle/keg cleaning and pasteurising.

The major consumers of electrical energy are the packaging area; cooling plant; compressed air plant; if applied, the carbon dioxide recovery plant; WWTP and air conditioning. Pumps, ventilators, drives, and electric lighting count for a large part of the electricity consumption, with about 8–12 kWh/hl in a brewery.

Figure 4.14 shows data on overall specific energy consumption in breweries (MWh/hl of product) reported by various brewing installations. Among the related techniques reported, wort vapour condensers, boiler economiser, heat recovery in various stages of the process and use of vacuum pumps are reported.

4.3.2 Water consumption

Figure 4.15 shows data on specific water consumption (m³/hl of product) reported by various brewing installations. Most of the reported specific water consumption values are below 0.6 m³/hl of product. The reported rate of water recycling varies between < 1 % and 22.7 %.
Water consumption for modern breweries generally ranges from 0.4 to 1 m³/hl of beer produced. An example Finnish brewery reported an average water consumption of 0.32 m³/hl [199, Finland, 2003]. Water consumption for individual process stages, as reported for the German brewing industry, are shown in Table.

Table: Water consumption for different brewery processes

<table>
<thead>
<tr>
<th>Department</th>
<th>Specific water consumption (m³/hl beer produced)</th>
<th>Measured*</th>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>from to</td>
<td>from to</td>
<td></td>
</tr>
<tr>
<td>Brewhouse</td>
<td>0.130 0.236</td>
<td>0.174 0.26</td>
<td></td>
</tr>
<tr>
<td>Cold storage</td>
<td>0.032 0.054</td>
<td>0.04 0.08</td>
<td></td>
</tr>
<tr>
<td>Fermentation cellar</td>
<td>0.024 0.067</td>
<td>0.01 0.06</td>
<td></td>
</tr>
<tr>
<td>Storage cellar</td>
<td>0.031 0.109</td>
<td>0.01 0.076</td>
<td></td>
</tr>
<tr>
<td>Filtering cellar</td>
<td>0.059 0.163</td>
<td>0.09 0.098</td>
<td></td>
</tr>
<tr>
<td>Bottling cellar</td>
<td>0.013 0.064</td>
<td>0.04 0.12</td>
<td></td>
</tr>
<tr>
<td>Cask cellar</td>
<td>0.20 0.204</td>
<td>0.026 0.397</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous (*)</td>
<td>0.489 0.893</td>
<td>0.470 1.331</td>
<td></td>
</tr>
<tr>
<td>TOTAL PROCESS</td>
<td>** = Measurements by Heidemann, Rosenwinkel and Seyfried (1990 to 1992) or brewery figures</td>
<td>** = Estimates</td>
<td>** = Literature</td>
</tr>
</tbody>
</table>

The water consumption figure varies depending on the type of beer, the number of beer brands, the size of brews, the existence of a bottle washer, how the beer is packaged and pasteurised, the age of the installation, the system used for cleaning and the type of equipment used. If an on-site well is used, the water may require treatment before use, during which losses of up to 30% may occur. Bottling consumes more water than kegging. Consumption levels are high for once through cooling systems and/or losses due to evaporation in hot climates.

The largest water-consuming processes are [72, Brewers Europe 2002].
4.3.3 Waste

Solid materials enter the brewery in the form of raw and ancillary materials. Solid materials leave the brewery as co-products such as brewers’ grains and surplus yeast, primary and secondary packaging material, and other solid waste. Generally, only a very small amount of hazardous waste is produced, e.g. spent laboratory chemicals and batteries. Major co-product, by-product, residue and solid waste fractions are identified in the example shown in Figure 4.16. The example installation produces beer bottled mainly in returnable bottles, and uses plastic crates. The generation of flue-gas and waste water treatment residuals are not considered.

Husk and malt grits may be mixed into brewers grains which are used in the production process. Surplus yeast, brewers grains, trub from the whirlpool and husk and malt grits may be used as animal feed. Yeasts are also used in cosmetics, pharmaceuticals and spreads. Spent diatomaceous earth, i.e. kieselguhr, can be used in the cement industry, broken glass may be reused for glass manufacturing. Label pulp from cleaning the returnable bottles, cardboard and paper wastes may be reused in the paper industry. Plastics and metal from hop cans and replacement equipment may be recycled.

4.3.4 Emissions to water

Usually, there are fluctuations in the generation of waste water. The peak flow can be in the order of 2.5–3.5 times the average flow, depending on how close to the production area the
measurement is made. The period of peak flow is normally short. Peak flows occur in the brewhouse and beer processing area in connection with cleaning operations. In the packaging area, peak flows occur during closing down of the line as bottle washers and tunnel pasteurisers are emptied. A third area, where large peaks can occur, is in the waste water treatment area during backwash of filters.

The concentration of organic material will depend on the waste water to beer ratio and the discharge of organic material into the WWTP. The typical discharge of organic material from a brewery is normally in the range of 0.8–2.5 kg COD/hl beer. Larger discharges can occur and can be attributed to the discharge of surplus yeast, trub or other concentrated wastes into the WWTP that could be disposed of in better ways. Production of non-alcoholic beer may result in very high discharges if the condensed alcohol is discharged into the WWTP. Normally, the process waste water has a low content of non-biodegradable components. Brewery waste water normally has a COD/BOD ratio of 1.5–1.7 indicating that the waste water is easily degradable.

The waste water discharge is equal to the water supply minus the produced beer, the evaporated water in the brewery and utility plants, and the water present in the by-products and solid waste. It is reported that in Austria 0.26–0.6 m$^3$ of waste water is produced per hectolitre of beer. It is reported that in modern breweries 0.3–0.9 m$^3$ of waste water is produced per hectolitre of beer. An example Finnish brewery reported an average waste water production of 0.24 m$^3$/hl [74, World Bank (IBRD) et al. 1998]. Table 4.2 shows waste water production in different brewing processes.

### Table 4.2: Waste water production in different brewery processes

<table>
<thead>
<tr>
<th>Department</th>
<th>Specific waste water volume (m$^3$/hl beer produced)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured*</td>
</tr>
<tr>
<td></td>
<td>from to</td>
</tr>
<tr>
<td>Brewhouse/cold storage</td>
<td>0.024 0.063</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Fermentation cellar</td>
<td>0.005 0.021</td>
</tr>
<tr>
<td>Storage cellar</td>
<td>0.005 0.013</td>
</tr>
<tr>
<td>Filtering cellar</td>
<td>0.019 0.059</td>
</tr>
<tr>
<td>Bottling cellar</td>
<td>0.036 0.068</td>
</tr>
<tr>
<td>Cask cellar</td>
<td>0.008 0.037</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0.020 0.204</td>
</tr>
<tr>
<td><strong>Total process</strong></td>
<td><strong>0.117 0.465</strong></td>
</tr>
</tbody>
</table>


The waste water is very variable and the pollution load of the different steps do not follow the volumes throughput, e.g. bottle cleaning produces a high amount of waste water but with only a low organic load, while waste water from fermentation and filtering account for only about 3 % of the total waste water volume but 97 % of the BOD load [74, World Bank (IBRD) et al. 1998]. Organic pollution in waste water mainly comes from the following sources:

- brewers grains;
- yeast and surplus yeast;
- trub;
- weak wort discharge;
- emptying and rinsing of water from kettles;
- emptying of process tanks;
- pre- and after-runs from diatomaceous earth filtration and filling;
- chase water from process pipes;
- rejected beer in the packaging area;
TSS in the waste water originate mainly from the discharge of by-products, diatomaceous earth, e.g. kieselguhr, and possible label pulp from the bottle cleaner. Nitrogen originates mainly from detergents used for tank cleaning, from the malt and from additives. Phosphorus may come from the cleaning agents used. Large variations in pH may occur due to the use of acids and caustic for the cleaning of process equipment and returnable bottles. Heavy metals are normally present in very low concentrations. Wear of the machines, especially conveyors in packaging lines, may be sources of nickel and chromium.

Figure 4.17 shows reported data on specific waste water discharges (m³/hl of product) from brewing installations.

Table: Untreated waste water characteristics for breweries

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD₅</td>
<td>mg/l</td>
<td>1000–1500</td>
</tr>
<tr>
<td>COD</td>
<td>mg/l</td>
<td>1800–3000</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>mg/l</td>
<td>10–60</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>mg/l</td>
<td>30–100</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>mg/l</td>
<td>30–100</td>
</tr>
<tr>
<td>pH</td>
<td>–</td>
<td>3–13</td>
</tr>
</tbody>
</table>

Source: [35, Germany 2002], [72, Brewers Europe 2002], [74, World Bank (IBRD) et al. 1998]
Table: Waste water and pollution generated in breweries

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water consumption</td>
<td>hl water/hl beer sold</td>
<td>4–10</td>
</tr>
<tr>
<td>Waste water generation</td>
<td>hl water/hl beer sold less</td>
<td>1.3–1.8</td>
</tr>
<tr>
<td></td>
<td>water consumption</td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>kg/hl beer sold</td>
<td>0.8–2.5</td>
</tr>
<tr>
<td>COD/BOD₅ ratio</td>
<td></td>
<td>1.5–1.7</td>
</tr>
<tr>
<td>Total suspended solids</td>
<td>kg/hl beer sold</td>
<td>0.2–0.4</td>
</tr>
</tbody>
</table>

Source: [72, Brewers Europe 2002]

4.3.5 Emissions to air

Apart from the emissions to air from energy generation processes, the main potential emission sources are dust from material intake and transport of raw materials, i.e. grains, and filtration aids, i.e. kieselguhr. Ammonia from cooling operations may be accidentally released.

4.3.5.1 Dust emissions

The raw material intake and transport mainly generate dust. In addition, dust could be generated by the supply and handling of filtration aids such as kieselguhr. However, as the dust emission from these systems is normally limited by the integration of cyclones and bag filters, the emission is generally very restricted [72, Brewers Europe 2002].

A general overview of the data received for dust emissions to air from the brewing process is shown in Figure 4.18.

![Figure 4.18: Total dust emissions to air from the brewing process](source: [193, TWG 2015])

The meaning of the symbols used in Figure 4.18 is indicated in Table 3.5.

4.3.5.2 Odour
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The largest source of odour emissions is the evaporation of volatile organic compounds derived from wort boiling. Recovering heat from wort kettles saves energy by condensing approximately 95% of the vapour. This also reduces odour emissions because condensable odorous vapours are removed from the exhaust air. The vapour emissions occur for a short period of typically 3 to 5 minutes at the beginning and at the end of each production batch [212, The Brewers of Europe 2015].

Other odour sources are waste water treatment, storage and handling of co-products and by-products, oil storage, ventilation of beer cellars and packaging lines and emissions to air from the boiler house.

Noise

The main noise sources are transport within the brewery with lorries and forklifts, condensers and cooling towers.
4.4 Techniques to consider in the determination of BAT

In a brewery, water is mainly used for mashing, heat transfer and cleaning operations. Water consumption for modern breweries generally ranges from 4–10 hl/hl beer. Table shows reported water and waste water saving opportunities in a brewery. Table shows some typical achievable reductions in water consumption in breweries.
<table>
<thead>
<tr>
<th>Measure</th>
<th>Method</th>
<th>Description/purpose</th>
<th>Equipment technique</th>
<th>Major benefits</th>
<th>Other benefits</th>
<th>Potential cost*</th>
<th>Potential payback*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquor-metering</td>
<td>Metering-and-training</td>
<td>Avoid excess wort production</td>
<td>Meter</td>
<td>Water and waste water savings</td>
<td>Consistent wort quality</td>
<td>High</td>
<td>Med</td>
</tr>
<tr>
<td>Wort disposal</td>
<td>Storage and disposal</td>
<td>Reduce waste water COD</td>
<td>Tank</td>
<td>Waste water savings</td>
<td></td>
<td>Low</td>
<td>Short</td>
</tr>
<tr>
<td>Keeping brewers' grains dry</td>
<td>Training</td>
<td>Minimise leaching during storage and transport</td>
<td>Brush (leads to dust emissions)</td>
<td>Waste water savings</td>
<td>Ease of grain</td>
<td>Low</td>
<td>Med</td>
</tr>
<tr>
<td>Cleaning mash tun and copper</td>
<td>High-pressure hose</td>
<td>Reduce water use for manual cleaning</td>
<td>Pressure washer</td>
<td>Water and waste water savings</td>
<td>Improved cleanliness</td>
<td>Med</td>
<td>Med</td>
</tr>
<tr>
<td>Wort boiling</td>
<td>Reduce boiling time</td>
<td>Reduce steam consumption</td>
<td>Training</td>
<td>Water and energy saving</td>
<td></td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Copper condensate recovery</td>
<td>Heat-exchanger</td>
<td>Recover waste heat and reduce odours</td>
<td>Heat-exchanger</td>
<td>Source of hot liquor</td>
<td>Energy savings, reduced steam discharge</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Trub disposal</td>
<td>Storage and disposal</td>
<td>Reduce waste water COD</td>
<td>Tank</td>
<td>Waste water savings</td>
<td></td>
<td>Low</td>
<td>Short</td>
</tr>
<tr>
<td>Heat-exchanger automation</td>
<td>Actuated valves on temperature control</td>
<td>Optimize cooling and hot liquor production</td>
<td>Valves and controllers</td>
<td>Water and waste water savings</td>
<td>Consistent wort cooling</td>
<td>Med</td>
<td>Long</td>
</tr>
<tr>
<td>Heat-exchanger optimisation</td>
<td>Minimise cold liquor storage time</td>
<td>Prevent production of extra hot liquor</td>
<td>Training</td>
<td>Water and waste water savings</td>
<td>Cooler wort into fermenter</td>
<td>Low/Med</td>
<td>Med</td>
</tr>
<tr>
<td>Hot liquor storage</td>
<td>Increase capacity</td>
<td>Prevent overflow from hot liquor tank</td>
<td>New tank</td>
<td>Water and waste water savings</td>
<td></td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Fermenter cooling</td>
<td>Cooling jacket or panels</td>
<td>Improved cleaning efficiency</td>
<td>New vessel or cooling panels</td>
<td>Water and waste water savings</td>
<td>Easier cleaning</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Fermenter cooling</td>
<td>Closed circuit cooling</td>
<td>Reduce water consumption</td>
<td>Chiller and recirculation pump</td>
<td>Water and waste water savings</td>
<td>Improved cooling</td>
<td>Med</td>
<td>Short</td>
</tr>
<tr>
<td>Fermenter cleaning</td>
<td>Training, use of scrapers</td>
<td>Reduce water and waste water volume</td>
<td>Training/cleaning equipment</td>
<td>Water and waste water savings</td>
<td></td>
<td>Med</td>
<td>Short</td>
</tr>
<tr>
<td>Yeast disposal</td>
<td>Storage and disposal</td>
<td>Reduce waste water COD</td>
<td>Tank</td>
<td>Waste water savings</td>
<td></td>
<td>Low</td>
<td>Short</td>
</tr>
<tr>
<td>Beer filtration</td>
<td>Cross-flow filtration</td>
<td>Reduce water use and waste water pollution</td>
<td>Proprietary equipment</td>
<td>Water and waste water savings</td>
<td>Less haze</td>
<td>High</td>
<td>Med/Long</td>
</tr>
</tbody>
</table>

*Potential costs and paybacks are for guidance only. Actual costs and paybacks will depend on the particular site.

*Potential cost: Low = Minor alterations to practices or existing installations (EUR 0 – a few 100s); Med = Some alterations to existing installations or minor new installations (EUR 200 – 1500); High = Extensive alterations or new installations (several EUR 1000s).

*Potential payback: Short = Months; Med = Less than a year; Long = Over a year.

Table: Water and waste water saving opportunities in a brewery
[23, Envirowise (UK) and Dames & Moore Ltd, 1998]
<table>
<thead>
<tr>
<th>Water saving measure</th>
<th>Typical reduction in process use (%)</th>
<th>Possible application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed circuit water recycle</td>
<td>up to 90</td>
<td>Fermenter cooler</td>
</tr>
<tr>
<td>CIP</td>
<td>up to 60</td>
<td>(New)</td>
</tr>
<tr>
<td>Reuse of cleaning water</td>
<td>up to 50</td>
<td>Cask cleaning</td>
</tr>
<tr>
<td>Countercurrent rinsing</td>
<td>up to 40</td>
<td>CIP</td>
</tr>
<tr>
<td>Good housekeeping</td>
<td>up to 30</td>
<td>Hose pipes</td>
</tr>
<tr>
<td>CIP</td>
<td>up to 30</td>
<td>Optimisation of CIP</td>
</tr>
<tr>
<td>Spray/jet upgrades</td>
<td>up to 20</td>
<td>Cask cleaning</td>
</tr>
<tr>
<td>Brushes/squeegees</td>
<td>up to 20</td>
<td>Fermenter cleaning</td>
</tr>
<tr>
<td>Automatic shut-off</td>
<td>up to 15</td>
<td>Pump cooling water</td>
</tr>
</tbody>
</table>

Table: Typical achievable reductions in water consumption in breweries

Mashing
The individually defined mash programme chosen is based, among other things, on the malt quality and the type of beer to be produced. The choice of mash process influences the energy consumption in the brewhouse and hence in the brewery as a whole.

4.4.1 Techniques to increase energy efficiency

4.4.1.1 Partially unmalted barley brewing

Description
Partial substitution of up to 20% of malt with unmalted barley.

Technical description
It is possible to use unmalted barley as partial replacement of malt. Up to 20% of malt can be substituted without addition of external enzymes. The existing equipment and process can be used, as long as good quality malt is used for the malt part of the grist (grain without chaff).

De-husked barley or normal barley may be used for the brewing process. Cleaning of normal barley is necessary. Barley should be mashed in together with the malt or before, so that enzymes present in the malt start to attack the starch in the barley as soon as possible. A flavour stability challenge may be created, if barley is mashed in after the malt.

Achieved environmental benefits
As only about 80% of the barley gets malted, a proportional reduction in consumption of water, heat and electricity in the malting process is achieved, and this is without routinely introduction of external enzymes for the mashing process.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
No negative environmental effects are foreseen, as no external enzymes (requiring external energy for manufacturing) are applied. The resulting spent grains from the brewhouse carries similar value as cattle feed as all malt spent grains.

Technical considerations relevant to applicability
The technology is applicable in most breweries, as analytical data and flavour for quality of the finished beer is similar to all malt beers. Mashing time and temperatures are similar to all malt processes, but may have to be adjusted to achieve the desired real degree of fermentation. Fermentation, maturation and filtration processes do not need adjustments other than increased sampling, until the process has been tested. Additional required equipment:
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- dry or wet milling system;
- existing mills might be capable, if the barley is mixed with the malt.

Economics
The electricity consumption for the mill is expected to increase, as the barley is harder to mill than the malt. There do not seem to be major process problems—and need for capital expenditure—using up to 20% barley instead of malt. The price ratio barley/malt is not permanent, although barley should always be some 30% cheaper than malt.

Example plants
TWG, please provide information.

Reference literature
[241, Nordic Council of Ministers 2011]

4.4.1.2 Double malt kilning

Description
The malt drying process takes place in two steps. In the first step, water on the surface of the malt is evaporated at a high rate. In the second step, the water from the core of the grains is evaporated.

Technical description
The malt drying process takes place in two parts. In the first wet part, surface water in the malt is evaporated at a high rate and the majority of the heat supplied to the process is used for evaporating water. The exhausted drying air holds a high humidity of more than 90% and a temperature around 25 °C. The drying air supplied to the first part of the process is kept at 60 – 65 °C.

In the second dry part of the malt drying process, the chemically combined water is evaporated from the core of the grain through diffusion. The rate of evaporation is reduced considerably in comparison with the high rate in the first part of the process and continues to decline towards the end of the drying process. The malt temperature increases towards 75 °C as the drying air temperature is increased stepwise to 85 °C. The exhaust air temperature increases to 77–78 °C and the relative humidity of the exhaust air drops steeply and end at 3–4%.

Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data
This technique allows the following reduction in energy consumption:

- the heat consumption is based on primary energy (natural gas), and is 20% lower in a double malt kiln than in a single malt kiln;
- the power consumption from the power grid is 20% higher in a double malt kiln than in a single malt kiln.

The heat consumption for a single malt kiln is approximately 12 times larger than the electricity consumption for a double malt kiln. Hence the 20% lower heat consumption is significantly larger than the 20% increase in power consumption. The drying of the malting process is highly affected by temperature and humidity of air supplied.

Cross-media effects
Increased power consumption.
Example plants
At least one brewery in Denmark.

Reference literature
[ 241, Nordic Council of Ministers 2011 ]

4.4.1.3 Integration of the malt house with a district heating system

Description
District heating and energy is supplied by an external energy plant situated outside the malt house. Excess energy from the malt house is directed to an external energy supplier.

Technical description
The technique is referred to as district heating and the energy is supplied by an external energy plant situated outside the malt house. Integration of a company energy supply system with an external network of district heating producers is also possible the other way around. Excess energy can be sold to an external energy supplier, if the amount of energy is sufficient, production is not fluctuating much, the district heating network is in place and there is a need for the produced energy. A partly non-fossil fuel solution to reduce energy consumption and introduce consumption of non-fossil fuel in the malt house could be implemented.

Achieved environmental benefits
Replacement of on-site fuel use.

Environmental performance and operational data
In an example situation, district heat is produced by a local energy plant using different fuels: 55% biomass (wooden chips), 25% waste and as a supplement fossil fuel (oil and natural gas).

District heat at 120 °C is used to heat the inlet air to the malt kilns. The company used before natural gas heater. The malt house uses triple kiln malting. The batch is divided into two withering kilns for the first kilning step. In the final kilning the batch is placed into one curing kiln. The hot outlet air from the final kiln is used as hot inlet air to the first kilns. The warm outlet air from the first kilns is heat exchanged with glass air-to-air heat exchangers to heat the incoming air to the kilns.

The malt house has concluded, that district heating is more effective than natural gas in the two different malt processes. 15 kWh/ton or approximately 3 % heat energy is according to the malt house saved by use of district heating compared to use of natural gas.

Technical considerations relevant to applicability
Access to a district heating network is necessary.

Economics
The malt house has observed a financial saving of approximately 32%, when district heating was introduced to tower 2 and compared with costs of running tower 1 with natural gas as the energy source (2005). The energy prices are fluctuating with time.

Example plants
Viking Malt brewery in Sweden.

Reference literature
[ 241, Nordic Council of Ministers 2011 ]
4.4.1.4 Mash infusion process

Description
Mash infusion carried out in the mash vat.

Technical description
Shredded malt is fed, together with warm brewing water, into the mash vat. This so-called mash, is heated to a temperature of 78 °C and is stirred constantly. The mash infusion process is all carried out in the mash vat. Then, the thick part of the mash is separated and boiled in a mash pan, i.e. heated to 100 °C.

Achieved environmental benefits
Reduced air pollution, e.g. odour, and energy consumption compared with the mash decoction process.

Environmental performance and operational data
The mash infusion process does not need to boil part of the mash, as is required in the mash decoction process. This results in energy savings of between 20 and 50 %.

Table 4.3 shows the energy consumption in the brewhouse of a large brewery in Germany which uses a mash infusion process.

<table>
<thead>
<tr>
<th>Consumer</th>
<th>Electrical energy</th>
<th>Heat energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total (kWh)</td>
<td>Specific (kWh/hl)</td>
</tr>
<tr>
<td>Brewhouse wort preparation</td>
<td>675 500</td>
<td>0.84</td>
</tr>
<tr>
<td>Total consumption</td>
<td>6 520 730</td>
<td>8.1</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

In addition, the mash infusion process reportedly has lower odour emission levels than the decoction process.

Technical considerations relevant to applicability
Mash infusion is applicable in the processing of full malt beers. The mash infusion method traditionally requires high quality malt, though the malt grades available permit the use of a mash infusion process for many beer types.

Economics
No additional costs compared with the mash decoction process.

Driving force for implementation
The mash infusion process is primarily used because of its lower energy consumption, because it requires less equipment and because it is easier to automate, compared with the mash decoction process.

Example plant
A large brewery in Germany.

Reference literature
[35, Germany 2002], [72, Brewers Europe 2002], [122, Brewers Europe 2004], [192, COM 2006]
Mash decoction process

Description
Shredded malt is fed, together with warm brewing water, into the mash vat. This so-called mash, which is constantly stirred, is heated up to a temperature of 78 °C. Then, the thick part of the mash is separated and boiled in a mash pan, i.e. heated to 100 °C.

Cross-media effects
Higher air pollution, e.g. odour, and energy consumption in comparison to the mash infusion process (see Section 4.4.1.2).

Environmental performance and operational data
It is reported that because the mash is boiled during the process, it gives higher heat losses compared to the mash infusion process. In addition, the mash decoction process reportedly has higher odour emission levels than the mash infusion process.

Technical considerations relevant to applicability
The mash decoction process is applicable when unmalted raw materials are being used, e.g. maize.

Reference literature
[35, Germany 2002], [72, CBMC—The Brewers of Europe 2002], [122, CBMC—The Brewers of Europe 2004]

4.4.1.5 Mashing-in at higher temperatures

Description
The mashing-in of the grain is carried out at temperatures of approximately 60 °C, which reduces the use of cold water.

Technical description
Typical mashing-in takes place at 37 °C or 50–52 °C, heating to 60–62 °C and mashing off at 78 °C. Quality improvements have been achieved for malt used for mashing. One of the implications of this improvement is, that the need to keep temperature rests at e.g. 50 °C has diminished, and some breweries have demonstrated, that they routinely are able to mash in at 60 °C. The consequence for heat energy is, that hot water from the wort cooling only needs to be blended with smaller volumes of cold water.

Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data
The exact heat energy saving by mashing-in at 60 °C rather than at for example 50 °C vary, but in most brewhouses a higher mashing-in temperature will imply, that hot water from the wort cooling only needs to be blended with smaller volumes of cold water to produce 60 °C mashing-in water.

Brewers monitor the potential risks at increased mashing in temperatures. Insufficient protein- and beta-glucan degrading during mashing are most important risk, but possible to overcome by supply of malt of consistent high quality, i.e. with sufficient amounts of natural enzymes.

Example plants
TwG, please provide information.

Reference literature
[241, Nordic Council of Ministers 2011]
4.4.1.6 Heat recovery from wort kettle vapour

Description
Recovery of the heat from the vapour of the boiling wort (e.g. by plate heat exchangers).

Technical description
Many breweries have implemented some heat energy recovery systems other than reuse of the hot water generated from the wort cooler to a hot-water tank. There are energy conservation systems designed to recover the heat arising from vapour from the boiling wort, as this vapour may generate heat when recondensed. An example of such a vapour-condensation plant is shown in Figure 4.19.

![Energy recovery from vapour condensation](source: Nordic Council of Ministers 2011)

Figure 4.19: Energy recovery from vapour condensation.

Achieved environmental benefits
Reduced energy consumption. Reduction of odour emissions.

Environmental performance and operational data
Such vapour condensation systems are able to recover approximately 75% of the condensation heat. The remaining some 25% gets lost in transfers, when boiled-off vapour is released to the open air at times during the process and via heat losses.

Economics
TWG, please provide information.

Example plants
TWG, please provide information.

Reference literature
[ Nordic Council of Ministers 2011 ]
4.4.1.7 Increase of the degree of high-gravity brewing (HGB)

Description
Production of concentrated wort which reduces its volume and thereby saves energy.

Technical description
It is possible to produce stronger wort than that corresponding to the original gravity of the final beer produced by diluting it, before or mostly after fermentation, with carbonated and de-aerated water to the desired extract content. This process is referred as HGB.

Breweries will normally already apply HGB at a rate of 20–30%. This implies that a finished pilsner of 10 % plato is brewed at an original gravity of 12–13 % plato. It is possible to apply a HGB-degree of 40 % for most beers and in most breweries. The increased amount of HGB-degree is directly proportional to saved boiling heat in the brewhouse and saved cooling energy at fermentation.

Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data
Increased HGB-degree is providing proportionally heating energy savings, i.e. 25 % HGB-degree will result in 25 % heat energy savings in the wort kettle.

Driving force for implementation
HGB provides a quick way of increasing capacity as less fermenters are needed with HGB and without compromising the quality of the beer. As energy costs rise more focus is given to savings for the needed wort volume to boil and for the fermenting beer volume to cool.

Example plants
TWG, please provide information.

Reference literature
[ 241, Nordic Council of Ministers 2011 ]

4.4.1.8 Integrated energy system in the CO₂ recovery plant

Description
Integrated energy system in the CO₂ recovery plant by exchange of energy from heating and cooling processes.

Technical description
In this technique, an evaporiser captures the cooling energy arising from evaporation of CO₂ and passes this cold liquid CO₂ through a heat exchanger, which cools down relatively warm glycol returning from glycol evaporators at points of use elsewhere in the brewery. The technique is an integrated energy system in the CO₂ recovery.

This technique has ability to reuse the cooling energy from evaporation which otherwise in classical CO₂-recovery plants gets lost. The technique is able to work along with the brewery’s existing NH₃ cooling system (CO₂-NH₃). Heat coming from the recovery system is cooled by the brewery’s NH₃ cooling system. By this way two energy streams are used: heat released when liquefying CO₂ gas and heat taken up when evaporating liquid CO₂. This system simultaneously facilitates the liquefaction of incoming CO₂ gas (from the fermenters) and vaporisation of incoming liquid CO₂ (from the storage tanks).
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Achieved environmental benefits
Reduction of energy consumption due to reuse of cooling energy (< 1% extra electricity consumption compared to the savings).

Environmental performance and operational data
The amount of energy saved is approximately 85 kWh per 1000 kg CO₂ evaporated.

Cross-media effects
Energy consumption for running the heat exchanger.

Technical considerations relevant to applicability
The implementation of this techniques does not demand an existing CO₂-recovery plant.

Economics
The electrical energy and maintenance costs are relatively small. Installation cost of EUR 30 000 and a payback period of 11 months have been reported [241, Nordic Council of Ministers 2011].

Example plants
TWG, please provide information.

Reference literature
[241, Nordic Council of Ministers 2011]

4.4.1.9 Decrease of evaporation rate during wort boiling

Description
Evaporation rate can be reduced from 10 % down to approximately 4 % per hour (e.g. by two-phase boiling systems, dynamic low-pressure boiling).

Technical description
Evaporation rates have gradually come down from 10 % per hour to 6–7 % per hour in most breweries. Recent tests at breweries have demonstrated, that the possible limit for needed evaporation is somehow lower, and some breweries have documented that a 4 % evaporation rate is sufficient. Brewers are frequently monitoring the potential risks at reduced evaporation rates. Unwanted sulphur components in the wort and cloudy finished beer are two well-known risks. By decreasing the evaporation rate, heat energy is saved proportionally.

Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data
Reduced evaporation rate will lead to proportional savings of heat energy. If evaporation rate is reduced from 10 % to 6 %, a 40 % heat energy saving is expected. If the brewery wants to reduce evaporation rate from 6 to 4 %, it should be able for each brew to control evaporation rate +/- 0.3 %, whereas this margin at 6 % evaporation may be +/- 0.6 %.

Example plants
TWG, please provide information.

Reference literature
[241, Nordic Council of Ministers 2011]
4.4.1.10 Iso-mixer fermentation system

Description
Introduction of forced mixing in fermentation tanks.

Technical description
Introduction of forced mixing in fermentation tanks by use of rotary jet mixers reduces the processing and cooling time. The fermentation capacity is hereby maximised and a reduction of the operational cost is achieved.

The system is using a rotary jet mixer, which force a much better mixing in the fermentation tank. Previously it was assumed that CO$_2$ produced was sufficient to stir the tank and avoid yeast to settle.

Achieved environmental benefits
Reduced demand for cooling energy.

Environmental performance and operational data
A combination of the Iso-mixer system with external cooling via a heat exchanger will make it possible to redesign fermentation tank and avoid cooling zones in the tank. Instead the fermentation tank should be well insulated. Processing and cooling times can be reduced by up to 30%.

By using the iso-mixer system alone, no changes in the cooling energy are expected. However, using the iso-mixer a higher yield of alcohol will be gained, which allows the brewery to increase production. This is a higher productivity solution with a better utilisation of the raw materials. The savings are reduced raw material utilisation and reduced transportation energy of raw materials.

Cross-media effects
The iso-mixer pump consumes electricity to operate.

Economics
For a 2 million hl/yr brewery introducing jet mixer technology requires an investment of less than 30% of the cost of installing new fermenters, equal to a saving of more than EUR 2 000 000. Using the combined mixer and external cooling system will save cost for cooling energy, processing time and make fermentation tanks much cheaper.

Driving force for implementation
Increased productivity and potential cost savings.

Example plants
Implemented in Nordic breweries.

Reference literature
[ 241, Nordic Council of Ministers 2011 ]

Heat recovery from wort boiling

Technical Description
Wort boiling is the largest single heat consuming process in a brewery. When the wort is boiled, 6–10% normally evaporates. The vapour is usually emitted to the air, wasting energy and producing unpleasant odours. Recovering heat from wort kettles saves energy and avoids odour problems.
The simplest way to recover heat from the vapour is to use it to produce hot water for various processes, e.g., for use in production, cleaning operations, flushing brew kettles or for room heating. If, however, hot water is also produced during wort cooling, which is very common, there may be an excess of hot water which will be released into the WWTP. In this case, there are two reported options for recovering the heat from the vapour: either using the vapour to boil the wort or using the heat in the vapour to preheat the wort before boiling.

**Achieved environmental benefits**
Significantly reduced energy consumption. Reduced water consumption and improvements in the hot water balance of the operation. Reduced odour emissions.

**Environmental performance and operational data**
Vapour, heated by means of vapour recompression, is conventionally used to boil the wort in a special heat-exchanger. It is reported that the heat of the vapour condensate, which has a temperature of about 100 ºC, can be recovered by using it to produce hot water to boil the wort. The process is shown in Figure.

![Heat recovery from a steam-heated wort kettle to produce hot water](image)

Figure: Heat recovery from a steam-heated wort kettle to produce hot water

It is also reported that the heat can also be used to produce 98 ºC water for preheating the wort before boiling. The wort can be heated from 72 ºC to approximately 90 ºC by means of the heat recovered from the vapour condensate. This requires the installation of an energy store. Heat in the vapour condensate can also, if required, produce hot water. The process is shown in Figure.
Technical considerations relevant to applicability
Applicable in new breweries and in existing breweries when the installation has a high and inefficient energy consumption. In these cases, heat recovery is only considered after other significant energy reductions have first been made, e.g. to a level of 41.66–55.55 kWh/hl (150–200 MJ/hl).

Driving forces for implementation
Cost reductions, e.g. lower energy and water consumption costs.

Economics

Reference literature
[35, Germany 2002 ], [29, Deehrew Ltd 1996 ], [72, Brewers Europe 2002 ], [122, Brewers Europe 2004 ].

4.4.2 Techniques to reduce water consumption
See also Section 2.3.3.1.1.

4.4.2.1 Reuse of hot water from wort cooling

Description
Hot water is stored in insulated water tanks and used for various processes, e.g. for use in production, cleaning operations, flushing brew kettles or for room heating.

Technical description
Hot water consumption is one of the key issues in regard to energy savings. Hot water is normally produced in a heat exchanger when cooling down the wort from 100 °C to the fermentation temperature, e.g. about 10 °C. The hot water is stored in insulated water tanks and used for various processes, e.g. for use in production, cleaning operations, flushing brew kettles or for room heating.
Achieved environmental benefits
Reduced energy consumption. Reduced water consumption and improvements in the hot water balance of the operation. Reduced odour emissions.

Environmental performance and operational data
It is reported that if hot water is used for mashing only, there will be an excess of hot water giving an overflow from the hot water tank. Large amounts of water and energy can be lost due to this overflow. To optimise the hot water system, a hot water balance can be made for the entire brewery. It should carefully be investigated when, where and how much hot water is used. The investigation should also reveal if it is possible to use hot water instead of cold water heated by steam for functions such as CIP, sterilisation and bottle cleaning. It is also important that the hot water tank is sized correctly to avoid the brewery producing hot water from steam after a weekend stop in the brewhouse.

Technical considerations relevant to applicability
Applicable in all breweries.

Reference literature
[ 72, Brewers Europe 2002 ], [ 122, Brewers Europe 2004 ]

4.4.2.2 Reuse of waste water from the lauter turn

Description
Reuse of waste water as process water for mashing.

Technical description
At the end of mash separation, the residual, very dilute worts, are allowed to freely drain until an acceptable level of brewers’ grains moisture is achieved. After grains discharge, the fines deposited beneath the false floor are removed by a hot water underplate pressure cleaning and the false floor slots are kept unobstructed by an overhead hot water rinsing. These very dilute worts are high in TSS, lipids and polyphenols and, traditionally, have been considered unacceptable for process reuse and are consequently sent to the WWTP. This loss is significant in terms of water, energy and extract.

Waste water from the lauter tun is a significant contributor to a brewery’s total waste water. The pollutant load of the lauter tun waste water depends on several factors. In terms of water balance, the lower the spent grain moisture content, the greater the waste water volume. It is advantageous to reduce further the volume of dilute wort drainings, but care is needed not to entrain air or extend the time of wort collection. It is also common practice to apply deep bed raking during the bed drain down to speed up the draining of the residual dilute worts after completion of the wort collection to the kettle. The more aggressively this technique is employed, the more fines pass through to the waste water. A higher level of retained spent grain after discharge, inevitably results in more fines/COD being entrapped in the false floor plate and removed by the underplate pressure cleaning and going to the waste water.

To enable the reuse of the waste water as process water for mashing, the removal of the very fine colloidal size particles from the weak worts is necessary. This can be achieved by centrifugation or two-stage filtration, i.e. coarse filtration followed by ultrafiltration. After the coarse filtration stage, the waste water is subject to a cross-flow membrane process.

Achieved environmental benefits
Reduced emission levels of TSS and COD in the waste water.
Environmental performance and operational data
An example UK brewery developed a pilot plant to deal with a specific highly polluted waste water separately from the rest of the waste water. The lauter tun produced approximately 20 % of the total waste water load of the brewery, as shown in Table 4.4.

Table 4.4: Waste water characteristics in a brewery

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total brewery waste water (mg/l)</th>
<th>Lauter tun waste water (mg/l)</th>
<th>Contribution of the lauter tun to the total load (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
<td>800</td>
<td>6 540</td>
<td>27</td>
</tr>
<tr>
<td>COD</td>
<td>2 000</td>
<td>13 100</td>
<td>22</td>
</tr>
</tbody>
</table>

Source: [61, UK 2002]

Before ultrafiltration can commence, it is necessary to remove coarse particles sized greater than 100 µ. 70 % of the suspended solids are easily settleable and likely to be removed by coarse filtration. Different in-line self-cleaning filters were trialled. Various screen sizes were used with this unit and 30 µ mesh was found to be optimal for solids removal with acceptable water content, i.e. 75 % moisture. These were versatile enough to cope with the variable solids loadings of the influent and also provided a discharge acceptable for disposal with the normal brewers’ grains, rather than creating a new solid waste stream for disposal.

After the coarse filtration stage, the waste water is subject to a cross-flow membrane process. The resultant concentrate is still very liquid at less than 1 % dry solids. If this was added to the normal wet brewers’ grains at 75 % moisture, the overall moisture content would increase to 78 %. For a worst case scenario, this was assumed to be unacceptable and therefore the concentrate would have to go to the WWTP. The cross-flow membrane filter retained 99 % of the TSS and 53 % of the COD, allowing for a 5-fold concentration effect.

The permeate post UF has undergone a 99 % reduction in suspended solids, a 45 % reduction in polyphenols and a 99 % reduction in lipids. This can reportedly be used as a 1 to 3 substitute for hot mashing water in the process. This results in an increase by 13 mg/l in polyphenols and 1 mg/l in lipids. This is reported to be considered an acceptable process variation. The reduction in pollution load is summarised in Table 4.5.

Table 4.5: Summary of the pollution reduction results treating lauter tun waste water

<table>
<thead>
<tr>
<th>Volume (m³)</th>
<th>Lauter tun waste water</th>
<th>30 µ filter waste water</th>
<th>Ultrafiltration 100 nm permeate</th>
<th>concentrating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total solids (mg/l)</td>
<td>6 540</td>
<td>3 110</td>
<td>38</td>
<td>16 010</td>
</tr>
<tr>
<td>COD (mg/l)</td>
<td>13 100</td>
<td>13 100</td>
<td>7 623</td>
<td>36 104</td>
</tr>
</tbody>
</table>

Source: [61, UK 2002]

Economics
It is reported that in the UK most breweries discharge their waste water into a MWWTP for treatment. A charge is made for this service by the MWWTP, which is usually a water company. The total cost of the treatment of the lauter tun has been estimated to be about GBP 97/brew. Assuming 3 000 brews in a year this amounts to about GBP 291 000/yr.

The reduced COD loading to the MWWTP reduces the waste water cost by about GBP 13 per brew. The permeate used as mashing water results in a saving in hot water, which is only actually achieved with an appropriate brewhouse hot liquor balance. In this instance, the recovered hot water still required water make up. The estimated total savings were about
GBP 59/brew, or about GBP 176 000/yr. Annual running costs were estimated to be about GBP 28 000, therefore the net savings were estimated to be about GBP 50 000. The installation cost about GBP 300 000, and therefore the payback period is estimated to be 2 years. An additional annual saving of GBP 50 000 would be realised if the UF concentrate was to be loaded with the normal brewers’ grains instead of being sent to the MWWTP.

The cost of such an installation will vary significantly from brewery to brewery, depending upon the lauter tun size, flowrates, buffer tank requirement, solids disposal route and degree of automation. In the pilot, from which these economic data were derived, the technique was not integrated into the automated control system of the brewery, nor was it connected to the CIP system. Although these factors may alter the economic assessment, it is reported to be likely that implementation of the lauter tun waste water treatment system would have an attractive financial payback period of 1–2 years.

Reference literature
[ 61, UK 2002 ]

4.4.2.3 Reuse of bottle pasteurising water

Description
Reuse of overflows from the pasteurisers.

Technical description
To reduce water consumption, overflows from the pasteurisers are collected in stainless steel tanks. Collected water is sent to a cooling tower and returned to the pasteuriser at a preset pressure having being dosed with, e.g. corrosion inhibitors and biocides.

Achieved environmental benefits
Reduced water and chemical consumption. Reduced waste water volume.

Cross-media effects
Possible development of legionnaires’ disease, corrosion or scale build-up.

Environmental performance and operational data
At an example beer bottling installation, the pasteurisers were responsible for 51 % of the total water consumption of approximately 7 000 m$^3$/week. Although the pasteurisers were designed for regenerative flows, there was a constant demand for cooling water which then overflowed to the drain. There was an average flow of about 10 m$^3$/hr with peaks of around 60 m$^3$/hr. This constant flow to the WWTP led to losses of corrosion inhibitors and biocides. In addition, there were evaporative losses of about 5 % from the cooling towers, requiring make up water. After installing a water recovery unit from the pasteurisers on the roof of the building, the total water consumption was reduced to 17 % of the site total. Savings in water and waste water of 80 % and of 23 % in chemicals were achieved.

In this example installation, bottling and canning systems are kept separate as bottle breakage in the pasteuriser can lead to frequent depositing of product, e.g. beer into the pasteuriser water.

Technical considerations relevant to applicability
The system can be used for pasteurisers, vacuum pumps and cooking retorts.

Economics
In an example packing installation, make-up water costs of approximately EUR 0.8/m$^3$ plus a constant flow to the WWTP of EUR 1.1/m$^3$ were achieved. This equates to EUR 7.2–43.2 being wasted per hour for each of the four pasteurisers. The capital costs were EUR 162 000 with a payback of around 15 months.
Example plants
A packing installation in the UK.

Reference literature

4.4.2.4 Cross-flow filtration

Description
The feed-water flow is parallel to the membrane and is brought under pressure.

Technical description
Cross-flow filtration is filtration where the feed-water flow is parallel to the membrane. All of the feed-water flow needs to be brought under pressure. The principle is shown in Figure 4.20.

![Figure 4.20: The principle of cross-flow filtration, compared to dead-end filtration](source: [192, COM 2006])

The cross-flow system is applied for RO, nanofiltration, ultrafiltration and microfiltration, depending on the pore size of the membrane (see also Section 2.3.6.3.7).

Achieved environmental benefits
When cross-flow filtration takes place, feed-water can be recycled and material can be recovered.

Cross-media effects
Energy consumption.

Environmental performance and operational data
Cross-flow filtration has a high energy consumption because all the feed-water is put under pressure. Compared to dead-end filtration, where all of the water passes through the filter and the residue builds up on the filter, cross-flow filtration has the advantage of reduced fouling. The filter is relatively resistant to fouling and can be easily cleaned.

It is reported that the main advantage of cross-flow filtration in winemaking, is the removal of almost all bacteria from the wines. In a study, unfiltered wines showed high bacterial counts and were sensitive to spoilage if exposed to higher temperatures. Cross-flow filtration through 0.22 µm removed almost all of the bacteria and thereby eliminated the chance of bacterial spoilage if the wines are to be exposed to higher temperatures. The minor changes caused by
cross-flow filtration in the alcohol concentration, titratable acidity, extract and colour are explained by the wines being cleaner than the corresponding unfiltered wines. No oxidative changes of the wines were experienced from the cross-flow filtration process. The tasting panel found no significant differences between the unfiltered and the cross-flow filtered wines of Pinotage, Shiraz and Cabernet Sauvignon.

Technical considerations relevant to applicability
Widely applicable in the FDM sector.

Example plants
Applied in breweries, wineries, dairies and WWTPs.

Reference literature

4.4.3 Techniques to reduce waste

4.4.3.1 Recovery and (re)use of yeast after fermentation

See also Section 2.3.5.2.

Description
After fermentation, yeast is separated and stored in tanks and is used as an animal feed, or is reused in the fermentation process. It may also be used for pharmaceutical purposes or sent to an anaerobic waste water treatment plant for biogas production.

Technical description
After fermentation, brewers’ yeast is separated and stored in tanks and, apart from being used as an animal feed (see Section 2.3.4.2), to be is reused in the fermentation process, used for pharmaceutical purposes, or sent to anaerobic WWTPs for biogas production, or disposed of as waste.

Achieved environmental benefits
Reduced waste water pollution. Reduced waste, e.g. when used as animal feed.

Environmental performance and operational data
It is reported that due to its very high COD level and its tendency to form organic acids, if brewers’ yeast is discharged to the WWTP, the pollution load of the waste water is significantly increased.

An example brewery recognised that it was losing beer worth more than GBP 1 million/year in its waste water. A waste minimisation audit showed that 80% of all beer losses were from a vessel that separated the beer from the brewers’ yeast cells. Clear beer was run off from the vessel using a fixed standpipe, before the bottom phase containing the yeast cells, was discharged to the drain. The position of the interface between the two phases depended on the type of beer, and any beer below the level of the standpipe was lost to drain. The process was modified so that the yeast phase was drained off first, until a capacitance level switch at a low level in the vessel detected the interface. The beer was then run off to storage.

The brewers’ yeast can be separated, to prevent it entering the WWTP, shows water and waste water saving opportunities of this technique and others in a brewery.

Technical considerations relevant to applicability
Applicable in breweries, distilleries, ethanol production and wineries.
Economics
Reduced waste water treatment charges. Low potential costs and high potential payback.

Driving force for implementation
Reduction in product loss. Avoiding high waste water treatment charges.

Example plants
Used in breweries and in ethanol production.

Reference literature

4.4.3.2 Recovery and reuse of natural filter material when the product is filtered using natural mineral adsorbents

Description
Natural mineral adsorbents (e.g. diatomaceous earth) are transferred to a reactor where they are dried in a stream of hot air. Then, they can be reused for filtration purposes.

Technical description
Filtration of the product is carried out in several processes during drinks manufacturing, e.g. during fining and before bottling to remove the remaining solid, insoluble turbid compounds and microorganisms. Filtration with natural minerals, e.g. bentonite, perlite and diatomaceous earth, provides a rough filtration, leaving some matter in the product. This process is reported to improve the quality of wine. The filter material can be collected, to prevent it from being washed into the WWTP. It can be treated for reuse, composted or possibly brought out to the vineyard or distilled, depending on the composition.

Cross-media effects
Energy consumption to recover and reuse the filter material.
Unless the filter is collected separately, it will be released to the WWTP leading to pollution of the waste water.

Environmental performance and operational data
In wine processing, it is reported that filtration with natural mineral adsorbents keeps its quality at a high level, e.g. the stronger the filtration, the poorer the wine will be.

Beer is filtered before bottling in a brewery, using diatom filters: around 4000 t diatoms/year are needed [240, COM 2015].

It is reported that diatomaceous earth can be dehydrated and then channelled into a reactor where it is gently dried and smouldered in a stream of hot air. After this process, the diatomaceous earth can be reused fully for filtration purposes. The exhaust gas leaving the reactor requires treatment. As the diatomaceous earth can be recycled many times, a reduction of filtration and disposal costs is achieved. Final disposal is commonly soil remediation and fertilisation [193, TWG 2015].

Technical considerations relevant to applicability
Applicable in drinks manufacturing installations where a rough filtration of the product is needed, e.g. in wineries.

Example plants
TWG, please provide information.
Used in the processing of wine, beer and apple juice.
Driving force for implementation
Reduced product losses.

Reference literature
[ 71, AWARENET 2002 ], [ 110, CIAA 2003 ], [ 158, Germany 2005 ], [ 193, TWG 2015 ], [ 240, COM 2015 ]

4.4.3.3 Brewery surplus yeast, rest beer and soft-drinks for bioethanol feedstock

Description
An alternative disposal method which can turn surplus yeast, rest beer and soft drinks into bioethanol, animal feed and CO₂.

Technical description
The majority of the bio-waste products (spent grain and yeast) are used as animal feed. Sugar liquids and alcohol containing beer waste fractions are normally disposed to the waste water system.

This technique can turn surplus yeast, rest beer and soft drinks into bioethanol, animal feed and CO₂. Integrated bioethanol plant can also utilise bakeries and supermarkets bakery biowaste to compliment brewery waste to increase the fermentation production and increase the CO₂ production.

The new technology evaporates alcohol from yeast and rest beer. Non-alcoholic waste-streams are fermented together with local bakery and supermarket bakery waste. CO₂ from fermentation process is lead for soft-drink production. Liquid animal feed is produced as by-product, which is sold to local farms.

Achieved environmental benefits
Most efficient by-products management.

Environmental performance and operational data
Surplus yeast is evaporated and alcohol is separated from yeast. The remaining fraction is sold to local farms as liquid animal feed.

Rest beer and liquid waste from soft drink production could also be handled in the same way, where the sugars are fermented into ethanol by continuous fermentation process. Typically rest beer is evaporated and non-alcoholic waste liquids are diluted with bread to make it liquid format. This saves fresh water consumption at ethanol plant. Carbon dioxide is captured during the fermentation process, which is reused.

In a related unit biowaste and side-products from the food processing industry are turned into 85 % ethanol. The ethanol is then transported to central dehydration unit, where the remaining water is evaporated by membrane technology. When alcohol reaches 99.8 %, it is ready to be mixed with petrol without any additional processing.

Cross-media effects
Potential increase of energy consumption.

Technical considerations relevant to applicability
Sufficient amount of biowaste product must be available to make the bio-ethanol production efficient and cost-effective.
**Economics**

The main economic advantage to brewery is the possibility to collect CO\textsubscript{2} from the fermentation and so reduce the amount of CO\textsubscript{2} bought.

**Example plants**

At least one installation in Finland.

**Reference literature**

[241, Nordic Council of Ministers 2011]

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**Process optimisation in a small brewery–a case study**

**Description**

A small brewery in the UK produces mainly casked ales and lager in old, traditional premises. Recognising that water consumption, beer losses and waste water charges were above the industry average, the company installed meters in the main process areas to measure water consumption and waste water discharges (see Section 2.3.3.1.2), e.g. they installed float-operated top-up valves in detergent tanks and replaced faulty valves. They also introduced better procedures for reusing hot water from wort cooling, installed high efficiency nozzles for cask cleaning and optimised cleaning procedures.

**Achieved environmental benefits**

Improved efficiency of water and energy use and minimisation of waste water generation.

**Environmental performance and operational data**

As a result, the company achieved an annual water consumption reduction of 73000 m\textsuperscript{3} (40%).

**Economics**

Low investment measures. Annual cost savings of nearly EUR 160000 were achieved with a payback period of less than three months for nearly EUR 130000 of savings.

**Reference literature**

[1, CIAA, 2002]

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4.4.4 Techniques to reduce emissions to air

4.4.4.1 Techniques to reduce dust emissions from the brewing process

4.4.4.1.1 Bag filter

A general description of the technique is given in Section 2.3.7.2.2.

**Environmental performance and operational data**

Bag filters are widely used in breweries as final abatement technique, but in most cases are preceded by a cyclone step.

Table 4.6 shows some installation-specific performance data related to the application of bag filters for abating emissions to air from brewing processes.
### Table 4.6: Dust emission levels to air from brewing processes after treatment in a bag filter

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm$^3$)</th>
<th>O$_2$ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional info</th>
</tr>
</thead>
<tbody>
<tr>
<td>073-1</td>
<td>&lt;0.4</td>
<td>20.90</td>
<td>NI</td>
<td>Yearly</td>
<td>Grinding plant filter</td>
</tr>
<tr>
<td>399-7</td>
<td>0.30</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Vibratory sieves of raw material</td>
</tr>
<tr>
<td>360-1</td>
<td>1.20</td>
<td>21.00</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Malt feed hopper</td>
</tr>
<tr>
<td>158-3</td>
<td>&lt;1.39</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Milling process</td>
</tr>
<tr>
<td>399-6</td>
<td>1.67</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Transportation and cleaning sieves of raw material</td>
</tr>
<tr>
<td>166-2</td>
<td>1.70</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Every five years</td>
<td>Malt reception</td>
</tr>
<tr>
<td>157-8</td>
<td>1.80</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Grain cleaning</td>
</tr>
<tr>
<td>157-5</td>
<td>1.90</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Grain transfer</td>
</tr>
<tr>
<td>360-4</td>
<td>2.00</td>
<td>21.00</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Malt transport system from silos to the brewhouse</td>
</tr>
<tr>
<td>157-6</td>
<td>2.20</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Malt transfer</td>
</tr>
<tr>
<td>160-5</td>
<td>2.31</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Grain cleaning</td>
</tr>
<tr>
<td>158-2</td>
<td>3.54</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Grain cleaning</td>
</tr>
<tr>
<td>165-1</td>
<td>3.90</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Twice a year</td>
<td>Malt discharge</td>
</tr>
<tr>
<td>160-8</td>
<td>9.38</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Milling process</td>
</tr>
</tbody>
</table>

NB: NI = no information provided

Source: [193, TWG 2015]

#### Reference literature

[193, TWG 2015]

#### 4.4.4.1.2 Cyclone

A general description of the technique is given in Section 2.3.7.2.3.

#### Environmental performance and operational data

Cyclones are widely used as abatement technique for breweries’ emissions to air, but usually before a final bag filter step (see Table 4.6). Table 4.7 shows some installation-specific performance data related to the application of cyclones for abating emissions to air from brewing processes.
Table 4.7: Dust emission levels to air from brewing processes after treatment in a cyclone

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>O₂ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional info</th>
</tr>
</thead>
<tbody>
<tr>
<td>360-2</td>
<td>1.75</td>
<td>21.00</td>
<td>NI</td>
<td>Yearly</td>
<td>Malt transport system</td>
</tr>
<tr>
<td>165-3</td>
<td>7.63</td>
<td>21.00</td>
<td>EN 13284-1</td>
<td>Twice a year</td>
<td>Sand remove</td>
</tr>
</tbody>
</table>

NB: NI= no information provided
Source: [193, TWG 2015]

Reference literature
[193, TWG 2015]

4.4.4.2 Techniques to reduce odour

TWG, please provide information.

4.4.4.3 Carbon dioxide recovery and purification

Description
The CO₂ generated during the fermentation process is collected, cleaned, compressed, dried, purified and liquefied.

Technical description
The CO₂ generated during the fermentation process can be collected, cleaned, compressed, dried, purified and liquefied. It can then be used.

CO₂ released during fermentation is passed to a recovery unit. The CO₂ to be recovered contains all the volatile components present or produced during fermentation including oxygen, fusel oils and carbonyl and sulphur compounds with very low flavour thresholds, e.g. hydrogen sulphide. For this reason, the CO₂ has to be purified to the degree necessary for its intended use.

The purification process or conditioning includes a foam separator, gas scrubbing with water to reduce the sulphur compounds, drying, flavour removal with activated charcoal, oxygen removal and compressing to liquid for its storage. It can then be drawn off as needed from the storage tank, re-vaporised and used in production, or sold as product. This biogenic CO₂ can be used e.g. for technical uses or for food and drink applications.

Achieved environmental benefits
Reduced CO₂ emissions at installation level. Reduced consumption of fossil fuels and energy for the production of CO₂ especially for use in the installation.

Cross-media effects
Energy consumption for processing the CO₂.

Environmental performance and operational data
In the brewing sector, the reduction in CO₂ emissions with this system is around 2 kg/hl (20 kg/m³) of beer produced.

Untreated CO₂ with an impurity of 20–1 000 ppm can be recovered from the fermentation process. The oxygen level in the liquefied CO₂ can be reduced from an initial value of 40 to 1 000 ppm to an output purity of 5 ppm. This is achieved by the oxygen reduction system. Figure 4.21 shows the process sequence in the CO₂ conditioning system.
If closed-circuit cooling water is used for cooling the air compressors and the CO₂ compressor, this prevents water losses and minimises waste water volumes.

The decision whether to buy CO₂ produced as a co-product by another sector may be based on the quality available.

**Applicability**

Applicable in breweries, wineries, distilleries, ethanol and cider production. The opportunities for using the recovered CO₂ vary between sectors, and are as follows:

- neutralising waste water, with minimum purification—all fermenting sectors;
- carbonating drinks—brewing, sparkling wine, cider, soft drinks and mineral water;
- as a carrier for drinks dispensing, e.g. beer, cider and carbonated soft drinks;
- for counter pressure in filtration units; tanks and bottles, e.g. beer, cider and carbonated soft drinks.

**Economics**

Industrial gas companies can supply CO₂, which is usually a co-product from other sectors, at a cheaper price than the production cost price in the installation.

**Driving force for implementation**

- Avoiding CO₂ emissions due to replacement of fossil derived CO₂ and avoiding the need to purchase CO₂ from third parties.
- The use of own-site recovered CO₂ avoids the risk of contamination, taste and odour problems from off-site sources.

**Example plants**

Used in the brewing and ethanol production sector.

**Reference literature**

[35, Germany 2002], [88, CIAA-CEFS 2003], [94, Germany 2003], [109, Finland 2003]
4.5 Emerging techniques

4.5.1 External cooling of the fermentation tank

**Description**
External cooling of the fermentation tank.

**Technical description**
Cooling of a fermentation tank is traditionally carried out by jacket cooling. As the traditional fermentation tank is not equipped with any kind of mechanical agitation, mixing of the beer is only driven by the gravitational forces of cooler beer sinking to the bottom of the tank along the cooled tank walls and warmer beer in the centre of the tank rising to the top of the tank. As the only driver in the tank is gravitational forces, the flow velocity down the smooth vertical stainless steel wall will be rather low and the corresponding heat transfer coefficient from convection (natural convection) will be low.

The idea of this technology is to replace traditional inefficient jacket cooling of the fermentation tank with more efficient cooling in an external heat exchanger where the beer is forced through by a circulation pump. The advantage of this cooling technology in comparison with the jacket cooling technology is the much larger overall heat transfer achievable with an external heat exchanger than with jacket cooling and an arbitrary size of the heat transfer area which no longer is fixed to the tank geometry. The heat transfer rate is primarily achieved by mechanically increasing the flow velocity over the heat transfer surface by a pump and by improving the conduction heat transfer coefficient by using very thin plates between beer and cooling media.

The external cooling system results in a smaller temperature difference of the cooling media and enables a higher cooling media temperature which means that the evaporation temperature of the refrigerant in the cooling plant can be increased leading to improved energy efficiency and increased capacity of the cooling plant. In addition to this environmental advantage, the forced agitation provided by circulating the beer leads to a better mixing of yeast and beer in the fermenting process which leads to a faster fermentation process.

**Achieved environmental benefits**
Reduced energy consumption.

**Reference literature**
[241, Nordic Council of Ministers 2011]
5 DAIRIES

5.1 General information about the sector

More than 12 000 dairy processing sites exist in EU, involving around 300 000 direct jobs. Five of the ten global top dairy companies are European and the European milk processing industry brings more than EUR 9.3 billion to the overall EU trade balance [206, EDA 2015].

Farms across the EU-28 produced approximately 164.8 million tonnes of milk in 2014, of which 159.6 million tonnes (or 96.8 %) were cows’ milk. Milk from ewes, goats and buffalos represented 3.2 % of the total production. The majority of the milk produced on farms was delivered to dairies and the remaining amount was used on the farms (see Figure 5.1).

Between 2013 and 2014 the production of cows’ milk on farms in the EU-28 increased by almost 5.8 million tonnes (3.8 %), while the number of dairy cows increased by 0.4 %. The EU-28’s dairy herd of 23.6 million cows in 2014 had an estimated average yield of 6 777 kg per head.

![Figure 5.1: Production and use of milk in the EU-28 in 2014 (million tonnes)](image)

Just over one fifth (21.2 %) of all the cows’ milk collected by EU-28 dairies in 2014 came from Germany, while slightly more than a sixth of the total (17.1 %) originated from dairies in France (see Figure 5.2). Dairies collected relatively little milk from other animals (sheep, goats and buffalos) in most EU Member States. However, in Greece the volume of milk collected from other species (669 000 tonnes) was higher than the level of milk collected from cows (615 000 tonnes). In Italy and France the quantities of milk collected from other animals were similar to Greece, but these volumes were dwarfed by the respective quantities of cows’ milk that their dairies collected. Spain was the country that presented the highest quantity of milk from other animals (1 120 000 tonnes), which represented 14 % of the total milk collected in Spain.
The milk delivered to dairies is converted into a number of fresh products and manufactured dairy products (see Figure 5.3). Some 68.8 million tonnes of raw milk in the EU-28 in 2014 were used to produce mainly cheese, drinking milk, milk powder, butter, skimmed milk and buttermilk. Close to a quarter (24.3 %) of the estimated 30.4 million tonnes of drinking milk produced in the EU-28 in 2014 came from the United Kingdom, despite this Member State accounting for only about one tenth of the milk produced in the EU-28. This relative specialisation was also observed for other dairy products: for example, Germany, Italy and the Netherlands accounted for almost three quarters (70.3 %) of the 5.5 million tonnes of cheese produced across the EU-28 in 2014.
5.2 Applied processes and techniques

Milk is approximately 87% water, with the remainder being protein, fat, lactose, calcium, phosphorus, iron and vitamins. Cows' milk is primarily consumed, but goats' and sheep's milk are also consumed in significant quantities. A number of dairy products such as cream, cheese and butter are produced from milk.

5.2.1 Milk and cream

Raw chilled milk is received at the dairy and transferred to bulk storage. The milk may be centrifugally separated to produce skimmed or semi-skimmed milk and a cream stream. The milk is then heat treated by a variety of methods such as pasteurisation and sterilisation, also known as UHT (ultra-high temperature). Heat processing may be a batch or continuous operation depending upon the quantity of the milk to be processed and the method employed.

The milk is first homogenised. Homogenisation disperses fat globules and prevents separation of the cream component. To achieve a sufficient creaming stability for pasteurised milks with a relatively short shelf-life, reduction of the fat globules size to a mean diameter of 1 to 2 μm is required, while the long shelf-life UHT milks require a much greater reduction in fat globule size, ≤0.7 μm.

Another effect of homogenisation is the large increase in exposed fat area, which greatly favours the action of lipases. For this reason, it is normal practice to pasteurise the milk to inactivate the lipase, immediately after homogenisation. Figure 5.4 shows a flow sheet for a short time pasteurised milk process.

Typical heating parameters for a continuous pasteurisation process are 72 °C for 15 seconds. This is known as high temperature short time pasteurisation (HTST). Hot milk is often used to partially heat incoming cold milk in a heating step known as regeneration. Following pasteurisation, the milk is rapidly cooled to <7 °C. Milk which is not in-container heat processed, is filled and sealed in containers under clean or aseptic conditions. Incoming milk may be homogenised after the regeneration stage, before being pasteurised.
UHT or sterilisation is used to increase the shelf-life of the product. Continuous UHT at a minimum of 135 °C for one second is carried out. This can be done in two different ways. Heating it indirectly, using heat exchangers with various types of plates and pipes or in two stages, i.e. first heating the milk indirectly to approximately 80 °C and then heating it directly by mixing steam and milk. The ratio of the weight of steam and milk used is approximately 1:10. If direct heating is applied immediately after the heat treatment, the milk is then cooled by expanding it under a vacuum to extract the steam mixed with the product in the sterilisation phase. This is also called flash cooling. The end temperature of the milk immediately returns to its level prior to mixing with the steam. Cooling by indirect exchange with a coolant or countercurrently with the incoming product, then follows. Figure 5.5 summarises the production of UHT milk.
Chapter 5

The heat treatment for long-life sterilised milk consists of two phases. The first phase is a continuous heat treatment or pre-sterilisation, similar to that described for UHT treatment. The second phase consists of the final treatment of the closed container after filling and sealing the pre-sterilised product. The second heat treatment generally takes place in an autoclave in batches or in a continuous retort at approximately 110 °C to 125 °C for 20 to 40 minutes with an end phase of sprinkler cooling. Long-life sterilised milk and other dairy products are packaged in closed containers such as plastic or glass bottles. Figure 5.6 summarises the production of sterilised milk.

Source: [44, Italian contribution 2001]

Figure 5.5: Production of UHT milk
5.2.2 Condensed and powdered milk

The first stage in the production of condensed and powdered milk is the concentration of the raw milk. Homogenised milk is usually concentrated with evaporators. Falling film evaporators are generally used followed by a drying step using a spray dryer. Alternatively, RO can be used to mechanically remove some of the water from the milk, without the application of heat. Electrical power is used to pump liquid through a semi-permeable membrane to increase the concentration of solids. Doubling of the concentration of milk and whey is common [19, German Dairy Association 2001]. The powder is typically agglomerated to improve reconstitution. Dry whole milk is susceptible to oxidative rancidity and may be packaged in a protective atmosphere to extend its shelf-life. These processes are shown in Figure 5.7 and Figure 5.8.
Figure 5.7: Flow sheet of processes for condensed products (e.g. UHT condensed milk) and intermediate products (e.g. milk concentrates)

Source: [15, German Dairy Association 1999]
Two different principles can be applied for drying: hot air drying and surface drying by heat conduction through a heat transfer system.

In hot air drying, hot air is used as the heating medium and is in direct or indirect contact with the liquid product. The heat transferred from the hot air to the product causes evaporation of the water content.

In surface drying by heat conduction through a heat transfer system, the heating medium is not in contact with wet food but separated from it by a heat transfer surface. The heat is transferred by conduction through the surface, and by convection from the hot surface to the food product for evaporating and removing water from the food. This has two main advantages compared to hot air dryers; less air volume is required and, therefore, thermal efficiency is higher, and the process may be carried out in the absence of oxygen.

The dryers used are spray, roller, and vacuum band and vacuum shelf dryers.

In spray drying, the material to be dried is suspended in air, i.e. the liquid is converted into a fog-like mist or atomised liquid, providing a large surface area. The atomised liquid is exposed to a flow of hot air in a drying chamber. The moisture evaporates quickly and the solids are recovered as a powder consisting of fine, hollow, spherical particles. Air inlet temperatures of up to about 250 °C or even higher, depending on the type of product, are used, but due to evaporation, the air temperature drops very rapidly to a temperature of about 95 °C, which is the outlet temperature of the air. The product temperature is 20 to 30 °C below the air outlet temperature. Heating the drying air can be accomplished by steam or by direct gas-fired air heaters or by indirect heaters fired by gas, liquid or solid fuels. Spray drying is applied on a large scale in the dairy industry and for drying coffee.
Generally, as an integral part of the process, the exhaust air is passed through cyclones and/or filters to recover particulate materials or dust which are carried over in the exhaust air. The recovered material is incorporated back into the product.

The principle of roller drying is that a thin film of material is applied to the smooth surface of a continuously rotating, steam-heated metal drum. The film of the dried material is continuously scraped off by a stationary knife located opposite the point of application of the liquid material. The dryer consists of a single drum or a pair of drums with or without satellite rollers. The applied steam pressure in the drums can vary from 4 to 8 bar, depending on the product. Roller drying is applied, e.g. for milk, starch and potato flakes.

Finally, in vacuum band and vacuum shelf dryers, food slurry is spread or sprayed onto a steel belt, which passes over two hollow drums within a vacuum chamber. The food is first dried by the steam-heated drum, and then by the steam-heated coils or radiant heaters located over the belt. The dried food is cooled by the second water-cooled drum and removed by a doctor blade. The rapid drying and limited heat damage to the food makes this method suitable for heat-sensitive foods.

In hot air drying, a gas/vapour is generated and exhausted into the air. This gas/vapour may contain dust and VOCs, which originate from the product. This may cause an odour problem which might require treatment prior to discharge. If drying is done using direct gas or fuel fired burners, the exhaust gases might contain CO₂, CO, SO₂, NOₓ, depending on the heat source and burner type. Food safety requirements should be respected, especially when drying very sensitive products.

For the evaporation of water, theoretically 0.611 kWh/kg (2.2 MJ/kg) energy is required. In practice, due to energy losses in the process, the energy consumption for water evaporation ranges from 0.691 to 0.972 kWh/kg (2.5 to 3.5 MJ/kg).

Noise may arise from the air inlet and outlet of the driers. If sound baffles are used to reduce the noise at outlets, these baffles need to be checked periodically to remain effective.

### 5.2.3 Butter

Butter is produced from cream which is centrifugally separated from pasteurised milk. The cream contains around 35% to 40% milk fat. The process is basically a mechanical one in which cream, an emulsion of oil in water, is transformed to butter, an emulsion of water in oil. This is achieved by a process of batch or continuous churning. Cream is rapidly chilled and held at that temperature for a set period in a process known as ageing. The cream is then subjected to churning and working. Churning agitates the cream to partially break down the oil in the water emulsion until fat globules bind together to produce butter grains. The liquid phase called buttermilk is removed and the butter grains are washed in water. Salt may be added before the working stage of the process begins. This involves slow agitation of the grains, subjecting them to a kneading and folding action. The butter is packaged and stored, typically in chilled or frozen storage. A number of continuous techniques are available such as methods in which cream is subjected to high speed churning and continuous working. Figure 5.9 summarises continuous buttermaking.
5.2.4 Cheese

There are a very wide range of cheese varieties and many subtle differences in processing methods. In general, however, the following process steps apply: production of a coagulum through the action of rennet and/or lactic acid, separation of the resulting curds from the whey, and manipulation of the curds to produce the desired characteristics of the cheese.
The traditional manufacture of cheese is a manual process but modern processes are highly mechanised. Starter cultures are added to the milk to produce lactic acid and rennet is then used to coagulate the milk protein. The curds and whey are separated and the curds washed and cut into cubes. Texturising of the cheese involves compressing and stretching the curds and can be carried out in tower systems. The curd blocks are milled, salt is added, and the curds are pressed. Pressed cheese is wrapped to protect it against moisture loss and mould growth during storage. Cheese is matured to develop flavour and texture in temperature and humidity controlled stores, with regular turning of the cheese surface. Figure 5.10 shows a flow sheet of the manufacture of cheese.

Figure 5.10: Manufacture of cheese
A further process involves melting. Milled cheese and other ingredients are put into a processing kettle and heated to a temperature normally not less than 75 °C to ensure a complete pasteurisation of the processed cheese. Agitation during processing is important for a complete emulsification of the processed cheese. The temperature and duration of the process depends on the type of processed cheese aimed for and the nature of the raw cheese.

Temperature is one of the key factors that influence milk curdling. The required temperature is obtained by using either heat exchangers or by direct injection of steam into the curdling vat. The temperature is between 30 °C and 40 °C. Starters and other ingredients are added to the milk. These ingredients help determine the specific characteristics of the final product. Curdling is carried out in suitable vats or tanks, using either enzymatic coagulants, i.e. animal or microbial rennet or acidifying starters.

When enzymatic coagulants or acidifying starters are used, a casein jelly is formed which encloses the fat. The jelly will have different characteristics depending on which coagulant method is used. This is important for achieving the desired final production. The curd is produced by the separation of the whey, which is then gathered and sent for further processing as appropriate. To obtain further separation of the whey, e.g. to obtain a hard or semi-hard cheese, another heat treatment is given to the curd under stirring at up to 40 to 53 °C. For other kinds of cheese, such as mozzarella or provolone, as well as the curd being heated at a higher temperature, mechanical processing is also carried out to obtain the characteristic stretching/melting properties. Furthermore, organic acids are used to control the pH and to hold the curd at the right pH for the stretching properties to form.

5.2.5  Yoghurt

Yoghurt is a fermented milk product which differs from cheese in that rennet is not added and thickening occurs as a result of acidification by lactic acid bacteria. The main ingredients of yoghurt include milk; milk powders or concentrated milk or ultra-filtered milk, and stabilisers, such as modified starches. Most of the yoghurt produced is manufactured in bulk before the addition of fruit and/or flavourings.

The main steps in the manufacture of yoghurt are as follows. The fat and non-fat solids content of the milk is first increased by the addition of milk powders. Stabilisers may be added at this stage. The milk is then homogenised at a temperature of around 55 °C and heat treated at 80 to 90 °C for 30 minutes in a batch process, or 90 to 95 °C for 5 minutes in a continuous process. The heat treated milk is then cooled to around 40 to 43 °C and seeded with two starter organisms—*Streptococcus salivarius* subspecies *thermophilus* and *Lactobacillus delbrueckii* subspecies *bulgaricus*. Fermentation takes around 4 hours. At the end of the process, the product is cooled to 15–20 °C, using either tank cooling coils or, more commonly, tubular or plate heat exchangers. Fruit and flavours are blended into the yoghurt which is then cooled to less than 5 °C and filled into pots ready for storage and distribution. Figure 5.11 shows the yoghurt production process. Set yoghurt is fermented in the package, while stirred yoghurt is fermented in a tank before being packaged.

In lactic acid fermentation, lactose or other sugars are converted into lactic acid and small amounts of other components. Lactic acid formation is accompanied by a decrease in pH, which is important for the taste, the aroma and the preservation of the product. There are several species of bacteria which are able to produce lactic acid. Each species gives its own typical taste and aroma. Lactic acid fermentation is an anaerobic process. It is sometimes necessary to remove as much of the oxygen as possible to enhance the fermentation process. Lactic acid fermentation is carried out at 20 to 40 °C.

To start the process, bacteria cultures known as starters are added to the raw material to be fermented. The preparation of starter cultures is a sensitive process since the risk of airborne infection should be reduced to an absolute minimum. Starter cultures are, therefore, prepared in
a separate room supplied with filtered air with a slight positive pressure compared to normal atmospheric pressure. The equipment cleaning system is also carefully designed to prevent detergent and sterilant residues from coming into contact with the cultures and spoiling them. These very high hygiene constraints, coupled with the requirements of the temperature regulation, i.e. heat treatment of the substrate first and then cooling, require a specific energy consumption and use of cooling water.

Source: [5, German Dairy Association 1999]

Figure 5.11: Yoghurt production
5.2.6 Ice cream

Ice cream is a dairy based product which typically contains 6 % to 12 % fat, 7.5 % to 11.5 % non-fat milk solids, and 13 % to 18 % sugars. Stabilisers, emulsifiers, colours and flavours are also added. Sugar is usually added as sucrose, and the non-fat milk solids are usually from skimmed milk solids. The fat source may be milk, cream, butter or butter oil. Most ice cream contains vegetable fat. The ingredients are blended, heated to around 70 °C to 75 ºC and homogenised. The mixture is then pasteurised by heating to 80–85 °C for 2 s to 15 seconds before cooling and ageing by holding at chilled temperatures for 4 h to 24 hours.

Colours and flavours are added at the ageing stage. Continuous freezers are used to rapidly freeze the ice cream down to around -6 ºC, with compressed air being introduced into the ice cream during the freezing process. The increase in volume due to the addition of air is known as over-run. The ice cream is filled into containers and frozen further in tunnel freezers operating at -30 °C to -40 ºC.

5.2.7 Whey

In cheese manufacturing, about 90 % of the milk used ends up as whey. Whey is still seen as a valuable feed material, particularly amongst small producers. However, the development of the need for functional proteins in the human food industry has seen the increasing clarification, purification and fractionation of whey produced by the dairy industry for a variety of different human food purposes. Typically this can involve a variety of technologies, such as ultrafiltration, nanofiltration, reverse osmosis, and crystallisation, as well as thermal, ultraviolet, ultrasonic or microwave pasteurisation techniques.

In the case of crystallisation, whey is normally evaporated to a supersaturated solution with a total solids content of 60 % to 73 % to produce lactose. In cooling down the solution, crystallisation starts and the crystals begin to grow. The crystals are removed from the liquid phase by centrifugation. Depending on the required grade, further purification or refining can take place by washing the crystals, or redissolving them and recrystallising them, followed by treatment with active carbon for the removal of any impurities.

5.2.8 Cleaning procedures in the dairy industry

5.2.8.1 Cleaning with chemicals

Processing equipment and production facilities should be cleaned and disinfected within fixed intervals according to the hygienic needs of dairy industry. This cleaning process aims to remove soils and bacterial contamination from former production cycles. Hence, cleaning and disinfection processes are essential steps to provide product quality and consumer safety [210, EDA 2016].

5.2.8.1.1 General approach

Every cleaning procedure aims to remove soils deriving from foregoing production steps to guarantee soil- and bacteria-free products in the next production cycle. This procedure of cleaning-in-place (CIP) is today commonly water-based.

Most commonly in dairy industry is the use of cycled alkaline (caustic) and acid wash to remove soils from production equipment. Therefore sodium hydroxide in concentrations between 1 % and 5 % is used example. This wash step aims to remove proteins and other organic soils. To enhance cleaning effect and soil removal, combinations of sodium hydroxide solutions and complexing or chelating compounds have been developed. These additional
compounds are responsible for removal of e. g. co-factors of enzymes needed for bacterial augmentation. Commonly EDTA salts are added to the alkaline solution to increase cleaning effect. As a consequence of the caustic cleaning procedure a mineral scale is left by the contact of alkaline solutions with metal surfaces. To remove this scale commonly nitric acid solutions are used after the alkaline wash step. This acid wash step may also include the use of additional ingredients and sanitizers to reduce the load of for example bacterial contamination.

The effectiveness of the alkaline-acid-washing procedure is remarkably influenced by the quality of the used water. Commonly hard water is less effective in cleaning procedures. Hence, the use of softened water can improve cleaning efficacy. This includes the use of water that shows maximum capacity for all organic residuals as for example fat, oil, carbohydrates and proteins. Each of these compounds has an individual solubility in aqueous solutions. This solubility can be influenced by pH, temperature, dissolved salts (water hardness) and added compounds, detergents and sanitizers. How the optimal aqueous solutions should be assembled is case-dependent. In case of dairy installations the focus of cleaning should rely on the removal of fat, proteins and microbial contamination. Hence, a mixture of caustic, detergent and sanitizing compounds should be added to the aqueous solution. Furthermore the mixture should be improved with respect to the single needs of each dairy installation.

5.2.8.1.2 Dairy soils and the selection of the right cleaning chemicals

In dairies surfaces are mainly soiled by fat, proteins and microbial load. In which ratio each of these contaminations constitutes the soil on production facilities is dependent on which product is processed and generated by the installation. Therefore, selection of the optimal cleaning chemical composition should be made individually for each case.

Proteins are a heterogeneous group of soil compounds in dairy industry. Their solubility in aqueous solutions is remarkably dependent on temperature and pH-level of the solution. Protein solubility can be increased by alkaline lysis of the protein soil with sodium or potassium hydroxide.

Fats and oils from dairy produce are insoluble in water and are inert to alkaline lysis. Hence, surfactants can be added to remove fatty compounds. An alternative way to dissolve dairy soils may be the use of enzymes. A common disadvantage of this alternative may be that enzymes are to be inactivated by alkaline or acid condition which affords an additional cleaning step connected to increasing costs of cleaning.

Also microbial load has to be reduced within the cleaning procedure. Disinfection can be realised by a broad range of substances with different properties regarding killing effectiveness, stability in aqueous solutions, bio-degradability and material corrosivity. Commonly used substances are sodium hypochlorite or peroxyacetic acid. Each substance shows individual disinfection properties. For example sodium hypochlorite has good rinsing characteristics but can show toxic effects depending on environmental fate. This aspect is better respected by the use of peroxides.

In fact that each dairy installation has its own specific contamination characteristics also the assembling of cleaning chemicals should be designed specifically to fit the needs of the installation.

5.2.8.1.3 Biocides

Biocides may be used to lower the microbiological load of dairy facilities. But the use of biocides is regulated by different countries individually and it should be paid attention to country individual maximum residue levels and environmental aspects.
All biocides aim to affect cell structure of microorganisms to prevent their replication within dairy installations. It can be distinguished between oxidizing and non-oxidizing biocides and UV-radiation. Biocides typically used in dairy industry include (minimum toxic effects):

- 2,2-Dibromo-3-nitrilopropionamide (15 mg/kg);
- methylenebisthiocyanate (4 mg/kg);
- quarternary ammonium compounds (substance dependent);
- 2-Bromo-2-nitropropane-1,3-diol (254 mg/kg);
- iso-Thiazolones (substance dependent);
- tetra-(hydroxymethyl)-phosphonium sulphate (no toxicity observed in rats);
- peracetic acid (1 540 mg/kg);
- glutaraldehyde (1.3 mg/kg);
- sodium hypochlorite (1-5 mg/kg).

5.2.8.2 CIP procedures

Cleaning-in-place (CIP) is the most common cleaning procedure used in industrial production of food and beverages. Especially dairy and milk industry have to use CIP procedures due to the impossibility of a simple disassembling, cleaning and reassembling of big industrial facilities. Therefore trustworthy CIP procedures have to be used to guarantee quality of dairy products and safe for consumers as well as producers. Which special affords should be made on CIP procedures in dairy industry is remarkably depending on type of soil derived from daily production. Furthermore, adherence of soil is determined by different physical forces (e.g. van der Waals forces, electrostatic forces or mechanical forces), what additionally exerts limitations on choice of CIP technique.

Another aspect which has to be respected when thinking about cleaning strategy is the process technology which has to be cleaned, which consists of an individual sequence of pipes, tubes, barrels and other containers. Different types of steel show differing tolerances against acids and caustic substances, what influences also choice of chemistry used within CIP procedure. Furthermore if production facility is constituted by polymeric substances not all organic cleaning ingredients may be suitable, considering that these compounds may be able to dissolve the polymeric materials.

Waste water treatment

Some important characteristics of dairy waste water for the purposes of treatment are [8, Environment Agency of England and Wales-2000] [35, Germany-2002]:

- large daily variation in flowrate;
- variable pH;
- waste water may be nitrogen deficient, unless the raw water has a high nitrate content or nitric acid is used;
- waste water may be high in phosphorus if phosphoric acid is used for clean-up. Milk also has a high phosphorus content, e.g. 93 mg P/100 g whole milk;
- the treatment of dairy waste water results in lower surplus sludge than domestic waste water treatment, owing to, e.g. the lower content of suspended solids, the lower F/M ratio used and the higher waste water temperatures;
- despite utilising preceding equalisation basins, it is still prudent to allow for peak loads when designing the oxygen supply.

In the dairy sector, solids from washing water from vehicle washing units are generally removed at source. This may be carried out by using sand or grit traps, or the rainwater from the sealed surfaces is generally passed into the on-site waste water treatment system.
waste water is generally applied (see Section 2.3.3.1.4), by high solids content, very high BOD and high salinity. After segregation, primary treatment is required and the following techniques can be used:

- screening (see Section 2.3.6.1.1);
- flow and load equalisation (see Section 2.3.6.1.3);
- neutralisation (see Section 2.3.6.1.4);
- sedimentation (see Section 2.3.6.1.5);
- DAF (see Section 2.3.6.1.6);
- centrifugation (see Section);
- precipitation (see Section 2.3.6.1.8).

Following primary treatment, secondary treatment may be required. For waste water with a BOD concentration greater than 1000–1500 mg/l, anaerobic treatment processes are used (see Section 2.3.6.2.2). Anaerobic techniques are widespread across Europe for dairy waste water when BOD is greater than 3000 mg/l. Following surface aeration, the resultant final waste water from the anaerobic process can be discharged directly to a MWWTP. Nevertheless, there may be a risk of phosphorus release in the final waste water if anaerobic processes are used. For lower polluted waste water streams, aerobic treatment (see Section 2.3.6.2.1) is applied.

- shows a typical waste water treatment flow sheet applied to dairy waste waters.

![Typical waste water treatment applicable to a dairy](8, Environment Agency of England and Wales 2000)
5.3 Current consumption and emission levels

5.3.1 Energy consumption

Dairies have a significant energy consumption. Around 80% of the energy is consumed as thermal energy from the combustion of fossil fuels to generate steam and hot water. It is used for heating operations and cleaning. The remaining 20% is consumed as electricity to drive machinery, refrigeration, ventilation, and lighting. The most energy-consuming operations are the evaporation and drying of milk [21, Nordic Council of Ministers 2001]. In pasteurisation, e.g., significant energy is also needed for the heating and cooling steps. Recovery of heat by heat exchangers can be applied. Evaporation is normally combined with vapour recompression.

A wide range of energy consumption data has been reported for the European dairy industry. Figures are included in Table 5.1.

Table 5.1: Energy consumption in European dairies

<table>
<thead>
<tr>
<th>Products</th>
<th>Energy consumption (MWh/tonne of processed raw materials)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market milk</td>
<td>0.045 - 0.70</td>
</tr>
<tr>
<td>Cheese</td>
<td>0.09 - 1.09</td>
</tr>
<tr>
<td>Powder (e.g. milk, whey)</td>
<td>0.39 - 0.76</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

<table>
<thead>
<tr>
<th>Products</th>
<th>Energy consumption (GJ/processed milk)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electricity : Fuel</td>
</tr>
<tr>
<td>Market milk and yoghurt</td>
<td>0.15 - 2.5 : 0.09 - 1.12</td>
</tr>
<tr>
<td>Cheese</td>
<td>0.08 - 2.9 : 0.07 - 1.6</td>
</tr>
<tr>
<td>Milk and whey powder</td>
<td>0.06 - 2.6 : 0.05 - 2.3</td>
</tr>
</tbody>
</table>

|                                | Remarks                                                  |
| Market milk and yoghurt       | Minimum for liquid milk, maximum for specialities        |
| Cheese                        | Depends on the type of cheese and production run.        |
| Milk and whey powder          | Maximum fuel for whey evaporation                        |
|                                | Maximum fuel for whey products                           |

Source: [89, EDA 2002]

Similar figures are reported for Nordic dairies, as shown in Table.

Table 5.2: Energy consumption for some Nordic dairies

<table>
<thead>
<tr>
<th>Products</th>
<th>Energy consumption from electricity and fuel oil (kWh/l processed milk)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sweden : Denmark : Finland : Norway</td>
</tr>
<tr>
<td>Market milk and cultured milk</td>
<td>0.11 - 0.34 : 0.07 - 0.09 : 0.16 - 0.28 : 0.45</td>
</tr>
<tr>
<td>Cheese and whey</td>
<td>0.15 - 0.34 : 0.12 - 0.18 : 0.27 - 0.82 : 0.21</td>
</tr>
<tr>
<td>Milk, powder, cheese</td>
<td>0.18 - 0.65 : 0.3 - 0.71 : 0.28 - 0.92 : 0.29 - 0.34</td>
</tr>
<tr>
<td>Milk powder, cheese and liquid products</td>
<td>0.18 - 0.65 : 0.3 - 0.71 : 0.28 - 0.92 : 0.29 - 0.34</td>
</tr>
</tbody>
</table>

NB: * Figures in brackets show the number of dairy installations in each category.
Source: [21, Nordic Council of Ministers 2001]

More energy is used in dairies where butter, as well as drinking milk, is produced and where the production of powdered milk is greater. Four installations of the ice-cream industry in Nordic countries have reported to have a total energy consumption in the range 0.75 - 1.6 kWh/kg of
ice-cream produced [21, Nordic Council of Ministers 2001]. Other reports show an energy consumption of 2–10 GJ/t ice-cream produced [65, CIAA-EDA 2002].

5.3.2 Water consumption

Water consumption is mainly associated with cleaning operations. The factors affecting water consumption in European dairies are [89, EDA 2002]:

- availability of surface and groundwater for cooling;
- time and amount of water used for rinsing;
- characteristics of CIP programmes;
- maintenance, e.g. reparation of leaks.

A reasonably efficient consumption of water is reported to be around 1–5 l/kg milk [134, AWARENET, 2002], however, it is reported that a water consumption of 0.8–1.0 l/kg milk can be achieved by using advanced equipment and a good operation [74, Greek Ministry for the Environment, 2001]. According to a German survey, 132 dairies used, on average in 1999, 2.06 l/kg of milk [19, German Dairy Association 2001]. Table shows water consumption for some Nordic dairies.

Table 5.2 shows reported water consumption in European dairies.

Table 5.2: Water consumption in European dairies

<table>
<thead>
<tr>
<th>Product</th>
<th>Water consumption (m³/tonne of processed raw material)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market milk</td>
<td>0.33–8.12</td>
</tr>
<tr>
<td>Cheese</td>
<td>0.25–4.12</td>
</tr>
<tr>
<td>Powder (e.g. milk, whey)</td>
<td>0.50–3.19</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

<table>
<thead>
<tr>
<th>Product</th>
<th>Water consumption* (l/kg processed milk)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Market milk and yoghurt</td>
<td>0.8</td>
</tr>
<tr>
<td>Cheese and whey</td>
<td>1.0</td>
</tr>
<tr>
<td>Milk powder, cheese and/or liquid products</td>
<td>4.2</td>
</tr>
</tbody>
</table>

*Cooling water is included
Source: [89, EDA 2002]

Table: Water consumption for some Nordic dairies [42, Nordic Council of Ministers, et al., 2001]

<table>
<thead>
<tr>
<th>Product</th>
<th>Water consumption (l/processed milk)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sweden</td>
</tr>
<tr>
<td>Market milk and yoghurt</td>
<td>0.96–2.8</td>
</tr>
<tr>
<td>Cheese and whey</td>
<td>2.0–2.5</td>
</tr>
<tr>
<td>Milk powder, cheese and/or liquid products</td>
<td>1.7–4.0</td>
</tr>
</tbody>
</table>

Figures in brackets show the number of dairy installations in each category.
In the UK dairy industry, there is a wide variation in the water consumption/amount of milk processed ratio, compared to the volume of the milk received for processing per installation, as shown in Figure.

![Figure: Water consumption/processed milk ratio as a function of the quantity of processed milk](image)

Seven ice-cream installations in Nordic countries have reported a water consumption in the range 3.6–10.3 l/kg of produced ice-cream [42, Nordic Council of Ministers, et al., 2001]. For ice-cream installations where no water recycling is applied in the cooling system, a water consumption of 10–325 l/kg of product has been reported [118, CIAA-EDA, 2002].

### 5.3.3 Waste

The characteristics of dairy residues may vary significantly, depending on the final products, system type and operation methods used in the manufacturing plant. The solid and liquid wastes are mainly composed by different types of primary, secondary and tertiary packaging, servicing and testing materials, lubrication fluids, and waste consumables. Depending on the integration of the dairy facility, these may include either upstream wastes (from farming operations) or downstream wastes (from logistics and warehousing operations).

Dairy wastes are produced at many stages of the operations, from primary processing and separation of milk, through to production, packing and distribution of the final products. They can be liquid, semi-solid, solid, or diluted with water (as interfaces); unless discharged to the WWTP, they are collected in tanks or silos if liquid, but also in various containers and/or palletised if solid. Most dairy food waste is also governed by food and feed legislation, particularly the Animal By-Products Directive [99, EC 2002].

The solid wastes, on average, are mainly packaging related. The type of packaging varies significantly across Europe depending on both the primary container (which can range from multilayered carton-board through to a wide variety of plastics), and the type of retailing systems used in the different Member States from small shops to very large hypermarkets. Volumes of dairy wastes and their constituents differ over time. They are affected by the production profile of the plant which is usually a sequence of periodic processes.

A typical process flowmap of food wastes from dairy is shown in Figure 5.12.
Liquid waste –highlighted in blue boxes in Figure 5.12– is treated using traditional types of waste water treatment, anaerobic digestion or land spreading. A final waste solution is to incinerate, and this may be done if the dairy waste falls into Category 2 of the Animal By-Products Directive (contaminated with a foreign substance, such that it is unsuitable for human or animal consumption).

Dairy operators are increasingly finding ways in which to reprocess dairy food surpluses and by-products (e.g. whey, see Section 5.2.7) into other food, animal feed or energy materials.

Packaging waste such as paper, wooden pallets, big bags and plastic films, and other wastes need to be reused or disposed of. Wastes are also produced in fat traps, and in flotation and biological WWTPs. As well as these wastes, major solid or liquid wastes and by-products are also produced, e.g. whey residues, non-conforming products, sludge from separation during milk clarification and filtration, product loss on the heat transfer surface and discharged in the waste water during the cleaning of the equipment, curd waste, and small pieces of cheese. Whey may be segregated and processed to make further useful products. The non-conforming products are used as animal feed or sent for landfill and the sludge produced in the WWTP is sent for landfill.

Product losses in the dairy industry, expressed as a percentage of the volume of milk, fat or whey processed, are summarised in Table 5.3.

Table 5.3: Product losses in some processes in the dairy industry

<table>
<thead>
<tr>
<th>Type of processing</th>
<th>Product losses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Milk</td>
</tr>
<tr>
<td>Butter/transport of skimmed milk</td>
<td>0.17</td>
</tr>
<tr>
<td>Butter and skimmed milk powder</td>
<td>0.60</td>
</tr>
<tr>
<td>Cheese</td>
<td>0.20</td>
</tr>
<tr>
<td>Cheese and whey evaporation</td>
<td>0.20</td>
</tr>
<tr>
<td>Cheese and whey powder</td>
<td>0.20</td>
</tr>
<tr>
<td>Consumer milk</td>
<td>1.9</td>
</tr>
<tr>
<td>Full-cream milk powder</td>
<td>0.64</td>
</tr>
</tbody>
</table>

Source: [ 74, World Bank (IBRD) et al. 1998 ]
Reported solid outputs per tonne of processed milk are shown in Table 5.4.

Table 5.4: Solid output per tonne of processed milk

<table>
<thead>
<tr>
<th>Solid output (kg)</th>
<th>WWTP sludges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid milk and yoghurt</td>
<td>1.7–45.0</td>
</tr>
<tr>
<td>Cheese</td>
<td>1–20</td>
</tr>
<tr>
<td>Milk and whey powder</td>
<td>0.5–16</td>
</tr>
</tbody>
</table>

Product loss during milk manufacture can be as high as 3–4 %, with normally 0.5–1.5 % of product being wasted. These milk losses can occur during cleaning; the run-off during the start-up, shut-down or changeover of an HTST unit; or from accidental spills. Product losses to waste water can contribute greatly to the COD, nitrogen and phosphorus content. Typical milk losses are shown in Figure 5.13.

Figure 5.13: Typical losses of milk in the dairy industry

The main sources of wastes produced in milk, yoghurt and cheese processing are indicated in Figure, Figure and Figure.
Figure: Type and amount of wastes produced in milk processing

Figure: Type and amount of wastes produced in yoghurt processing
Chapter 5

Table gives the reported total amounts of waste produced in Nordic dairy installations and their disposal. The figures do not include waste that is intended for animal feed. Non-conforming products sent for landfilling are included.

<table>
<thead>
<tr>
<th>Products</th>
<th>Total solid waste (kg/1000 l)</th>
<th>Of which</th>
<th>Recycled</th>
<th>Incinerated</th>
<th>Composted</th>
<th>Sent for landfilling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market milk, cultured products</td>
<td>1.1–14</td>
<td>5–41 %</td>
<td>0–48 %</td>
<td>0–14 %</td>
<td>14–95 %</td>
<td></td>
</tr>
<tr>
<td>Cheese, whey, powder</td>
<td>0.5–10</td>
<td>1–91 %</td>
<td>0–80 %</td>
<td>0–2 %</td>
<td>9–88 %</td>
<td></td>
</tr>
<tr>
<td>Ice-cream (kg/1001 kg)</td>
<td>35–48</td>
<td>4–33 %</td>
<td>0–6 %</td>
<td>0 %</td>
<td>67–95 %</td>
<td></td>
</tr>
</tbody>
</table>

* The figures in brackets show the number of dairy installations in each category.
* Source: [21, Nordic Council of Ministers 2001].

Table: Production and disposal of solid wastes from some Nordic dairies

The overall solid output for ice cream manufacturing reported for Europe is in a wider range, i.e. 30–150 kg/t product [65, CIAA-EDA 2002].
5.3.4 Emissions to water

Waste water is the main environmental issue in the dairy sector. The sector uses a vast amount of water, and generates a huge amount of waste water in maintaining the required level of hygiene and cleanliness.

Table 5.5 shows reported waste water discharge flows in European dairies.

Table 5.5: Waste water discharge flows in European dairies

<table>
<thead>
<tr>
<th>Product</th>
<th>Waste water discharge flow (m$^3$/tonne of processed raw material)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market milk</td>
<td>0.32 – 5.07</td>
</tr>
<tr>
<td>Cheese</td>
<td>0.78 – 6.20</td>
</tr>
<tr>
<td>Powder (e.g. milk, whey)</td>
<td>1.21 – 2.95</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

Waste water volume in a well managed installation is reported to be about 1 – 2 l/kg of milk processed. Data reported for specific waste water discharge for dairy activities in Austria are shown in Table.

<table>
<thead>
<tr>
<th>Type of product</th>
<th>Waste water volume (l/kg of milk processed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“White” products, e.g. milk, cream and yoghurt</td>
<td>3</td>
</tr>
<tr>
<td>“Yellow” products, e.g. butter and cheese</td>
<td>4</td>
</tr>
<tr>
<td>“Special” products, e.g. concentrates of milk or whey and dried milk products</td>
<td>5</td>
</tr>
</tbody>
</table>

Table: Approximate volumes of waste water in dairy activities [152, Austria, 2002]

In the UK, around 14 million m$^3$ of milk is produced for processing each year. It is reported that a new dairy in the UK is achieving a 1:1 volume of milk processed:waste water volume ratio, i.e. one litre of waste water for each litre of milk litre processed and that a 1.5:1 ratio is achievable in existing dairies. A comparison is reported between a dairy generating 2 litres of waste water per litre of milk processed. This would produce around 28 million m$^3$/year of waste water for disposal to a WWTP. If this waste water is considered to have an average COD concentration of 3 000 mg/l, then the total loading would be around 84 000 t COD/yr, equivalent to the waste of more than two million people. Also, if 1 m$^3$ of milk is released into a watercourse, its oxygen depleting potential, in terms of BOD$_5$ load, is equivalent to the daily raw sewage of 1500 – 2000 people.

Untreated dairy waste waters have an average BOD$_5$ load ranging from 0.8 to 3.5 kg BOD$_5$/t milk. Other significant pollutants present in the waste water are phosphorus, nitrogen and chloride. Individual waste water streams of a wide pH range are produced. The temperature of the waste water streams may also need to be considered. The waste water may contain pathogens from contaminated materials or production processes [74, World Bank (IBRD) et al, 1998]. Table gives data on the typical untreated waste water from dairy processing.

<table>
<thead>
<tr>
<th>Component</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
<td>24 – 5700 mg/l</td>
</tr>
<tr>
<td>TSS</td>
<td>135 – 8500 mg/l</td>
</tr>
<tr>
<td>COD</td>
<td>500 – 4500 mg/l</td>
</tr>
<tr>
<td>BOD$_5$</td>
<td>450 – 1790 mg/l</td>
</tr>
</tbody>
</table>
Table: Reported untreated dairy waste water contamination levels [8, Environment Agency of England and Wales 2000]

Volume and emission levels of dairy waste water in Europe are shown in Table. The typical BOD of various milk products is shown in Table.

Table: Volume and emission levels of dairy waste water in Europe

Table: Typical BOD emission levels of various milk products

The largest proportion of waste water is cleaning water. This is used for equipment cleaning, e.g., line purging, at product changeover, start-up, shut-down and changeover of HTST pasteurisation units as well as some product washing.

Although CIP operations contribute to saving water, energy and chemicals, they still generate large volumes of waste water, which may have a high or low pH due to the use of acid and alkaline cleaning solutions. The use of phosphoric and nitric acids will increase the phosphate and nitrate content of the waste water. Badly designed CIP systems and inadequate product removal prior to the start of the CIP cycle cause large quantities of product to enter the cleaning.
water. Some UK dairy sites have achieved a reduction of 40–65% in their waste water COD as a result of improvements in this area [43, Envirowise (UK) and Entec UK Ltd., 1999]. Waste water with high concentrations of dissolved solids is produced by the regeneration of ion exchange resins and from membrane backwashing.

Large evaporators are used in the production of milk concentrate, which is the first stage in the production of milk powder, and dried whey. The evaporated water is condensed, giving rise to large quantities of condensate. Normally this is clean, but vacuum leaks on the condensers can lead to contamination with product. Condensate may be used in other processes, such as preheating incoming milk or as cleaning water after suitable treatment, e.g. RO, followed by disinfection.

There are smaller contributions to the waste water from the non-dairy ingredients used in some of the products and from lubricants. TSS are associated with coagulated milk, particles of cheese curd and non-dairy ingredients.

For cheese manufacturing, about 90% of the milk used ends up as whey. Sweet whey is often recovered and used as a food grade additive. Salt whey, produced after salt has been added to the curd to remove additional liquid, is not suitable for this application unless the salt is removed by RO. The RO permeate is highly saline. Unless whey is processed quickly, it becomes acidic due to lactic acid formation. If acid whey is discharged to a WWTP, it may cause low pH levels.

This waste water has an extremely variable composition, depending on the technology applied and whether whey is segregated. The characteristics of a typical waste water from cheese manufacturing are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Installation with whey recovery</th>
<th>Installation without whey recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD$_5$</td>
<td>2397</td>
<td>5312</td>
</tr>
<tr>
<td>COD</td>
<td>5312</td>
<td>20559</td>
</tr>
<tr>
<td>Fats</td>
<td>96</td>
<td>463</td>
</tr>
<tr>
<td>N$_{total}$</td>
<td>90</td>
<td>159</td>
</tr>
<tr>
<td>P$_{total}$</td>
<td>26</td>
<td>21</td>
</tr>
</tbody>
</table>

Table Composition of cheese manufacturing waste water [134, AWARENET, 2002]

**Example of a strategy to minimise the use of EDTA**

An example dairy processing whey used 60 tonnes of EDTA per year before it started to apply an enzymatic technique. Two million litres of whey per day, equivalent to 700000 t/yr, are processed in this installation to manufacture whey protein concentrate, functional whey protein concentrate products and whey protein extract. 13500 tonnes of lactose, 10000 tonnes of whey permeate, 5500 tonnes of whey protein extract, 2000 tonnes of sour whey powder and 1500 tonnes of milk protein concentrate are also produced.

The company has tried to reduce its emissions of EDTA. In early 1997, caustic was added to the detergent with the aim of reducing EDTA release by 30%. This did not prove efficient. Also in 1997, the company tried NTA as a substitute. This reduced the EDTA use by 50%, but this attempt was abandoned because of poor cleaning results, leading to a decrease in the microbiological quality of products.
An enzyme-based procedure was tried in the main installation for 1.5 years in 1998/99. The composition of the detergent was changed. It was found that chlorine and EDTA could be substituted by IDS for dissolving inorganic materials. This did not prove successful, probably because the cleaning, which was reportedly too effective, impeded the formation of the secondary membrane coating layer needed for protein filtration. This happened again when the membranes were replaced, so the company decided to abandon this option.

A similar enzyme-based procedure, combined with the use of phosphonates as chelating agents, was used in 1999 after being tested as an alternative procedure in a pilot plant in 1998. EDTA was not used at all. This resulted in difficulties in removing calcium compounds, especially calcium phosphate. This led to bacterial contamination and reduced performance.

Consequently, the company decided to combine the last technique with intermittent cleaning steps using EDTA a few times per month and by recycling the cleaning solution when cleaning NF membranes [127, Strohmaier, 2002].

### 5.3.5 Emissions to air

Many dairies produce thermal energy on site. Emissions of carbon dioxide, sulphur dioxide and nitrogen oxides derive from the energy production in the boiler plants and are not discussed here. Many dairies still use halogenated compounds in their cooling systems, mostly HCFCs, but small amounts of CFCs are still used in some countries. The interaction of halogen refrigerants with ozone in the air has resulted in the progressive prohibition of the placing on the market and use of ozone-depleting substances and of products and equipment containing those substances [202, EC, 2000]. There is currently a proposal for a Regulation of the European Parliament and of the Council on certain fluorinated greenhouse gases [246, EC, 2003].

Bag filters can be used to reduce dust emissions to <5 mg/Nm$^3$. Filters use significantly less energy than cyclones and produce less noise. If filtering installations suitable for CIP are used for outgoing air, it is not necessary to use cyclones, allowing huge energy savings and noise reductions to be achieved. The filter powder of food quality can be used for other purposes.

#### 5.3.5.1 Dust emissions from dryers

A general overview of the data received for dust emission from dryers is shown in Figure 5.14 (lower values) and Figure 5.15 (higher values).
Bag filters, cyclones and wet scrubbers are used as final abatement techniques for dust emissions from dryers. The combination of cyclones-bag filters is also a common implemented treatment schedule. Generally bag filters are associated with the lowest achieved dust emission levels.

The % O\(_2\) content in the emissions flow is often not reported, but from the received data it is assumed that most dryers operate close to atmospheric O\(_2\) levels.

**Figure 5.14**: Total dust emissions to air from dryers (1 of 2)

**Figure 5.15**: Total dust emissions to air from dryers (2 of 2)
5.3.6 Consumption of chemicals

Most of the chemicals are used for the cleaning and disinfection of process machinery and pipelines. Fresh product dairies mainly use caustic and nitric acid and some disinfectants, such as hydrogen peroxide, peracetic acid and sodium hypochlorite. Disinfection agents are also used in a range of 0.01–0.34 kg/t processed milk [160, European Dairy Association, 2002]. Table 5.6 shows the consumption of cleaning agents used in European dairies. Of the total chemical consumption in Nordic dairies, 55% is caustic and 30% nitric acid. Table 5.6 shows the consumption of cleaning chemicals used in some Nordic dairies.

Table 5.6: Consumption of cleaning agents used in European dairies

<table>
<thead>
<tr>
<th>Products</th>
<th>Consumption of cleaning agents (kg/t processed milk)</th>
<th>Caustic as NaOH, 100 %</th>
<th>Nitric acid as HNO₃, 100 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market milk and yoghurt</td>
<td>0.2–10</td>
<td>0.2–5.0</td>
<td></td>
</tr>
<tr>
<td>Cheese</td>
<td>0.4–5.4</td>
<td>0.6–3.8</td>
<td>0.1–1.5</td>
</tr>
<tr>
<td>Milk and whey powder</td>
<td>0.4–5.4</td>
<td>0.8–2.5</td>
<td>*</td>
</tr>
</tbody>
</table>

Values vary with the length and capacity of production runs
*Not applicable
Source: [89, EDA 2002]

Table: Consumption of cleaning chemicals used in some Nordic dairies [42, Nordic Council of Ministers, et al., 2001]

Whey processing involving electrodialysis, ion exchange, ultra and nanofiltration, requires large amounts of phosphoric, sulphuric and hydrochloride acid as well as potassium hydroxide and sodium hypochlorite. Chelating agents are widely used in dairy cleaning operations and are discussed in Sections 0 to 0.

Noise

Dairy installations situated in urban areas usually receive complaints regarding noise, e.g. associated with vehicle movements, refrigeration and UHT installations. Noise is caused by the movement of milk tankers and distribution lorries, evaporators, spray driers, and cooling condensers [21, Nordic Council of Ministers 2001]. Bag filters use significantly less energy than cyclones and produce less noise. If filtering installations suitable for CIP are used for outgoing air, it is not necessary to use cyclones allowing huge energy savings and noise reductions to be achieved.
5.4 Techniques to consider in the determination of BAT

5.4.1 General environmental performance

5.4.1.1 Reducing EDTA use by minimising milk fouling and milkstone formation by production planning

Description
Production planning to prevent the milk fouling and milkstone build-up and the consequent use of EDTA.

Technical description
Milk fouling and milkstone formation can be reduced by using milk with high protein stability. The stability of milk protein is reduced by repeated processing and pumping. Production planning to prevent reprocessing can, therefore, contribute to the prevention of milkstone build-up and the consequent use of EDTA. Milk fouling and milkstone formation are also higher if the milk has a high microorganism count, so can be reduced if adequate hygiene conditions are enforced. There are a number of other factors which cause protein instability in milk, such as enzyme activity.

Achieved environmental benefits
Optimal use of milk and reduced EDTA and energy consumption.

Environmental performance and operational data
By optimising the milk processing time and using good quality raw milk, in which proteins have high heat stability, the formation of milk fouling and milkstone can be reduced. The milk fouling and milkstone reduce the efficiency of the heat exchange and the flowrate, especially in plate heat exchangers. Consequently, indirect heat exchangers have to be cleaned no more than 8–9 hours after start-up. Longer times between cleaning may cause a build-up of milk fouling and milkstone which is more difficult to remove. A differential pressure gauge can be used to monitor the pressure drop between the processor inlet and outlet to judge when the equipment needs to be cleaned. Low milk quality affects the running time because the heat stability of the proteins is reduced and they precipitate easier on the surfaces.

The heat stability of milk may be checked by heating the milk to its boiling point and evaluating the amount of sediment produced or by a simple test carried out by mixing milk and ethanol and checking if any precipitation occurs on glass surfaces. More stable proteins require higher concentrations of ethanol for precipitation to occur.

The milk stability also determines the products which milk can be used to make. For example, milk containing higher stability proteins is required for drinking milk than for cheesemaking.

Cross-media effects
There are no cross-media effects associated with this technique.

Technical considerations relevant to applicability
Applicable in all dairies.

Economics
TWG, please provide information.

Driving force for implementation
Reduction of energy and waste water treatment costs.
Optimal use of milk and reduced EDTA consumption.
5.4.1.2 Use of computer-controlled milk transfer, pasteurisation, homogenisation and CIP equipment

Description
Use of computerised processes in dairies.

Technical description
An example dairy installation receives 450 000 litres of milk, at a quality complying with the Directive 92/46/EEC. The installation requires its suppliers to use mechanical milking, have proper refrigeration capacity and to apply HACCP. The flow sheet for the processing in the installation is illustrated in Figure 5.16.

![Flow sheet for dairy processing](image_url)
The milk reception is via two parallel programmable logic control closed systems. The introduction of a technique using special valves has significantly reduced the milk losses. It is reported that where the valves have been introduced, milk losses during transfer between pipes, when filling tanks and human errors have been totally eliminated, thus waste water pollution from that source, has decreased.

The milk is also pasteurised by computer controlled plate heat exchangers, which have a greater surface area for heat exchange than others and are equipped with automatic fat standardising and homogenising units.

The processing is carried out in a closed system. The control for storing and pumping the raw materials, intermediaries, and products to the different processing units of the installation is carried out by a computer aided system. Using this system, the losses have been minimised. The same control system operates the CIP system. Here, the last rinsing water is used for the next cleaning circle.

The pasteurised fresh milk is packed in PE bags, PET bottles or HDPE bottles.

In another example, the programming of chained sending of product to pasteurisation is implemented. While a product is being pasteurised, the next sending is programmed. So, the stand-by step is removed.

**Achieved environmental benefits**
Reduced milk wastage and waste water contamination. The computerised CIP system also led to reduced water and reagent savings.

**Environmental performance and operational data**
During pasteurisation, the greater surface area for heat exchange and the recirculation of warm water reportedly results in about 25% savings in energy consumption and about 50% savings in water consumption, in comparison with the old pasteuriser previously used.

The computerised process control avoids or decreases milk losses in reception and during further processing. The automatic dosing reportedly results in about 15% savings both in water and in the consumption of cleaning and disinfecting agents.

**Technical considerations relevant to applicability**
Applicable in new and existing installations. Increased yield is gained, and time is saved during this process.

**Economics**
Investment costs are high.

**Driving force for implementation**
Reduced costs for energy and water.

**Example plants**
At least one dairy Dairies in Hungary and Spain [193, TWG 2015].

**Reference literature**
[81, Sole 2003 ], [193, TWG 2015 ], [226, EDA 2016 ]
Process-integrated environmental management at a dairy – a case study

Description
The example dairy processes 1.2 million litres of milk per week, producing around 200 tonnes of yoghurt and 15 tonnes of cottage cheese per week. The balance of the milk is used for pasteurised and UHT milk and cream production. Waste water is discharged to a MWWTP.

The installation operator decided to upgrade the existing on-site WWTP, which comprised sedimentation of a proportion of the waste water, prior to discharge to sea. The estimated waste water treatment costs were halved by introducing and operating process-integrated techniques for minimising waste water generation and contamination.

All the staff were involved in completing the following actions:

- for cottage cheese, the whey was already collected for animal feed (see Section 5.4.4.6.3), but the number of tanks installed was increased to allow for the collection of curd washwater and yoghurt residues, also each tank was fitted with high level alarms (see Section 2.3.1.4)
- yoghurt pipelines were modified by incorporating 135° bends to improve drainage (see Section)
- drainage times on emptying yoghurt vats were increased by 5 minutes
- burst rinsing was introduced for yoghurt vats, with all rinsings collected for animal feed (see Section)
- a requirement to collect all the drainings of yoghurt and fruit throughout the dairy, for use as animal feed, was more rigidly enforced (see Sections 0 and ).

Achieved environmental benefits
Reduced waste water volume and pollution, e.g. COD.

Environmental performance and operational data
The MWWTP set consent standards of 1130 kg COD/d and a volume consent of 450 m$^3$/d, both of which were exceeded frequently. Average COD discharges were reduced to 450 kg/d and volumes were brought within the consent limits to around 420 m$^3$/d.

Economics
The waste water treatment charges were EUR 125 000/yr instead of the expected EUR 500 000/yr with very little investment cost.

Reference literature
[1, CIAA 2002]

5.4.2 Techniques to increase energy efficiency

5.4.2.1 Partial milk homogenisation of market milk

Description
The cream is homogenised together with a small proportion of skimmed milk. The size of the homogeniser can be significantly reduced, leading to energy savings.

Technical description
The cream is homogenised together with a small proportion of skimmed milk. The optimum fat content of the mixture is 12%. The rest of the skimmed milk flows directly from the centrifugal separator to the pasteurisation section of the pasteuriser. The homogenised cream is remixed into the skimmed milk stream before it enters the final heating section. Using this technique, the size of the homogeniser can be significantly reduced, leading to energy savings.
Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data
In an example dairy, the introduction of partial homogenisation into a pasteurisation line with a nominal capacity of 25 000 l/h led to a reduction in the homogenisation capacity to 8 500 l/h. The total electrical power was reduced by about 65 % by installing a smaller homogeniser of 55 kW.

Technical considerations relevant to applicability
Applicable in dairies.

Economics
Smaller homogenisers are cheaper in terms of investment costs and operational costs. The price of the smaller homogeniser is about 55 % of the price of a piece of equipment with the capacity to treat the nominal capacity of the line.

Driving force for implementation
Lower investment and energy costs.

Example plants
It is widely used in modern dairies.

Reference literature
[21, Nordic Council of Ministers 2001]

5.4.2.2 Energy-efficient homogeniser

Description
The homogeniser's working pressure is reduced through optimised design and thus the associated electrical energy needed to drive the system is also reduced.

Technical description
This technique allows reducing pressure with maintained homogenisation effect. The energy needed to drive a conventional homogeniser is proportional to the pressure at which the system runs in order to reduce the fat globule size sufficiently. The homogeniser working pressure can be reduced (through innovations in the design of the homogenisation device), and the associated electrical energy needed to drive the system could then be reduced.

Achieved environmental benefits
Reduced electricity consumption.

Environmental performance and operational data
With a homogeniser with an efficient design, electricity consumption could be reduced by about 30 % (see Table 5.7). Electric energy consumption could in such cases be reduced by an additional 15–33 % (savings increase with higher capacity).

Table 5.7: Comparison between two different homogenisation devices

<table>
<thead>
<tr>
<th></th>
<th>Conventional design (1)</th>
<th>Efficient design</th>
<th>Advanced design (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogenisation pressure (bar)</td>
<td>200</td>
<td>135</td>
<td>97</td>
</tr>
<tr>
<td>Electric power needed (kW)</td>
<td>151</td>
<td>104</td>
<td>75</td>
</tr>
<tr>
<td>Electricity use per year (kWh/yr)</td>
<td>724 000</td>
<td>499 100</td>
<td>360 900</td>
</tr>
<tr>
<td>Electricity cost per year (EUR)</td>
<td>72 400</td>
<td>49 910</td>
<td>36 090</td>
</tr>
</tbody>
</table>

(1) Conditions: homogeniser capacity 25 000 l/h; desired homogenisation effect 75 % NIZO; production time 4800 h/year; electricity price 0.1 EUR/kWh.
(2) The advanced design is only applicable to homogenisation of milk at capacities of 15 000 l/h or more.

Source: [182, Tetra Pak 2015]
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Technical considerations relevant to applicability
The technique is applicable to high-pressure homogenisation of emulsions and suspensions, aseptic or non-aseptic, high- or low-viscous products, including pasteurised milk, UHT milk, cream, yoghurt, condensed milk, ice cream mix, fruit juices, concentrates, etc.

Driving force for implementation
- Reduced operational cost.
- A lower pressure also means less load on the homogeniser, so maintenance and wear parts replacement intervals will be less frequent, which means reduced downtime.

Example plants
This technique is generally used in the EU-28 and in the world. For example, Arla Foods Holstebro in Denmark has implemented the advanced homogenisation device.

References
[ 182, Tetra Pak 2015 ]

5.4.2.3 Sterile water use in homogeniser

Description
Flushing the aseptic barriers with sterilised water instead of steam.

Technical description
This technology for high pressure aseptic homogenisers is based on flushing the aseptic barriers by sterilised water instead of steam. The sterile water at 50–60 °C is used in the plunger surface during reciprocating movement and it allows reducing friction and temperature between seals and plunger surface. The sterile water temperature is extremely relevant in order to extend the plunger seals lifetime two or three times compared to pressurized steam barriers systems.

Cold water enters the regenerative plate heat exchanger and by a system of connectors, arrives to steam injector which overheats the water. The liquid reaches thereafter a holding tube and stay for the sterilisation time. The liquid returns then to the regenerative plate exchanger, from which it started its cycle, though in the opposite way and in the exchanger cleaned side, where it cools down before reaching the homogenisation aseptic chambers.

Achieved environmental effects
Reduction of steam and water consumption. Water that before was used in the heat exchanger for the condensation, now is mixed with the steam.

Environmental performance and operational data
In an example dairy (#314), the old typical system uses around 300 kg/h of steam condensed to 50 °C with raw water in a heat exchanger (with usually no heat and water recovery). With the implementation of this technique 20 kg/h of steam consumption are estimated.

Economics
An investment cost of EUR 30 000 has been reported (for a homogeniser of 17 m³). The payback period is less than 1 year and a half.

Driving force for implementation
Improving installation's energy efficiency.

Example plants
At least one installation in Italy (#314).

Reference literature
[ 193, TWG 2015 ]
### 5.4.2.4 Use of continuous pasteurisers

#### Description
Flow-through heat exchangers are used (e.g. tubular, plate and frame). The pasteurisation time is much shorter than that of batch systems.

#### Technical description
In continuous pasteurisation, flow-through heat exchangers, e.g. tubular, plate and frame, are used. These have heating, holding and cooling sections. To reduce energy consumption and waste water generation, continuous pasteurisers are used instead of batch pasteurisers.

#### Achieved environmental benefits
Reduced energy consumption and waste water production, compared to batch pasteurisers.

#### Environmental performance and operational data
Batch wise pasteurisation uses a temperature of 62 to 65 °C for up to 30 minutes. Continuous pasteurisers include high temperature short time pasteurisation (HTST) and high heat short time pasteurisation (HHST). HTST uses a temperature of 72 to 75 °C for 15 to 240 seconds. HHST applies a temperature of 85 to 90 °C for 1 to 25 seconds.

#### Technical considerations relevant to applicability
Applicable in dairies.

#### Economics
TWG, please provide information.

#### Driving force for implementation
Reduced energy and waste water treatment costs.

#### Reference literature
[71, AWARENET 2002]

### 5.4.2.5 Regenerative heat exchange in a pasteurisation process

#### Description
The incoming milk in the countercurrent flow is preheated by the hot milk leaving the pasteurisation section.

#### Technical description
Pasteurisers are normally equipped with some regenerative countercurrent flow heating sections. The incoming milk is preheated with the hot milk leaving the pasteurisation section.

#### Achieved environmental benefits
Reduced energy consumption.

#### Environmental performance and operational data
Typically energy savings over 90 % can be achieved. It is reported that, in an example dairy, by applying indirect heat exchange between the after-thermal treatment product and the inlet product, the specific energy consumption of 148 000 kcal/t can be reduced by 80 %, i.e. to 29 000 kcal/t. The reported temperatures of the process are as follows:

- initial temperature of 4 °C
- regeneration heating temperature of 65 °C
- pasteurisation temperature of 78 °C
- regeneration cooling temperature of 20 °C
- pasteurised milk temperature of 4 °C.
Also, heat exchangers have reportedly been applied in the dairy between the inlet cold product, i.e. cold milk, and the steam coming from the extraction during vacuum expansion after UHT treatment. The specific energy consumption of 251 000 kcal/t can be reduced by 26 %, i.e. to 185 000 kcal/t. The reported temperatures of the process are as follows:

- initial milk temperature of 4 ºC;
- regeneration heating temperature of 70 ºC;
- UHT treatment temperature of 140 ºC;
- UHT milk filling temperature of 25 ºC.

Technical considerations relevant to applicability
It is widely applied in dairies. In older dairies, heating and cooling energy can be further reduced by replacing the old plate exchangers by more effective ones.

Economics
Reduction in energy costs. In an example installation (#133) investment costs of around 145 000 EUR (with low operating costs) have been reported for the installation of a new heat exchanger in milk pasteurisation [193, TWG 2015].

Another reported example comes from a new dairy, where nine plate exchangers were installed with higher regenerative efficiencies. Calculations were made for increasing the efficiency from 85 to 91 % or from 91 to 95 %. Savings in heating energy of 2 712 MWh/yr and in electricity of 542 MWh/yr were estimated, with an investment cost of EUR 370 000 and a payback of 3.6 years.

Driving force for implementation
Reduction in energy costs.

Example plants
Dairies in Denmark (installation #133) [193, TWG 2015].

Reference literature
[21, Nordic Council of Ministers 2001], [43, Italian contribution 2002], [193, TWG 2015].

5.4.2.6 Hibernation for pasteurisers and sterilisers

Description
The pasteuriser/steriliser unit is into hibernation mode during water circulation (for aseptic lines without losing the aseptic status).

Technical description
Often pasteurisers and sterilisers spend a significant amount of time in non-productive circulation. With the hibernation function the pasteuriser/steriliser unit will go into hibernation mode during water circulation (for aseptic lines without losing the aseptic status). During this mode the flow rate decreases, the cooling is reduced to a minimum and the total energy consumption (steam, electricity and cooling water) will be reduced.

Achieved environmental benefits
With the hibernation mode, unnecessary waste of energy is reduced when the pasteuriser/steriliser is in non-production circulation mode, e.g. waiting for raw material or for fillers to become available.

Environmental performance and operational data
A reduction in energy consumption during hibernation mode between 60 % and 85 % can be achieved. An example of energy savings is shown in Table 5.8.
Table 5.8: Energy reduction in a UHT unit by applying hibernation

<table>
<thead>
<tr>
<th>Milk treatment with UHT unit with direct steam injection (')</th>
<th>With hibernation</th>
<th>Without hibernation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam consumption (kg/h)</td>
<td>1 350</td>
<td>2 250</td>
</tr>
<tr>
<td>Electricity consumption (kW/h)</td>
<td>8</td>
<td>35</td>
</tr>
<tr>
<td>Tower water (kW/h)</td>
<td>350</td>
<td>1 050</td>
</tr>
<tr>
<td>Steam reduction (kg/year)</td>
<td>540 000</td>
<td>NA</td>
</tr>
<tr>
<td>Electricity reduction (kw/year)</td>
<td>16 400</td>
<td>NA</td>
</tr>
</tbody>
</table>

(') Capacity of UHT unit: 15 000 l/h. 2 h/day of water circulation, 3 000 days/year.
NB: NA = not applicable.
Source: [183, Tetra Pak 2015]

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique in dairies.

Driving force for implementation
Reduced operational cost.

Example plants
This technique is generally used in the EU and/or worldwide.

References
[183, Tetra Pak 2015]

5.4.2.7 Ultra-high temperature (UHT) process without intermediate pasteurisation

Description
UHT milk is produced in one step from raw milk, thus reducing the energy needed for pasteurisation.

Technical description
Cold raw milk, with fully crystallised fat, is preheated, separated, standardised to a predetermined fat content and homogenised. The milk is then heat-treated to UHT-temperature before cooled to ambient temperature and sent to aseptic buffer tanks. The process from raw milk to UHT-milk is thus made in one step with substantial savings in energy, product losses and equipment by removal of the traditional pasteurisation step.

Figure 5.17 shows a comparison between this technique and the conventional process.
Achieved environmental benefits
Reduction of steam, electricity, water, cleaning agents and product losses (waste generation).

Environmental performance and operational data
Compared with a traditional UHT process line, reduction of electricity consumption can be up to 38 %, steam consumption up to 45 %, fresh water consumption up to 60 %, and product losses up to 33 %.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique in dairies. It is also applicable for flavoured milk processes.

Economics
Reduction of investment cost of 30 % compared to a traditional line. Reduction of operating cost of 50 % compared to a traditional line.

Driving force for implementation
- Increase of production yield.
- Reduced total cost of ownership.
- Reduced floor space.

Example plants
This technique is implemented in 7–8 installations worldwide.

References
[ 185, Tetra Pak 2015 ]
5.4.2.8 Multistage Two-stage drying in milk powder production

Description
A spray-drying process is used in combination with a downstream dryer, e.g. fluidised bed dryer.

Technical description

After the milk has been thickened from 11% to 50–60% dry matter in an evaporator, the condensed milk may further be dried to 95–97% dry matter content. Spray dryers or roller dryers are used in milk powder processing. Although roller dryers may be found in the dairy sector and are sometimes useful for specialised products, spray dryers with downstream or integrated fluidised bed dryers (FBDs) have become more common (see Figure 5.8). This is due to their lower energy usage, the primarily dust-free product, and due to their reduced thermal stress which has influence on the specification of the product.

A spray drying process using a downstream FBD is also called a multi stage dryer—two stage drying. Most modern configurations are with three stages of drying. The multistep concept should be considered when building new installations and taking into account the economics. Product specifications should also be taken into account.

Figure 5.18 shows a two-stage drying process carried out by using a spray dryer with a rotary atomiser and a separate external FBD. The outlet air is filtered by a CIP filter, which consists of a tubular filter without cyclone.

When using multistage drying two-stage drying, lower residual product moisture with less harm to product quality as well as more efficient energy utilisation can be achieved. The solids leave the spray dryer with 3–5% residual moisture. The final drying step in the fluidised bed takes place under mild conditions with low energy usage.

Source: [19, German Dairy Association 2001]

Figure 5.18: A two-stage drying process in a large dairy
Achieved environmental benefits
Reduced energy and water consumption. Reduced dust emissions.

Cross-media effects
Spray dryers produce noise emissions and explosive dust/air mixtures can occur.

Environmental performance and operational data
A large dairy in Germany produces skimmed milk and sweet whey powder. It processes 240 000 t of raw milk and produces 19 000 t milk and whey powder. The dairy uses a two-stage drying system with a capacity of 1 t/h. The waste gas volume is 45 000 m$^3$/h. The drying process uses the largest share, i.e. 58 %, of the thermal energy consumption of the installation, i.e. 39 million kWh out of the total consumption of 67.5 million kWh. About 30 % of the total power consumption, i.e. 18 million kWh, was reportedly attributed to the drying process. In this example dairy, the reported specific electricity consumption was 315.8 kWh/t product or 25 kWh/t raw milk. The specific thermal energy consumption was 2052.6 kWh/t product or 162.5 kWh/t raw milk. Taking into account that about 600 kWh energy is required to evaporate 1 tonne of water, these figures are near to the theoretical energy need. The total water consumption of the drying step was also low, i.e. 9 500 m$^3$ or 0.5 m$^3$/t product or 0.04 m$^3$/t raw milk.

It is reported that if an integrated FBD is used, the energy consumption for drying can be reduced by approximately 20 %. Fire and explosion protection is required. An example of an early warning fire alarm is CO-detection.

Technical considerations relevant to applicability
Applicable in the dairy sector.

Economics
Investment involves additional capital and operational costs.

Driving force for implementation
Reduced energy and water costs.

Example plants
A large dairy making powdered milk in Germany.

Reference literature
[19, German Dairy Association 2001]

Use of an aseptic packaging system not requiring an aseptic chamber

Technical description
An example dairy installation receives 450 000 litres of milk. The installation requires its suppliers to use mechanical milking, to have proper refrigeration capacity and to apply HACCP.

UHT milk processing is applied, followed by homogenisation and online aseptic packaging. High efficiency tubular type heat-exchangers are used in this process. The brick-shaped packages are made of paper-based laminated material, which includes several layers of plastic film and aluminium foil. The packages are formed from a continuous strip of the material, which enters the filling machinery through a hydrogen peroxide sterilising bath. Subsequently, the strip is formed into a tube around the sterilised product feed line, and appropriate longitudinal and cross seams are made by heat-sealing the plastic inner surfaces as the package is filled. This continuous aseptic packaging system does not require an aseptic chamber.

The packaging process is shown schematically in Figure. The numbers in the unit operations in follow after those in Figure 5.16.
Aseptic packaging of UHT milk, without an aseptic chamber

Achieved environmental benefits
Energy saving in heat treatment, lower packaging waste and lower milk losses.

Environmental performance and operational data
The spoilage, when this system is used, is reportedly below 0.5%.

Technical considerations relevant to applicability
Applicable in new and existing installations.

Economics
Investment costs are high.

Driving force for implementation
Reduced costs for energy and water.

Example plants
At least one dairy in Hungary.

Reference literature
[81, Sole 2003]
Provision of in-line storage tanks to minimise product recirculation in pasteurisers

Technical description
A production line can be designed in such a way that the capacities of the individual components are optimised with respect to the others, in order to prevent product build-up or shortage in some parts of the line. Later changes in the production line or in the filling schedule might, however, disturb the balance causing interruptions in the continuous operation.

For instance, if the capacity of the in-line storage tanks is too small compared to the output of the pasteuriser in a pasteurisation line, the milk has to be recirculated in the pasteuriser several times during the day. This consumes energy and harms the quality of the product. Furthermore, longer interruptions increase the frequency of cleaning the pasteuriser.

Interruptions in the line and recirculation of the milk in the pasteuriser can be avoided or minimised by adapting the size/number of in-line storage tanks to the output of the pasteuriser and by optimising the product changeovers.

The total consumption of electrical power required for the running of pumps, homogeniser and centrifugal separator also decreases, as the total processing time becomes shorter. Reductions in cleaning frequencies reduce the consumption of energy, water and chemicals. The negative effect of excess heat treatment on the quality of the product is also reduced.

Achieved environmental benefits
Energy is saved mainly in the form of reduced cooling water consumption.

Environmental performance and operational data
In an example dairy, supplying a pasteurisation line with in-line storage tanks before filling, together with automation of the product changeovers, resulted in a 30% reduction of the processing time. The annual energy savings in this dairy amounted to 250 MWh in electrical energy and 230 MWh in thermal energy. The estimated payback period is 4.5 years.

Technical considerations relevant to applicability
Applicable in dairies. Lack of space might be a constraint in existing installations.

Economics
Lower operational costs, e.g. reduced energy and water consumption.

Driving force for implementation
This solution offers improved flexibility, better quality and lower operational costs, e.g. reduced energy and water consumption.

Reference literature
[21, Nordic Council of Ministers 2001]

5.4.2.9 Production of cheese

5.4.2.9.1 High temperature cheese ripening with later humidification and ionisation of the ventilation air

Description
The temperature of the air is increased to shorten ripening times. The ventilation air is humidified and cleaned by a discharge tube which ionises the air which is passed through ventilation ducts.
Technical description
In cheese manufacturing, the temperature of the air is increased to shorten ripening times. This leads to a reduction in the demand for storage facilities, cooling power and ventilation energy. As a higher temperature increases the risk of dehydrating the cheese and of contamination by mould, the ventilation air is humidified and cleaned by a discharge tube which ionises the air which is passed through ventilation ducts. As ions in the ventilation air react with dust particles, microorganisms and viruses, the air is effectively cleared of these sources of contamination.

Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data
In an example cheese installation, a project was started in January 1994 to reduce energy consumption. Before the project, the manufacturer stored cheese at 12 °C to allow ripening to take place. The temperature was increased to 15 °C. The ventilation air was humidified and cleaned of dust and microorganisms by ionisation prior to entering the warehouse. The new equipment allows the air temperature to rise to 16 °C at 85 % relative humidity. Energy savings amounting to 272 000 kWh/yr, or 85 000 m$^3$/yr of natural gas, were reported. A shortening of the ripening time by 50 %, an improvement of the product quality and a reduction of the consumption of plastics and fungicidal agents were also reported.

Technical considerations relevant to applicability
Applicable in cheese manufacturing installations. High temperature ripening is limited due to the desired taste, product quality and stability.

Economics
In the example installation, considerable savings were achieved in labour costs, maintenance and in the use of materials for cleaning the ventilation system. The payback period is around two years.

Driving force for implementation
Reduction in energy costs.

Example plants
A cheese warehouse in the Netherlands.

Reference literature
[77, CADDET 1997], [128, CIAA-Federalimentare 2003], [144, CIAA-EDA 2003]

5.4.2.9.2 Using ultrafiltration (UF) for protein standardisation of cheese milk

Description
The milk flows under pressure over a membrane that withholds the protein molecules, thus increasing the cheese yield per processed milk unit.

Technical description
Ultrafiltration (UF) can be used for protein standardisation of cheese milk. The milk flows under pressure over a membrane that withholds the protein molecules, thus increasing the protein content of the retentate. The membrane pore size ranges from about 10 to 100 nm.

As using UF leads to an increase in the cheese yield per processed milk unit, the generated quantity of whey is smaller compared to traditional standardisation. Furthermore, even when UF requires additional electrical power, thermal energy and water compared to traditional standardisation, in large scale production, the increase in cheese yield compensates for the increased consumption of energy and water. The permeate from the UF unit is further treated by RO. The RO water, which is of drinking water quality, can be used for cleaning purposes.
Achieved environmental benefits
Reduced energy and water consumption, whey and waste water in comparison with traditional standardisation.

Cross-media effects
The membranes need to be cleaned. As chemicals are used for this, the filtration circle has to be well rinsed with large amounts of water. Disposal of used membranes.

Environmental performance and operational data
The UF unit in a Danish dairy consists of 10 spiral wound modules equipped with polymer membranes, four pumps and the necessary flow transmitters and regulating valves. The filtration capacity is 65 000 l/h. The protein content of the milk is standardised to 3.7–3.8 % by controlling the ratio between feed and permeate. Compared to the traditional standardisation method, the cheese yield is higher, i.e. about a 12 % reduction in milk volume was gained. A calculation made for a 25 000 t/yr yellow cheese production, led to the estimated savings in water and energy shown in Table 5.9.

<table>
<thead>
<tr>
<th></th>
<th>Electrical energy</th>
<th>Thermal energy</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>473 MWh/yr</td>
<td>1 235 MWh/yr</td>
<td>7 500 m³/yr</td>
</tr>
<tr>
<td></td>
<td>19 kWh/t cheese</td>
<td>49 kWh/t cheese</td>
<td>300 l/t cheese</td>
</tr>
</tbody>
</table>

Source: [21, Nordic Council of Ministers 2001]

UF-membranes have a limited lifetime of 1–3 years due to application. After use they are incinerated or sent for landfill.

Technical considerations relevant to applicability
UF can be applied to both skimmed milk and whey. UF units can be installed in new and existing installations because of their low space requirements.

Economics
The investment cost in the example Danish dairy is EUR 430 000 and the payback period 5.9 years.

Driving force for implementation
Cheese of homogenous quality can be produced using this technique. It also offers a larger flexibility for making different types of cheese.

Example plants
A dairy in Denmark.

Reference literature
[21, Nordic Council of Ministers 2001]

Utilisation of heat from warm whey for preheating cheese milk

Technical description
The incoming milk is preheated with warm whey, which is simultaneously strained off from another vat. Heat exchangers and tanks are needed for circulating the water. Savings in energy for heating the incoming milk and cooling energy for the processed whey are achieved.

Achieved environmental benefits
Reduced energy consumption.
Environmental performance and operational data
In a Danish example dairy, the cheese milk is heated from 12 to 32 ºC with heat from a closed system with circulating water at 34.5 ºC. The temperature of the water decreases to 13 ºC and it is subsequently reheated in the cooling section of the whey pasteuriser, where the whey is cooled from 36 to 14.5 ºC. In addition to the plate heat-exchangers, two buffer tanks of 150 m³ were installed for the circulating water. Savings, assuming 250 million kg/yr whey, were estimated to be 1200 MWh/yr electrical energy, 6065 MWh/yr heat energy and 4200 m³/yr water.

Technical considerations relevant to applicability
Applicable in new and existing installations. In existing installations, the lack of sufficient space can be a constraint.

Economics
In the Danish example dairy, the cost estimation was made, but this was for the whole whey processing, including an RO unit as well as the heat treatment and heat recovery. The total costs amounted to about EUR 1.6 million with a payback of 3.8 years.

Driving force for implementation
Reduced energy costs.

Example plants
A dairy in Denmark.

Reference literature
[21, Nordic Council of Ministers 2001]

Heat recovery from pasteurisation in ice-cream production

Technical description
Heat and water can be recovered from the ice-cream pasteurisation process. The ice-cream mix enters the pasteuriser at a temperature of 60 ºC and is then heated to 85 ºC, followed by cooling to 4 ºC prior to ageing. The cooling phase consists of two steps. In the first step, the ice-cream is cooled to 70 ºC by regenerative heat-exchange and in the second step, cooling water is used for further cooling to approximately 20 ºC. The final temperature of 4 ºC is achieved by cooling with ice-water.

The heat released to the water, from the ice-cream mix in the second cooling step can preheat the water for various purposes, mainly for cleaning operations. This requires a number of storage tanks for the hot water.

Achieved environmental benefits
Reduced energy and water consumption.

Cross-media effects
The hygiene quality of the water has to be checked as leaks in the plates of the heat-exchanger can result in contamination of the water with the product.

Environmental performance and operational data
In an example ice-cream installation, the heat from the second cooling step is used for preheating—approximately 25 % of the total amount of water used in the installation. The heat recovery yields hot water at approximately 70 ºC. The average inlet temperature of the cooling water is 10 ºC and the corresponding quantity of heat recovered is 7.600 GJ/yr, which represents approximately 14 % of the energy consumption of the installation. The hot water is used for CIP and the quantity of water saved is approximately 1000 l/t of ice-cream mix produced.
Technical considerations relevant to applicability
Applicable in new and existing installations. Space is needed for water storage tanks.

Economics
Reduced costs for energy and water.

Example plants
At least one ice-cream installation in Sweden.

Reference literature
[21, Nordic Council of Ministers 2001]

5.4.3 Techniques to reduce water consumption

5.4.3.1 Dry cleaning

This technique is described in Section 2.3.3.2.1.

Technical description
Reported examples of where the technique is applied:

- adopt dry cleaning methods to collect the solid residues from cheese production;
- sweep curd losses instead of washing them to the drain;
- treat spills of curd, yoghurt or ice-cream mix as waste rather than just washing them to the drain;
- use dry processes to collect excess salt rather than just washing it to the drain;
- fit drains with screens and/or traps to prevent any solid material from entering the waste water.

Technical considerations relevant to applicability
Use of compressed air might not be applicable for existing installations as it may not be possible to fill in a cooled block of butter. In such cases the butter can be removed with use of compressed air and then steam or hot water. The melted butter should be leaded back to a tank for reuse in the process [226, EDA 2016].

Reference literature

5.4.3.2 Reduce cleaning requirements of centrifuges by improved preliminary milk filtration and clarification

Description
By improving the preliminary milk filtration and clarification processes, the deposits in the centrifugal separators are minimised, leading to a reduction of the frequency of cleaning.

Achieved environmental benefits
Reduced water consumption and waste water pollution.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
TWG, please provide more information.
Technical considerations relevant to applicability
Applicable in dairies.

Economics
TWG, please provide information.

Driving force for implementation
Savings in water consumption.

Example plants
TWG, please provide information.

Reference literature
[ 71, AWARENET 2002 ]

5.4.3.3 Reuse and recycling of water for cleaning

See also Section 2.3.3.1.1.

Description
Reuse and recycling water for cleaning in dairies.

Technical description
Cooling water, condensates generated in evaporation and drying operations, permeates generated in membrane separation processes and cleaning water can be reused in dairy installations (e.g. condensate from the evaporator could be reused for the rinse step in the CIP). In the design, it is important keep in mind, in one hand, their quality characteristics and temperature of each water streams and, in the other hand, the quality and temperature requirements in each process. This reuse is dependent to microbiological and chemical quality of this water and the hygienic and microbiological requirements of installations. One way of minimising any hygiene risks is to treat the water with UV radiation.

In two Spanish installations (#189, #191), the mainstreams to be reused are:
- the production condensates which they are generated during thermal treatments and freezing and refrigeration;
- heated water from refrigeration: a right hygienic quality will be ensured if product contact surface is cleaned with this water;
- rejected water from reverse osmosis: its reuse is possible for washing-down of surface.

In some cases, cross-contamination risks will need to be considered when reusing water, for instance between starter batches in cheesemaking.

Avoiding an unnecessary contamination of condensate maximises the potential for water recycling or reuse, sometimes without any treatment, depending on the intended use. The cleanest condensate may be suitable for use as boiler feed-water.

Table 5.10 shows some water recycling opportunities in dairies.
Table 5.10: Water recycling opportunities at dairies

<table>
<thead>
<tr>
<th>Reuse</th>
<th>Use</th>
<th>CIP used cleaning solution</th>
<th>CIP final rinse</th>
<th>Condensate</th>
<th>Permeate from RO installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning the outsides of vehicles</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Crate cleaning</td>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Manual cleaning of the outside of equipment</td>
<td></td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CIP pre-rinse</td>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CIP main cleaning supply</td>
<td></td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>CIP final rinse</td>
<td></td>
<td>NO</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Water purge of product lines</td>
<td></td>
<td>NO</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

NB: 1=Direct reuse; 2=Reuse after screening of solids; 3=Reuse after advanced treatment, e.g. membrane separation and/or disinfection.

Source: [192, COM 2006]

For more information about water recycling in dairies after using membrane separation techniques, see Section 5.4.3.4.

Water from the cheese production can also be reused. In a Danish installation (#129), this water is pasteurised to ensure that it has drinking water quality, and is used it for CIP cleaning in production area.

Many dairy operations involve cooling with cold water in heat exchangers, which results in warm cooling water. Usually the warm cooling water from the process is reused for cleaning purposes, mainly for cleaning milk tankers. Warm cooling water can generally be used for cleaning the installation, regardless of its temperature. In the dairy industry, water above 50 °C can be reused for the cleaning of milk tankers or for the manual cleaning or CIP of equipment.

**Achieved environmental benefits**

Reduced water and energy consumption and waste water generation, and reduced contamination of waste water.

**Environmental performance and operational data**

It is reported that an example dairy in the UK processing 2 500 tonnes of milk per day recovers all condensate from its evaporators and then treats it by RO and disinfects it to provide cleaning water. The amount of water evaporated is of the order of 2000 m$^3$/d. Approximately 10 % of incoming flow is rejected and sent to waste water treatment. The company aims to have zero drinking water input to the site. Before treatment, the warm condensate is used to initially preheat incoming milk.

The use of membrane techniques in whey processing enables valuable by-products, whey protein concentrate and lactose concentrate to be produced. When an RO stage is included, demineralised water is produced which is suitable for use as boiler feed-water or membrane CIP.

In an example Nordic dairy reusing warm cooling water for cleaning, a reduction in water consumption of about 2 % has been reported [21, Nordic Council of Ministers 2001].

In a Swedish installation (#393) cooling water is collected and stored it as lukewarm water in a 100 m$^3$ tank. This water is reused for the CIP process. The water is stored at approximately 70 °C. This will save the energy that is required to heat up the water from 8 °C to 70 °C.
Cross-media effects
Electricity consumption for pumps.

Technical considerations relevant to applicability
Reusing cooling water can be applied in new and existing installations. The space requirements for the warm water storage tanks may be a constraint in existing installations. Its use also depends upon what chemicals, if any, were previously used in the cleaning.

Economics
High investment cost, low operating cost (#189, #191). [193, TWG 2015]

Driving force for implementation
- High savings in terms of waste water treatment cost.
- Reduced need to purchase drinking water and the production of valuable by-products.

Example plants
Two dairies, one in Sweden and the other in Finland are reusing warm cooling water for cleaning [21, Nordic Council of Ministers 2001]. At least one milk producing dairy in the UK uses treated evaporator condensate for cleaning.

Installations #129, #189, #191 and #393. [193, TWG 2015]

Reference literature
[21, Nordic Council of Ministers 2001], [57, Environment Agency of England and Wales 2002], [193, TWG 2015]

5.4.3.4 Water recycling by using membrane filtration techniques

See also Section 2.3.3.1.1.

Description
Recycling of water in dairies by using membrane filtration techniques.

Technical description
Used water, from various dairy production steps is purified using membrane filtration techniques and recycled in several process parts. This high quality water can then be recycled as boiler feed water, process, cooling and/or rinsing water or be discharged directly into a drainage ditch. Examples of water recycling in dairies include:

- condensate from evaporation plants can be filtrated in a condensate polisher to convert a waste stream into a water stream, using RO;
- waste water is sent to an UF and RO plant and reused in the process;
- waste water from the activated sludge treatment is reused to the CIP, after passing through UF and RO membranes.

Achieved environmental benefits
Reduction of water use and waste water generation. Valuable by-products can be produced and waste generation reduced.

Environmental performance and operational data
In installation #406 water vapour produced during evaporation of whey is condensed and recycled within creamery operations following treatment in reverse osmosis membrane plant. Process condensate from the evaporator is monitored by conductivity probes to check for any product entrainment prior to being fed forward to the membrane plant to protect the membranes. Recovered water (permeate from membrane plant) is routed to process water tank along with
other sources of incoming water used for applications such as CIP make up and rinse, boiler make up, cooling tower make up etc. This recovery of process condensate for recycling reduces:

- freshwater abstraction by over 300 000 m$^3$/year contributing more than 50% of current site demand;
- energy consumption associated with treatment of waste water;
- chemical use associated with treatment of waste water.

Moreover in installation #406, significant investment has been made in process water treatment. This includes additional capacity for process effluent balancing, anoxic treatment, aeration and settlement. This supplements existing physico-chemical (dissolved air flotation) and biological (aerobic) treatment processes. The investment in the process water treatment plant also extends to multiple stages of tertiary treatment to produce a high quality water (biologically inert and conductivity < 200 µS/cm) suitable for reuse in dairy process operations (see Figure 5.19). The water treatment system to enable reuse is designed to recover 1 700 m$^3$/day of water for return to process in the creamery. Several stages of treatment are required including membrane separation processes (UF followed by RO) with the resultant permeate receiving subsequent ultra violet treatment and chlorination. The permeate is then returned to the creamery for use in production processes.

![Water Recycling Scheme in a Dairy](image)

**Figure 5.19: Water recycling scheme in a dairy**

In installation #408, separated whey is sent through a Ultra Filtration (UF) plant where the proteins are removed. The condensate from the UF is then sent through a Reverse Osmosis membrane plant which separates the water and lactose. The lactose is sent for further processing and then the water (milk water) is then further filtered through a membrane polisher. This polished water can then be used in CIP or as boiler make up water.

In installation #295, product condensates are put through an RO to produce water for several secondary applications such as CIP.
Cross-media effects
Consumption of energy is required to treat the waste water. Use of chemicals, due to requirements in regards of protection of the membrane material.

Technical considerations relevant to applicability
Applicable in all dairies.

Economics
Operating costs are usually high in membrane plants but depends on the scale of the installation. The investment in enhanced waste water treatment and recovery enables the production of recovered water from process waste water suitable for reuse in creamery operations at less than 50% of the purchase price of municipal potable water [193, TWG 2015].

Driving force for implementation
Reduction in costs related to water and energy supply.

Example plants
Installations #295, #406, #408.
At least one cheesemaking dairy in the UK produces demineralised water from RO and uses it as boiler feed-water or membrane CIP.

Reference literature
[26, Envirowise (UK) 2000], [193, TWG 2015]

Reusing warm cooling water for cleaning

Technical description
Cleaning is the most water consuming process in the dairy sector and large savings are possible in this area.

Achieved environmental benefits
The water and energy savings depend on the amount of re usable warm cooling water used and its temperature.

Environmental performance and operational data
When using this water for cleaning surfaces which may be in contact with products, the hygiene of the warm cooling water is of the utmost importance. The quality is generally good, provided that the water does not contain any traces of product from leaks in the equipment. Normally, it is stored for some time in an insulated buffer tank awaiting further use. The use of UV radiation and other techniques are described in Sections 0, 0 and 2.3.6.3.8.

Technical considerations relevant to applicability

Economics
The costs are associated with the installation of the equipment required for reusing warm cooling water for cleaning, i.e. a storage tank and pipework for collection and distribution of the water.

Driving forces for implementation
Reduces costs for water and energy.

Example plants

Reference literature
[21, Nordic Council of Ministers 2001]
5.4.4 Techniques to reduce waste

5.4.4.1 Segregation Separation of residues of outputs, to optimise use, reuse, recovery, recycling and disposal (and minimise water use and waste water contamination)

Description
This technique is described in Section 2.3.5.3.

There are many other opportunities to apply this technique within the sector:

- collect leaked and spilt ingredients and partly and fully processed materials;
- collect whey which is not intended for making mitzithra cheese, baby food or other products;
- collect milky waste water generated at the start-up of pasteurisers;
- recovery of the milk with presses from briks refused due to defects;
- keep the solid waste obtained after centrifugation from entering the waste water;
- collect and recover product/product mixtures from product changeovers;
- separate and collect buttermilk, first rinses and residual fat in butter churning operations, to use it in other processes, e.g. as a base for low fat spreads;
- collect rinsings from yoghurt vats;
- collect the drainings of yoghurt and fruit throughout the dairy;
- collect and empty the products from wrongly filled containers for use as animal feed, e.g. by maceration of packaging;
- measure the fats/solids in the line (using a turbidity meter) and re-direct them to a balance tank (can then be re-dosed into the pasteuriser to increase the product yield);
- general separation of the liquid from the packaging;

Environmental performance and operational data
In a Swedish installation (#387) a rotating compressor screw crushes the packages and drain off liquid products. A compressor screw squashes 99.5 % of the liquid out. The liquid products are reused as animal foodstuff or can be anaerobically digested to produce biogas. The packaging is then shredded and used as fuel at co-generation facilities or can be sent for recycling into new cardboard. The system capacity is 8 000 Packages/hour (board) and 5 000 Packages/hour (plastic). [193, TWG 2015]

Technical considerations relevant to applicability
Applicable to all dairies.

Economics
An investment cost of around EUR 250 000 has been reported for the installation of a separation system of liquid from the packaging (capacity: 8.000 packages/hour for carton, 5.000 packages/hour for plastic) [193, TWG 2015].

Example plants
Installations #314, #387 and #405. [193, TWG 2015]

Reference literature

5.4.4.2 Just-in-time mixing component filling
Description
Milk products are diversified as late as possible, preferably immediately prior to filling.

Technical description
A filling machine concept called component filling enables milk products to be diversified as late as possible, preferably immediately prior to filling. In this machine there are two pipelines, one with skimmed milk and the other with milk of a standardised fat content. These are mixed at the filling machine to the ratio required for each particular product. For example, a dairy might produce three types of milk, with three different fat contents and these would be achieved by changing the amount supplied from the two pipelines. Losses of product and packaging materials caused by changeovers in production can be eliminated using this technique. Component filling also reduces the need for in-line storage tanks and the corresponding cleaning requirements.

Achieved environmental benefits
Reduced product and packaging waste. Reduced water consumption, e.g. for cleaning and reduced waste water pollution.

Environmental performance and operational data
Normally, 75–100 litres of milk can easily be lost because of the changeover of production in a traditional filling operation.

Technical considerations relevant to applicability
Applicable to new and existing milk production installations. Modification of the pipework and an automation system is needed before installing the machine in an existing installation.

Economics
The price of a new component filling machine with a filling capacity of 12 000–12 500 packs/h is approximately EUR 1 million (2001), not including any process modification that may be needed. In many cases, one component filling machine may replace several ordinary fillers.

Driving force for implementation
Flexibility of the production is increased, allowing a more consumer-driven approach. The faster the product moves through the supply chain, the need for cold storage space is reduced.

Example plants
There are a total of three component filling machines in the Nordic countries, including one in Finland.

Reference literature
[21, Nordic Council of Ministers 2001], [109, Finland 2003]

Online detection of transition points between the product and the water phases
Technical description
Pipelines are usually filled with water before start-up. Water is then pushed out by the product through a drain valve. Traditionally, drain valves were closed manually according to visual observation or automatically by counting the time needed to fill the pipeline with the product. To achieve an accurate detection of transition points between the product and the water phases, online methods are now used for fully automated production lines, e.g., measuring the volume using flow or density transmitters; measuring the density using conductivity transmitters (see Section 2.3.1.5) and using optical sensors (see Section 2.3.1.6) to differentiate water from the product.

These techniques can be used to recover product from CIP initial rinses, HTST start-up, shut-down and changeover and from the rinsing of other equipment and pipework.
Achieved environmental benefits
Reduced waste water pollution.

Environmental performance and operational data
Optical sensors are reportedly the most reliable, accurate and have a shorter response time compared to the other online methods. It is reported that when using optical sensors, the amount of rinse water containing milk that goes to the WWTP can be reduced to a couple of litres per start up. In addition, product losses can be reduced by 50 %. In filling lines used for liquid milk products, the use of these sensors reduced the amount of changeover mixtures by 30 – 40 %.

In an example installation using conductivity transmitters, the BOD load in the waste water decreased by 30 %. Regular calibration of the density transmitter is needed.

Technical considerations relevant to applicability
Transmitters and sensors can be installed both in new and existing installations. Minor modifications in the process control system are needed to install them.

Conductivity transmitters are mostly used in CIP centres for detecting the transition points between water and detergent solutions, but they can also be used for production lines. Optical online sensors are commercially available. They can be used for the standardisation of the fat content of milk.

Economics
The price of an optical sensor is about EUR 2 700 (2001). The cost of implementing process control includes, not only the price of sensors, but also other associated hardware and software, e.g. transmitters and display equipment.

Driving force for implementation
Product losses and waste water treatment costs are reduced.

Example plants
An example dairy in Finland has installed 61 online optical sensors in its process lines. Conductivity transmitters and flow transmitters are widely used in Nordic countries.

Reference literature
[21, Nordic Council of Ministers 2001]

5.4.4.3 Optimised operation of centrifuges
Minimisation of waste from centrifugal separators

Description
Operation of centrifuges according to their specifications to minimise the discharge of product as waste.

Technical description
Both the frequency and the volume of waste discharges from centrifuges are usually specified by the manufacturers of the equipment. Where this information is known, the actual performance can be checked against the specification. By running the equipment at its specified performance, it may be possible to reduce the amount of the phase discharged as waste and increase that retained as product, whilst maintaining quality and hygiene standards. This may be achieved by maintaining close co-operation with quality assurance personnel.

Achieved environmental benefits
Reduced wastage of raw materials.
Environmental performance and operational data
It is reported that in dairies, 1 % of raw milk supplied is wasted and that 0.1 % of this is during the processing of the milk and most of that is lost via discharges during centrifugal separation.

Technical considerations relevant to applicability
Applicable for all centrifugal separators.

Driving force for implementation
Reduced loss of raw materials and increased yield.

Reference literature
[ 7, Environment Agency of England and Wales 2000 ]

5.4.4.4 Butter production
5.4.4.4.1 Rinsing of the cream heater with skimmed milk or water Minimisation of losses during buttermaking

Description
Rinsing of the cream heater with skimmed milk or water which is then recovered and reused, before the cleaning.

Technical description
Due to the high viscosity of cream, the cream heater may be rinsed with skimmed milk or water, which are then retained and reused, before the cleaning. This reduces fat losses. Buttermilk which results as a by-product can be used as a product and not disposed of, e.g. into the waste water. These savings may be used, e.g. as a base for low fat spreads.

Achieved environmental benefits
Reduced food waste.

Technical considerations relevant to applicability
Applicable in butter and cream making.

Economics
TWG, please provide information.

Driving force for implementation
Reduced waste and increased product yield.

Example plants
TWG, please provide information.

Reference literature
[ 226, EDA 2016 ]
5.4.4.5 Production of ice cream

5.4.4.5.1 Continuous freezing of ice cream mix

Description
Continuous freezing of ice cream mix using optimised start-up procedures and control loops that reduce the amount of start-up rework and waste.

Technical description
Continuous freezing of ice cream mix using optimized start-up procedures and control loops that reduce the amount of start-up rework and waste. The improved control also gives a much more even output, closer to desired target. This is achieved by decreasing the standard deviation. This leads to less waste, or alternatively, the ice cream producer can make more sellable products from the additional amount of ice cream mix within the same available time and without extra use of raw material.

Achieved environmental benefits
This technique leads to a more efficient utilisation of raw material (ice cream mix), which avoids environmental impact in the whole supply chain. It also reduces waste and consequently the TOC or COD load in the waste water. Finally, it reduces electricity consumption.

Environmental performance and operational data
Considering, for example, an ice cream bulk filling line with a capacity of 4,000 litres/hour. With two product changes per day, the COD effluent load in the start-up waste could be reduced from 20 to 13 kg COD/tonne ice cream mix (35% reduction). With more stops/product changes the reduced amount of start-up waste and COD load will be even higher.

In another example, an installation with a production capacity of 2,000 litres ice cream/hour, a production time of 3,000 hours/year, 2 basic start-ups per day, 2 product changes per day, the benefits of applying this technique can be:

- less start-up waste: 12,500 kg/year (25,000 litres);
- less product waste: 25,000 kg/year (44,000 litres);
- reduced electricity consumption: 12,000 kWh/year.

Technical considerations relevant to applicability
This technique can be applied in ice cream installations with continuous freezing of ice cream mix. It can be used both in new installations and for upgrading existing ice cream freezers.

Economics
The pay-back time is normally less than one year.

Driving force for implementation
- Reduced operational costs.
- Shorter start-up times.
- More sellable products per kg of ice cream mix and thus higher profit.

Example plants
This technique is in operation in many ice cream installations of the EU-28 and savings have been validated.

Reference literature
[181, Tetra Pak 2015]
5.4.4.6 Cheese production

5.4.4.6.1 Minimisation of the production generation of acid whey and its discharge to the WWTP

Description
Whey is processed as quickly as possible to reduce the formation of lactic acid.

Technical description
For acid type cheeses, lactic acid mother cultures are grown on media and then bulk cultures are propagated and added to milk to make cheese. Acid whey is separated after curd formation. If acid whey is discharged to a WWTP, it may cause low pH levels. To prevent this, spillages are avoided by draining the top or platform of the salting vats. In addition, whey can be processed quickly so less acid whey is produced due to lactic acid formation.

Achieved environmental benefits
Reduced waste water pollution.

Technical considerations relevant to applicability
Applied in the manufacture of acid type cheeses, e.g. cottage cheese, quark and mozzarella.

Economics
Reduced waste water treatments costs.

Reference literature
[ 8, Environment Agency of England and Wales 2000 ]

5.4.4.6.2 Reduction of fat and cheese fines in whey

Description
The highest possible yield of fat and protein is achieved and after, the whey is screened to collect remaining fines.

Technical description
To accomplish the reduction of fat and cheese fines in whey, first, during the processing of the curd, the highest possible yield of fat and protein is achieved and after, the whey is screened to collect remaining fines.

Achieved environmental benefits
Reduced product loss. If whey is allowed to enter the WWTP, the pollutant load is lower, but see Section 5.4.4.6.1 for minimising this.

Cross-media effects
There may be odour emissions, depending on, e.g. the type and size of the fines screened.

Technical considerations relevant to applicability
Applicable in cheese manufacturing installations.

Economics
Optimisation of production costs. Reduced waste water treatments costs.

Driving force for implementation
Reduced product losses.

Example plants
TWG, please provide information.
5.4.4.6.3 Recovery and use of whey

Description
Whey is recovered (if needed using techniques such as evaporation or membrane filtration) and used, e.g. to produce proteins or mitzithra cheese or as a carbon source in a biogas plant.

Technical description
Sweet whey is produced during the making of rennet type hard cheeses, e.g. cheddar or Swiss cheese. Salt whey is produced after salt has been added to the curd to remove additional liquid. Sweet whey is collected and reused in the process or in other processes to make by-products, e.g. for protein recovery, as animal feed, in the production of mitzithra cheese, as a food supplement and as baby food. Even when salt whey cannot be reused in the process without the removal of the salt, it can either be collected as it is, or concentrated by evaporation and used as animal feed.

The whey can be sent to an ultrafiltration plant where the proteins are removed. The condensate from the UF is then sent through a reverse osmosis membrane plant which separates the water and lactose. The lactose is sent for further processing and then the water (milk water) is then further filtered through a membrane polisher. This polished water can then be used in CIP or as boiler make up water.

Figure 5.20 shows a flow diagram of a membrane processing system in cheese manufacturing.

Achieved environmental benefits
Reduced waste water pollution. Reduced waste, i.e. whey is reused.

Environmental performance and operational data
In a dairy installation, whey, a by-product of cheesemaking, is concentrated using an evaporation stage prior to spray drying to make whey powder. The evaporators are regularly
cleaned in place, which involves flushing out residual concentrated whey prior to detergent cleaning, i.e. pre-rinsing. A significant quantity of whey was being lost to drain when the evaporator was taken off-line for CIP [192, COM 2006].

A turbidity probe was installed at the end of the fill line to the concentrate tank as part of an automatic recovery system. The probe detects the presence of water/whey mixtures and sends this information back to the control system. Recovery of concentrated whey to the whey storage tank is then controlled via a densiometer, while the turbidity probe controls the recovery of the water/whey mixture to a separate tank. The mixture is subsequently mixed with raw whey for reprocessing. When the turbidity is between certain set points indicating the presence of whey, the flow is automatically diverted to the recovery tank via actuated valves. When the detergent cycle starts, the probe signal is overruled to ensure no acid or alkaline detergent is diverted into the whey tank. Contamination of the recovered whey is avoided and only clear or water containing detergent is discharged for waste water treatment. The whey recovery process is shown in Figure 5.21.

It is reported that no problems have occurred since the whey recovery system began operating in 1996. When the system was first installed, training was provided for operators to make them aware of how the new system operated and its benefits. Operating costs are reported to be negligible and the turbidity probe requires little maintenance. The probe is cleaned in place when the main evaporator is cleaned. Planned maintenance is performed annually. The benefits reported include cost savings, increased product yield, less whey lost to drain and lower WWTP costs.

The characteristics of a typical waste water from cheese manufacturing with and without whey recovery are shown in Table 5.1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Installation with whey recovery</th>
<th>Installation without whey recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD₅</td>
<td>2.397 mg/l</td>
<td>5.312 mg/l</td>
</tr>
<tr>
<td>COD</td>
<td>8.413 mg/l</td>
<td>20.559 mg/l</td>
</tr>
<tr>
<td>Fats</td>
<td>96 mg/l</td>
<td>463 mg/l</td>
</tr>
<tr>
<td>N_total</td>
<td>99 mg/l</td>
<td>159 mg/l</td>
</tr>
<tr>
<td>P_total</td>
<td>26 mg/l</td>
<td>21 mg/l</td>
</tr>
</tbody>
</table>
In installation #406, liquid whey is concentrated in a multistage evaporator. The initial concentration is carried out through Mechanical Vapour Recompression (MVR), raising the solids from 6% to 35%, followed by further concentration through Thermal Vapour Recompression (TVR), raising the solids to 60% prior to crystallisation and subsequent spray drying. Typically 3 500 MWh per year (electricity) are used in MVR compressor motors.

In installation #005 savings of 22 000 kWh electrical power each month and 500 t steam yearly have been achieved with the application of RO for whey thickening, in comparison to the prior used method of vacuum evaporation.

In installation #127, whey from cream cheese manufacturing is sent to biogas plant in fixed pipe for production of biogas.

Technical considerations relevant to applicability
Applicable in cheese manufacturing installations.

Economics
TWG, please provide information.

Driving force for implementation
Reduced waste water treatments costs.

Example plants
Installations #005, #127 and #406. [193, TWG 2015]

Reference literature
[21, Nordic Council of Ministers 2001], [71, AWARENET 2002], [192, COM 2006], [193, TWG 2015]

Recovery of salt whey by evaporation

Technical description
Salt whey is produced after salt has been added to the curd to remove additional liquid. Salt whey can be reused in the process or used as animal feed either directly or after drying by evaporation. Warm whey from cheese manufacture is cooled prior to storage by heat exchange with incoming raw milk. The condensed water may be used for cleaning.

Achieved environmental benefits
Reduced waste, e.g. whey is reused. Reduced waste water pollution.

Cross-media effects
Energy consumption.

Technical considerations relevant to applicability
Applicable in cheese manufacturing installations.

Reference literature
[71, AWARENET 2002]

Recovery of whey by removal of salt using RO

Technical description
Salt whey is produced after salt has been added to the curd to remove additional liquid. Salt whey can be reused in the process, along with sweet whey (see Section 5.4.4.6.3), only after the salt is removed by RO.

Achieved environmental benefits
Reduced waste, e.g. whey is reused. Reduced waste water pollution.
Cross-media effects
The RO permeate is highly saline.

Technical considerations relevant to applicability
Applicable in cheese manufacturing installations.

Economics
High costs.

Reference literature
[8, Environment Agency of England and Wales 2000]

5.4.5 Techniques to reduce emissions to water

5.4.5.1 Salt management - Handling of brine in cheese production

Description
Integrated salt management in cheese production for reduction of salt in waste water.

Technical description
Salt management techniques that can be implemented:

- extension of time for brine draining above tanks, i.e. no loss of brine to waste water;
- installation of conductivity meters with alarms in transition wells of the WWTP. The alarm allows operators to check and react to those cheese installations where the high salt content in waste water originates from;
- less salt discharge from CIP of brining system to the WWTP as frequency of CIP can be changed e.g. from one to two weeks;
- employee involvement—responsibility and more control and focus on reduction of salt content in waste water;
- disposal of body surplus brine to biogas plant (thus no longer led to WWTP). Disposal of surplus brine is assessed due to local conditions of the receiving water body. Surplus of brine is discharged to the WWTP continuously and not in one batch, to ensure the effectiveness of the biological treatment.

Achieved environmental benefits
Reduction of chloride in waste water.

Environmental performance and operational data
Reduction of raw material (salt) usage that have been achieved in installation #126:

- 2012: 0.08 tonnes of salt per tonne of produced cheese;
- 2013: 0.03 tonnes of salt per tonne of produced cheese;
- 2014: 0.05 tonnes of salt per tonne of produced cheese.

Brine was no longer discharged to the WWTP but to a biogas plant.

Cross-media effects
Small increase in energy consumption due to use of conductivity meters.

Economics
An investment cost of around EUR 32 000 (purchase of 3 conductivity meters, programming of crane to extend time for brine draining, installation of alarms, information to employees about salt content in waste water) and operating cost of around EUR 11 000 (including daily analysis of chlorides in waste water) have been reported.

Driving force for implementation
Reduction of costs associated to waste water treatment.
Example plants
At least one installation in Denmark (#126) [193, TWG 2015].

Reference literature
[193, TWG 2015]

5.4.6 Techniques to reduce emissions to air

5.4.6.1 Techniques to reduce dust emissions from dryers

5.4.6.1.1 Bag filter

The technique is generally described in Section 2.3.7.2.2.

Environmental performance and operational data
In a UK dairy (#406), atmospheric emissions from the drying of whey powder are first treated in a cyclone and subsequently a bag filter (see Figure 5.22) to achieve a total particulate matter emission concentration of typically < 10 mg/Nm$^3$. The indicative volumetric flow is around 105 000 Nm$^3$/h and the % abatement efficiency of the system reaches 99%.

Demineralised whey powder fines from the cyclone are returned to product stream (drier inlet along with whey concentrate). Whey powder fines from the bag filter have historically been recovered to the product stream. However on commencement of production of demineralised whey powder, the inclusion of bag filter fines is not possible due to the potential for entrainment of bag filter media which is not acceptable for the demineralised whey product. Bag filter fines are recovered as undergrade whey for use in applications such as animal feed. Filter is routinely inspected during shut-down and turn around periods. Filter media is typically replaced every 2 years via rolling programme.

![Figure 5.22: Example treatment for emissions to air from the drying of whey powder](image)

Table 5.11 and Table 5.12 present installation-specific performance data related to the application of bag filters for treatment of emissions to air from a dryer.
Table 5.11: Dust emission levels to air from a dryer after treatment in a bag filter

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm$^3$)</th>
<th>O$_2$ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
</table>
| 131-4                           | 0.13              | 4.36                        | NI                  | NI                     | Spray dryer (milk powder)  
Natural gas | Spray dryer (inland powder)  
Hot air from exchanger  
Cyclone step before |
| 255-4                           | 0.20              | 20.90                       | EN 13284-1          | Yearly                 | Spray dryer (whey protein concentrate)  
Natural gas  
Cyclone step before |
| 130-2                           | 0.28              | NI                          | VDI 2066            | Three times a year     | Spray dryer (whey protein concentrate)  
Natural gas  
Cyclone step before |
| 338-5                           | 0.30              | NI                          | EN 13284-1          | Once every three years | Concentrated liquid products  
Cyclone step before |
| 056-1                           | 0.70              | NI                          | EN 15259            | Yearly                 | Spray dryer (skimmed milk powder)  
Hot air from exchanger  
Tubular filter |
| 234-3                           | 0.80              | NI                          | EN 13284-1          | Biennial               | Spray dryer (demineralised whey powders)  
Steam |
| 235-1                           | 1.70              | 21.00                       | SFS 3866            | Biennial               | Spray dryer (skimmed milk, butter milk)  
Steam |
| 130-6                           | 2.00              | NI                          | VDI 2066            | Three times a year     | Spray dryer (permeate/lactose powder)  
Steam  
Cyclone step before |
| 019-1                           | 2.10              | NI                          | NI                  | NI                     | Powder (milk, whey) |
| 338-4                           | 2.50              | NI                          | EN 13284-1          | Once every three years | Concentrated liquid products  
Cyclone step before |
| 130-7                           | 3.40              | NI                          | VDI 2066            | Three times a year     | Spray dryer (whey protein concentrate)  
Steam  
Cyclone step before |
| 294-1                           | 3.69              | NI                          | EN 13284-1          | Four times a year      | Spray dryer (skim, milk protein concentrate)  
Steam |
| 295-2                           | 6.68              | NI                          | EN 13284-1          | Four times a year      | Spray dryer (whey protein powder)  
Steam |
| 294-3                           | 7.24              | NI                          | NI                  | Four times a year      | Spray dryer (butter milk powder, whey protein concentrate, skimmed milk powder)  
Steam |
| 063-3                           | 8.00              | NI                          | NI                  | Yearly                 | Spray dryer  
Steam |
| 294-6                           | 9.40              | NI                          | NI                  | Four times a year      | Spray dryer (lactose)  
Steam |
| 068-1                           | 10.00             | 21.00                       | NI                  | Yearly                 | Spray dryer (whey powder)  
Steam |

NB: NI = no information provided.
Source: [193, TWG 2015]
Table 5.12: Average and maximum values of continuous measurements of dust in dryer emissions to air after treatment in a bag filter

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>O₂ content (% dry basis)</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yearly average</td>
<td>Max</td>
<td></td>
</tr>
<tr>
<td>062-4</td>
<td>0.64</td>
<td>0.83</td>
<td>Spray dryer (lactose)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hot air from exchanger</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tubular filter</td>
</tr>
<tr>
<td>062-2</td>
<td>4.42</td>
<td>11.20</td>
<td>Spray dryer (whey protein concentrate)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hot air from exchanger</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tubular filter</td>
</tr>
<tr>
<td>062-1</td>
<td>4.45</td>
<td>12.00</td>
<td>Spray dryer (whey)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hot air from exchanger</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tubular filter</td>
</tr>
<tr>
<td>062-3</td>
<td>5.40</td>
<td>14.30</td>
<td>Spray dryer (whey protein concentrate)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hot air from exchanger</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tubular filter</td>
</tr>
<tr>
<td>405-1</td>
<td>21.00</td>
<td>44.00</td>
<td>Spray dryer (skimmed milk powder, butter milk powder)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fuel oil</td>
</tr>
<tr>
<td>405-2</td>
<td>21.00</td>
<td>50.00</td>
<td></td>
</tr>
</tbody>
</table>

NB: NI = no information provided.
Source: [193, TWG 2015]

Reference literature
[193, TWG 2015]

5.4.6.1.2 Cyclone
The technique is generally described in Section 2.3.7.2.3.

Environmental performance and operational data
Table 5.13 shows installation-specific performance data related to the application of cyclones as end-of-pipe technique for treatment of emissions to air from a dryer. Cyclones are also used as a pretreatment step before the final application of a bag filter (see Table 5.11).
Table 5.13: Dust emission levels to air from a dryer after treatment in a cyclone

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>O₂ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>255-1</td>
<td>1.40</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Spray dryer (milk dryer) Natural gas Very small particles (milk powder and water steam)</td>
</tr>
<tr>
<td>259-2</td>
<td>7.34</td>
<td>NI</td>
<td>ISO/IES 17025, COFRAC 1-1488</td>
<td>NA</td>
<td>Spray dryer (infant formula) Steam</td>
</tr>
<tr>
<td>294-4</td>
<td>8.78</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Four times a year</td>
<td>Spray dryer (casein) Steam</td>
</tr>
<tr>
<td>255-3</td>
<td>8.80</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Spray dryer (mix dryer - whey, buttermilk, milk) Steam Very small particles (milk powder and water steam)</td>
</tr>
<tr>
<td>234-1</td>
<td>11.40</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Biennial</td>
<td>Spray belt dryer (demineralised whey powders, special products) Steam</td>
</tr>
<tr>
<td>252-2</td>
<td>16.60</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Spray dryer (infantile and formulated powder) Hot air from exchanger</td>
</tr>
<tr>
<td>296-4</td>
<td>37.79</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Four times a year</td>
<td>Spray dryer (powder, lactose) Coal</td>
</tr>
<tr>
<td>296-5</td>
<td>46.50</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Four times a year</td>
<td>Spray dryer (powder, lactose) Coal</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.
Source: [193, TWG 2015]

Reference literature
[193, TWG 2015]

5.4.6.1.3 Wet scrubber

The technique is generally described in 2.3.7.3.1.

Environmental performance and operational data
Table 5.14 shows installation-specific performance data related to the application of wet scrubbers as end-of-pipe technique for treatment of emissions to air from a dryer.
Table 5.14: Dust emission levels to air from a dryer after treatment in a wet scrubber

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>O₂ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>130-1</td>
<td>0.10</td>
<td>NI</td>
<td>VDI 2066</td>
<td>Three times a year</td>
<td>Spray dryer (whey protein concentrate) Steam Cyclone and bag filter steps before</td>
</tr>
<tr>
<td>130-3</td>
<td>4.00</td>
<td>NI</td>
<td>VDI 2066</td>
<td>Three times a year</td>
<td>Spray dryer (lactose) Steam Cyclone step before</td>
</tr>
<tr>
<td>131-1</td>
<td>6.10</td>
<td>6.20</td>
<td>NI</td>
<td>NI</td>
<td>Spray dryer (child nutrition, whole milk powder) Natural gas</td>
</tr>
<tr>
<td>296-2</td>
<td>7.60</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Four times a year</td>
<td>Fluidised bed dryer (powder) Coal Bag filter step before</td>
</tr>
<tr>
<td>254-2</td>
<td>19.30</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Spray dryer (whey, microfiltration permeate) Natural gas Cyclone step before</td>
</tr>
<tr>
<td>232-2</td>
<td>65.75</td>
<td>NI</td>
<td>SFS 3866</td>
<td>Biennial</td>
<td>Spray dryer (demineralised whey powders) Old dryer intended to shut down Steam Characterisation of dust fraction: 31.8 micron 1.6 %, 31.8-8.8 micron 2.9 %, 8.8-2.7 micron 8.3 %, 2.7-1.0 micron 74.2 %, &lt; 1.0 micron 13.0 %</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.
Source: [193, TWG 2015]

Reference literature
[193, TWG 2015]
5.5 Emerging techniques

TWG, please provide information.
6 ETHANOL PRODUCTION

6.1 General information about the sector

Ethanol is manufactured by fermenting sugars into alcohol. The EU ethanol sector uses sugar coming from a wide variety of crops such as wheat, maize, barley, rye, triticale, and sugar beet raw juice, syrups and molasses. Of these, the most commonly used ones are wheat, beet and maize, with the planting and harvesting ratio depending on market conditions. As ethanol is produced from processed crops and organic materials, it is referred to as renewable ethanol. The ethanol distilleries are generally integrated with sugar and starch factories; consequently they also produce food, feed and fertilisers.

The European ethanol production is of 4 800 000 tonnes, from cereals (67 %), sugar from beets (29 %) and others (4 %) [198, FoodDrinkEurope 2015].

Ethanol has many different properties and can be used in a wide range of products such as beverages, pharmaceuticals, cosmetics, and, increasingly, as a renewable transport fuel and other uses. The essential uses of ethanol are food (30 %), fuel and others industrials uses (70 %). Moreover, the solvent and preservative qualities of ethanol are in high demand. Ethanol is used for its solubilising properties, its miscibility with water, its very low odour. Its antiseptic properties are also be sought after (disinfectant for external use), or its astringent and refreshing properties.

Ethanol of agricultural origin is used in different sectors: spirituous beverages, vinegar, cosmetics and perfumery, pharmacy and many others. Depending on their destination, several alcohol grades are manufactured, as seen in Table 6.1.

Table 6.1: Types of ethanol by industrial sector

<table>
<thead>
<tr>
<th>Industrial sector</th>
<th>Dehydrated food ethanol</th>
<th>Food ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosmetology, screen Wash, parachemistry</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Pharmaceutical</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Food (vinegar)</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>Food (sugar)</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Spirituous beverages and culinary preparations</td>
<td>-</td>
<td>X</td>
</tr>
</tbody>
</table>

Source: [198, FoodDrinkEurope 2015]

In the case of alcohol for medical purposes (called denatured alcohol), ethanol is mixed with substances that make it unpleasant. The physicochemical characteristics of ethanol make it an excellent support in drugs including treatments against coughs, decongestants, and many more. As a solvent, the pharmaceutical industry uses it for the manufacture of antibiotics, vaccines, lozenges, tablets and vitamins.
6.2 Applied processes and techniques

Ethanol of agricultural origin is obtained by distilling fermented raw materials containing fermentable sugars or ending by hydrolysis to fermentable sugars (roots, stems, tubers, starchy materials, cellulosic materials).

Derived from the fractional distillation of wine derived from fermentation, raw ethyl alcohol is then either rectified by fractional distillations to obtain superfine alcohol for food, vinegar, cosmetics, and pharmaceuticals, for use as solvents or again in industrial applications. Raw alcohol is dehydrated for fuel purposes.

A simplified scheme for the production of ethanol is presented in Figure 6.1.

![Figure 6.1: Ethanol production process](Source: [198, FoodDrinkEurope 2015])

The main process steps are further analysed in the following lines [198, FoodDrinkEurope 2015].

**Preparation of fermentable musts**

Beets: the raw juice is simply acidified to enhance the hydrolysis of sucrose and to place the yeast in a favourable environment to them and not to microorganisms such as lactic, butyric. The sugar syrups are diluted and acidified.

Grains: the grain is milled and the flour obtained, is liquefied, saccharified by enzymatic action combined with thermal activity. The objective is to break down the glucosidic linkages of the starch macromolecule to obtain fermentable sugars. The grinding is first pasted to allow enzymatic diffusion towards the starch molecules. The pasting is carefully carried out to avoid gelatinisation of the product. The industry also produces starch and glucose based products.

Starch crops require hydrolysis of carbohydrates to obtain glucose. The conversion from starch into glucose can happen by a double enzymatic process or a combined acid/ enzymatic process. Lignocellulosic feedstock requires biochemical conversion of hemicellulose into sugars.

**Fermentation**

The purpose of this step is to produce an alcohol from the musts prepared from the various substrates described above. The breakdown of simple sugars into alcohol is normally referred to alcoholic fermentation. Yeasts, usually Saccharomyces sp, e.g. cerevisae or bayanus, are used to
produce ethanol from carbohydrates and very small amounts of other organic compounds. This conversion can be represented by the following equation:

\[ C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \]

This is an anaerobic process, i.e. it does not require the presence of oxygen. The temperature affects the rate of fermentation, the efficiency of conversion and the flavour and the aroma of the finished product. The fermentation temperature is maintained around 30-35 °C and pH below 4.5 to prevent bacteria development.

Nitrogen, vitamins, salts and trace elements necessary for yeast development are used. Fermenters are cylindrical closed tanks, allowing CO₂ recovery. The fermentation can be continuous, semi-continuous or by batch operated. Selected strains of yeasts are often used to optimize the alcohol yield. Yeast is usually supplied to food ethanol and industrial ethanol manufacturers either in a crumbled/compressed/liquid form or as active dry yeast.

At the start of the process, the first tanks are ventilated to allow the yeast development by using air compressors and direct air injection in the tank bottom. At the end of the process, the fermentation is strictly anaerobic to produce ethanol.

Centrifugation of the whole or part of the process allows yeasts recovery which can be recycled after an optional treatment at pH 2 by addition of strong acid (washing yeasts) which helps to get rid of the creams of centrifuged yeast bacteria. The obtained alcohol is 10-14 % vol. The fermentation gases are washed to recover ethanol. CO₂ can also be exploited, when economically relevant.

More information about fermentation technique can be found in Section 4.2.2.2.

**Distillation**

There may be numerous variations of the distillation processes, depending on local production units. The process takes place in two basic types of equipment; the pot still and the column still. Stills may be operated singly or in groups. The addition of heat enables the separation of alcohol/aqueous compounds from the initial liquid feed in the still. Condensed aqueous alcohol is removed as a liquid spirit from the head of the still, whilst a residual stream is discharged from the base.

The pot still can be operated in a batch or continuous manner. In the former case, a batch of material is charged to the still pot, boiling is initiated, and the vapours are then continuously removed, condensed and collected until their average composition has reached a desired value. When operated in a continuous manner, feed is continuously passed to the still pot with the vapour and liquid portions being continuously removed.

In column distillation, the alcoholic liquid or beer enters a distillation tower heated with vapour. In each contacting device, generally a tray, an equilibrium is created between the vapour enriched with volatile components and the condensed liquid. Crude alcohol is drawn off from the top of the tower and then rectified through another tower where 95 % of the alcohol is separated from higher alcohols. At the bottom of the first tower, an aqueous blend or stillage is drawn off. A condensed water or stillage water, contaminated slightly with organics, is drawn off at the bottom of the second tower once the alcohol has been dehydrated. 95 % alcohol can be turned into anhydrous alcohol by a number of different technologies. These technologies can include azeotropic distillation using a third component, adsorption by a molecular sieve, or dehydration by a membrane technique. Some spirits and ethyl alcohols of agricultural origin can be distilled higher than 84 %.

A residual liquid such as stillage, pot ale, spent lees and spent wash, is discharged from the stills. The waste water contains TSS and very high BOD emission levels. Where recovery systems exist, a proportion of the stillage may be reused. Emissions to air include dust, VOCs
and odour. There may be minor emissions of incondensable volatiles, mainly carbon dioxide and ethanol from column stills. There are no issues for pot stills.

Concentrated stillage or dried stillage may be used in animal feed, as a feedstock in sugar and grain-based production, sent for landspraying or otherwise disposed of as waste. Solid outputs are also used for methane production, the gas being used for energy production. This can improve the energy balance in the distillation process.

Two main representative examples are given below:

Example one: an alcoholic liquid is introduced in a distillation column, with an exhaustion part and a concentration part, making it possible to continuously separate the ethyl alcohol obtained in a liquid form, with an alcohol content of at least 90 % vol. after vapour condensation at the top of the column.

The columns have a high number of trays which represent distillation stages. The raw alcohol is then rectified and/or dehydrated. Continuous rectification consists of several columns in which fractioning allows for the classification and the extraction of various impurities to be extracted from the raw alcohol.

Typically, there is a purifying column or hydro-selection that runs on low alcoholic degree, a distillation column operating at high alcoholic degree, a methanol extraction column, column concentration of “mauvais gout” alcohol (this alcohol represents about 2 % to 6 % of the raw alcohol used and is made of various withdrawn fractions in the previous columns) and a refining column. Impurities are generally very soluble in alcohol and slightly soluble or insoluble in water. For this reason, it is very difficult to separate impurities from alcohol with a high alcoholic content and therefore it is essential to dilute the raw alcohol to be rectified at the beginning of the rectifying process.

To separate the remaining water content, specific techniques are carried out like molecular sieve or use of a third molecule (cyclohexane).

Example two: a distilling process follows four main steps: stripping, purification, rectification and dehydration.

In the stripping column, fermented raw material is heated to obtain a mixture of water/alcohol. Steam is commonly used for the heating. From this step, approximately 40 % to 50 % alcohol in mass from the fermented raw material can be obtained.

This mix goes through a purification column to separate volatile compounds. The volatile compounds extracted from the purification column may be sent in a process of energy valorisation or additional process. The bottom of the column is the main flow, with approximately 50 % of alcohol in mass, to feed the rectification column. During this rectification step, the water is separated from the alcohol. In this step we separate also the water which comes from dehydration. The alcohol content, during the extraction in the rectification column to the dehydration is approximately 92 % of alcohol in mass.
6.3 Current consumption and emission levels

6.3.1 Energy consumption

Distilleries require electrical and thermal energy for virtually every step of the process. Electricity is needed for lighting, for process control of the installation, for heating, for cooling and as the driving power for machinery. It could be generated and supplied by utility companies. Often steam and electricity are generated on site, given that the efficiency factor is considerably higher.

Thermal energy is needed for heating processing lines and buildings. The heat generated by the combustion of fossil fuels or biomass fuel is transferred to the consumers by means of heat transfer media, which, depending on the requirements, are steam, hot water, and air. On-site combined generation of heat and power (CHP) is a valuable alternative for distilleries for which heat and power loads are balanced. High pressure steam boilers/steam turbines are used in the distilleries. Natural gas, coal and biomass are the most convenient fuels.

In large distilleries, steam and electricity are generated using CHP plants. Small distilleries are using boilers with different working pressures depending on the process needs and set-ups. Heat is needed for the conversion of starch to glucose, distillation columns, evaporation, drying and for sterilisation of tanks and pipelines. Depending on the process set-up fresh steam or recovered steam is used.

Specific energy consumption values of 1.97, 3.26 and 5.59 MWh/tonne of product have been reported. [193, TWG 2015] The distillation tower is heated by steam. For pot stills, 12 to 13 kWh per litre of pure alcohol is required.

6.3.2 Water consumption

The distillery sector needs water and often uses different qualities of recycled water for operation. A systematic approach is generally in place to control the use of water and to reduce water consumption and its contamination.

Each application of water requires its own specific quality. In the distillery sector, the quality requirements depend on whether or not contact between water and the food product is possible. This is normally incorporated in the hazard analysis critical control point system (HACCP). The following sources of water are used in the distillery sector: tap water, groundwater, surface water, water originating from the raw material, recycled water and process water.

Most water consumption (around 70%) is related to energy production: boiler system which drives the plant and cooling of process water and equipment. The rest (around 30%) is for fermentation process, feed treatment, saccharification of starch. Water is very often recycled in the process [198, FoodDrinkEurope 2015].

Cooling water is needed to maintain the temperature of fermentation and to condense vapours. In the distilleries, the cooling systems commonly applied are closed circulation cooling systems or cooling towers. In open cooling systems, i.e. cooling towers, not only does evaporation of the water occur but also a small part of the water could be sprayed.

Specific water consumption values of 2.94, 5.08 and 16.08 m³/tonne of product have been reported. [193, TWG 2015]
6.4 Techniques to consider in the determination of BAT

6.4.1 Techniques to reduce emissions to air

6.4.1.1 Carbon dioxide recovery and purification

See Section 4.4.4.3.

6.4.2 Techniques to reduce waste

6.4.2.1 Recovery and further processing of stillage distiller’s dried grains with soluble (DDGS)

See also Section 2.3.5.2.

Description
Grain and beet vinasses are concentrated and added to the solid residues before being dried for animal feed production.

Technical description
Alcohol can be produced from maize. The maize is ground and then dissolved in water. Sugars are produced using enzymes in a two-step process. The sugars are then fermented to produce alcohol and following this, the alcohol is separated from water by distillation. Solids from the stillage are separated using decanter centrifuges and the remaining liquid phase is evaporated. The concentrated liquid and the separated solids are mixed and dried by heating them to produce 90% dry matter. The product is called distiller’s dried grains with solubles (DDGS) and it can be used as animal feed. It contains proteins, vitamins and minerals.

The alcohol is separated from the mash by distillation. The dealcoholised mash is called vinasse. The vinasse is dewatered applying variously, decanter centrifuges, evaporating and drying techniques. The water removed from the vinasse is partly (depending on the installation setup and its product portfolio) used as process water for other production steps, otherwise as waste water sent for waste water treatment.

The resulting vinasse can either directly be sold as distiller’s grains with solubles (DGS) with a dry substance ranging from about 32–40%, or be dewatered up to a dry substance of about 90% and is then called distiller’s dried grains with solubles (DDGS). It is typically used as animal feed and contains proteins, fibres, vitamins and minerals.

In the case of gluten and/or bran separation from the ground grain before the fermentation, the solid content of the stillage is lower. In these cases the stillage can be dewatered applying only decanter centrifuges and evaporating techniques. The resulting product is called condensed distillers soluble (CDS) and is typically used as animal feed. It contains proteins, vitamins and minerals and has a dry substance of 23–30%.

Achieved environmental benefits
Animal feed is produced.

Environmental performance and operational data
The temperature of the mixed liquid and solids before drying is about 70 ºC and it is heated to 110 ºC. The product has a temperature of about 30 ºC. The evaporator is cleaned with sodium hydroxide, which can also be used to control the pH during the alcoholic fermentation. Some consumption information is shown in Table 6.2.
Table 6.2: Consumption data for the drying of DDGS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Consumption/t DDGS produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vapour</td>
<td>4.5 t</td>
</tr>
<tr>
<td>Electrical energy</td>
<td>300 kWh</td>
</tr>
<tr>
<td>NaOH</td>
<td>15 kg</td>
</tr>
<tr>
<td>Water</td>
<td>0.1 m³</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

Cross-media effects
Dust may be emitted when drying techniques are applied and energy is consumed. Odour may be emitted. Production of waste water.

Technical considerations relevant to applicability
Applicable in alcohol manufacturing from grains.

Economics
Valorisation of vinasse by production of feed. The product can be sold for almost the same price as the maize.

Driving force for implementation
Without this recovery, the stillage residue needs to be disposed of.

Reference literature
[92, Gergely E. 2003], [198, FoodDrinkEurope 2015]

6.4.2.2 Recovery and (re)use of yeast after fermentation

See Sections 2.3.5.2 and 4.4.3.1.

Concentration of mash from molasses distilling

Technical description
Alcohol can be produced via the fermentation of molasses from sugar beet processing, followed by distillation/rectification. The mash, also known as slops, has a very high pollution level, e.g. BOD₅ of 18000–22000 mg/l, and contains compounds which are difficult to biodegrade. The discharge of slops into the waste water would hamper the operation of any WWTP. Treatment of slops is thus needed.

The slops can be concentrated by a multi-effect vacuum evaporator and processed to obtain vinasse and salts containing potassium sulphate. The vacuum evaporator achieves a dry matter content of 70%, which is then centrifuged to separate the vinasse from the salts. Vinasse, which is a dark brown syrup containing all the inorganic substances from the wort and slops, is used as animal feed. The salts are used as a potassium fertiliser.

The condensed vapours resulting from the slops concentration are passed to the WWTP through a cationic exchanger to eliminate the ammonium. This process gives rise to ammonium sulphate, which is returned to the evaporator so that potassium in the slops can be converted to potassium sulphate.

Achieved environmental benefits
Reduced waste water pollution. Reduced waste, e.g. the vinasse is used as animal feed and the salts as a potassium fertiliser.
Operational data
Consumption and emission figures from 1999/2000 of an example German molasses distillery are shown in Table.

Table: Consumption and emission data for the slops evaporation unit of a German molasses distillery.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water consumption</td>
<td>m³/t vinasses</td>
<td>1.5</td>
</tr>
<tr>
<td>Energy consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td>t</td>
<td>5305</td>
</tr>
<tr>
<td>Electricity</td>
<td>MWh</td>
<td>993.2</td>
</tr>
<tr>
<td>Auxiliary materials input for the 1999/2000 campaign</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caustic</td>
<td>kg</td>
<td>1402</td>
</tr>
<tr>
<td>Defoaming agents</td>
<td>kg</td>
<td>3419</td>
</tr>
<tr>
<td>Ammonium sulphate</td>
<td>kg</td>
<td>139300</td>
</tr>
<tr>
<td>Regenerating salt</td>
<td>kg</td>
<td>600</td>
</tr>
<tr>
<td>Products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vinasse</td>
<td>t</td>
<td>3539</td>
</tr>
<tr>
<td>Salts</td>
<td>t</td>
<td>754</td>
</tr>
<tr>
<td>Waste water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>m³/h</td>
<td>10–12</td>
</tr>
<tr>
<td>COD content</td>
<td>mg/l</td>
<td>2500–4000</td>
</tr>
<tr>
<td>BOD content</td>
<td>mg/l</td>
<td>1000–2000</td>
</tr>
<tr>
<td>NH₄-N content</td>
<td>mg/l</td>
<td>600–800</td>
</tr>
<tr>
<td>P tot content</td>
<td>mg/l</td>
<td>0.5–1.0</td>
</tr>
<tr>
<td>Emissions to air</td>
<td></td>
<td>Not significant. The exhaust air is cleaned by a biofilter made of peat mulch</td>
</tr>
<tr>
<td>Noise emission</td>
<td>55 dB(A)</td>
<td>(entire unit with doors closed)</td>
</tr>
</tbody>
</table>

Technical considerations relevant to applicability
Applicable in molasses distilleries.

Driving forces for implementation
Improvement of the operation of the WWTP. Production of by-products.

Example plants
At least one molasses distillery in Germany.

Reference literature
[35, Germany 2002]
6.5 Emerging techniques

TWG, please provide information.
7 FISH AND SHELLFISH PROCESSING

7.1 General information about the sector

This sector includes the process of white or pelagic fish; fatty fish; shellfish, i.e. crustaceans and molluscs, and fresh water fish. Fish processing is very widespread and varied. Many species of fish are mass processed, including cod, tuna, herring, mackerel, pollock, hake, haddock, salmon, anchovy and pilchards. Marine fish account for 90 % of the fish production in the world. The other 10 % includes fresh water fish and farmed fish. Approximately 75 % of the world’s fish production is for human consumption, with the remaining 25 % used for producing fish meal and fish oil. Currently, about 30 % of all the fish produced for human consumption are marketed fresh.

Increased seafood production is a crucial element of the solution to meeting the global food challenge. According to the Food and Agriculture Organization of the United Nations, capture fisheries and aquaculture supplied the world with about 158 million tonnes of fish and other aquatic species (ca. 136 million tonnes for human consumption) in 2012, providing an apparent per capita supply 18.9 kg (see Figure 7.1). Of this total, aquaculture accounted for 42 %. During the past three decades, global aquaculture production has expanded from around five million tonnes in 1982 to over 66 million tonnes in 2012. Prognosis shows that in 2030 we can except to grow up to 93.6 million tonnes [205, Nordic Council of Ministers 2015].

The EU is a major consumption products of seafood products in the world with 12.3 million tonnes representing EUR 52.2 billion in 2011 (see Figure 7.2). It is the first importer of seafood products, absorbing 24 % of total world exchanges in value. EU consumption per capita is 22 kg. Northern Member States are more focused on processed fish while Southern Member States still favour fresh products and devote a larger part of household expenditures to fish. Central and Eastern European countries are below the EU average but register increase in consumption [205, Nordic Council of Ministers 2015].
Chapter 7

Figure 7.2: Supply seafood products balance in EU in 2011 (live weight equivalent)

Fishery production in the Nordic countries is shown in Figure 7.3.

<table>
<thead>
<tr>
<th>Country</th>
<th>Aquaculture</th>
<th>Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>13 213 319</td>
<td>1 449 587</td>
</tr>
<tr>
<td>Iceland</td>
<td>3 358 346</td>
<td>76 564</td>
</tr>
<tr>
<td>Denmark</td>
<td>33 586</td>
<td>76 564</td>
</tr>
<tr>
<td>Faroe Is.</td>
<td>437 035</td>
<td>13 757</td>
</tr>
<tr>
<td>Sweden</td>
<td>165 366</td>
<td>12 659</td>
</tr>
<tr>
<td>Finland</td>
<td>179 569</td>
<td></td>
</tr>
</tbody>
</table>

EU exports are almost entirely composed of products from captured fisheries, whilst EU aquaculture products stay in the European market. EU exports to third countries increased by 50% in value between 2009 and 2012 to reach EUR 4.1 billion. Spain, the Netherlands and Denmark are the leading exporting Member States to third countries Table 7.1 shows the major suppliers of seafood to the European market.
Table 7.1: EU’s main suppliers of seafood in 2012

<table>
<thead>
<tr>
<th>Country</th>
<th>Value (thousands of EUR)</th>
<th>Contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>3 874 711</td>
<td>20</td>
</tr>
<tr>
<td>China</td>
<td>1 565 995</td>
<td>8</td>
</tr>
<tr>
<td>Iceland</td>
<td>968 758</td>
<td>5</td>
</tr>
<tr>
<td>Ecuador</td>
<td>952 646</td>
<td>5</td>
</tr>
<tr>
<td>United States</td>
<td>873 906</td>
<td>5</td>
</tr>
<tr>
<td>Other suppliers</td>
<td>11 002 401</td>
<td>57</td>
</tr>
<tr>
<td>Total</td>
<td>19 238 417</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: [205, Nordic Council of Ministers 2015]

The overall value of the output of the processing industry in EU amounts to around EUR 30 billion. The United Kingdom, France, Spain, Italy and Germany are the leading countries in terms of production. The sector employs around 116 000 people. In 2012 the total number of enterprises in the European fish processing industry was 3 454 in 2012. The mainstay of European production is conserves and ready meals of fish, crustaceans and molluscs.
Chapter 7

7.2 Applied processes and techniques

7.2.1 General

Fish preliminary processing most commonly takes place at on-shore processing facilities. However, some processing such as the gutting, cleaning and sometimes head removal of fish can take place at sea, on board fishing vessels, e.g. when processing white fish that has a low oil content.

The primary objective of any handling method is to preserve the quality of the fish by bringing down the temperature near to 0 °C as quickly as possible. The factors such as: delay in handling and chilling, poor temperature control in the fish hold, damage from rough handling, poor standards of gutting, bleeding and washing the fish and mechanical damage due to the overfilling of the containers, have a deleterious effect on the quality of fish, and result in reduction of shelf life and loss of weight.

A number of methods are used to preserve fish. Some employ techniques based on temperature control, using ice, refrigeration or freezing; others on the control of water activity and include drying, salting, smoking and freeze-drying. Techniques may rely on the physical control of microbial fish loads, such as canning, microwave heating or ionising irradiation; or on chemical control of microbial activity and loads by adding acids, for example, to fish products. Techniques are also used that are based on decreasing of oxygen level, such as vacuum packaging. Most often, a combination of different techniques is used to preserve fish.

Freeze-drying or lyophilisation, is the process of removing water from a product by sublimation and desorption. The aim of the process is to preserve sensitive material that cannot be dried by evaporation. Beware of the risk of degradation of specific components at high temperatures, which would result in a loss of taste or other quality aspects.

The freeze-drying equipment consists of a drying chamber with temperature controlled shelves. This can be a batch chamber, where the trays remain fixed on the heating plates through the drying operation, or a semi-continuous type, in which the trays move through a vacuum lock into a drying tunnel. The equipment also includes a condenser, to trap water removed from the product in the drying chamber and to facilitate the drying process; a cooling system, to supply refrigerant to the shelves and the condenser; and a vacuum system, to reduce the pressure in the chamber.

The solid material is then fed manually or mechanically onto the trays in a drying chamber. The temperature of the drying chamber is well below 0 °C. The exact temperature depends on the product being dried. A vacuum is applied in the chamber. The ice evaporates under these conditions. This evaporation causes a further decrease in the temperature of the product, which is compensated for by adding heat by means of heating plates to the product through the temperature controlled trays. The evaporated water is refrozen on the surface of a condenser, which has a temperature well below the sublimation temperature under the existing conditions in the chamber. From time to time the condenser is de-iced by heating the condenser surface. The water is liquefied and drained. The vacuum is maintained by a vacuum pump. The outlet of the vacuum pump is emitted into the air. To prevent solids entering and damaging the vacuum pump, a filter is usually applied in front of the pump.

Finally, fish processing operations include proper waste management techniques. The further processing of fish into a wide variety of value-added products is now common with the increase in demand for food products that are ready to eat or require little preparation before serving. For the transportation of chilled and frozen fish products by road, rail, sea or air, it is essential that the cold chain is maintained throughout. This requires the use of insulated containers or transport vehicles and adequate quantities of coolants or mechanical refrigeration. Container technology now makes possible the combination of refrigeration combined with a modified or controlled atmosphere [205, Nordic Council of Ministers 2015].
These fish are then kept in ice or are frozen until they arrive at the installation, where they are thawed or re-iced and stored until the time of further processing. Fatty fish have oils distributed throughout the fillet and in the belly cavity. They have different oil contents depending on the species, but on average fatty fish fillets may have up to a 30% oil content. Typically, they are not gutted on board, as this is carried out later in the processing installations.

The pretreatment of white fish involves the removal of any ice and a screening based on their size. Large fish may also be scaled depending on the process, although this is not carried out when skinning is performed.

Skinning and cutting involves removing the edible parts of the fish and cutting it into pieces of the appropriate size. Skinning can be done manually or automatically. With automatic operations, white fish are skinned by pulling the fillet over an automatic knife, whereas fatty fish are skinned by pulling the fillet over a freezing drum. Then, fish are transported, e.g., by fluming, to cutting tables from the holding vessels and then eviscerated, i.e., head, tails, and inedible parts are removed. In small fish, such as sardines, only heads and tails are removed, and for medium-sized and large fish, the guts are removed as well. For white fish, this stage just involves the removal of the fillet flesh, whereas for oily fish, the process involves gutting, de-heading and removal of fillets.

Fish and shellfish are processed and preserved by a large variety of methods and may be consumed in their primary form, raw or cooked. They may also be further processed to produce fish or shellfish-based foods, such as moulded products or prepared dishes. Some preservation methods involved in fish and shellfish processing include freezing, chilling, canning, curing, drying, smoking, fermenting and MAP.

### 7.2.2 Preliminary processing

#### 7.2.2.1 Generally

Fresh fish received shall be inspected and adequately washed with potable water before processing. All fish received in a frozen state shall be either thawed promptly and processed or stored at a temperature that will maintain the fish in a frozen state. Thawing shall be carried out in as rapid a manner as possible so that the internal temperature of the fish does not exceed 3.3°C.

The main objective of preliminary processing is the full or partial separation of edible parts from inedible ones. As a result, semi-products are obtained of the shape, size, and quality approved by the consumers and meets the needs of the further processing. It also allows for efficient utilization of inedible parts e.g., for animal feed production. Isolating the highly perishable parts extends the life of the parts used in further processing. The decrease of the mass of the raw material affords economy in the transport of the semi-products or the final products.

There are a few major semi-products of fish preprocessing from the least to the most labour intensive: headed and gutted fish fillets, V-cut fillets, butterfly fillets, fish after nobbing. Subsequent operation result in the growing degree of the edible/inedible part separation. The choice of the particular form of preprocessing depends on the requirements of the technology, the kind and size of the material and the technical potential of the producer. The economic and marketing aspects have also a great importance.

In the modern fish industry, preliminary processing is mainly mechanised. There are special machines to scaling, gutting, deheading, nobbing, filleting, skinning, cutting and meat separation. In preprocessing process, other machines are also used e.g., freezers, de-icers or graders. There are many types of the above mentioned machinery. They differ in output capacity, size and species range of the processed material, the way in which the operation is
performed, the technological yield, etc. Figure 7.4 and Figure 7.5 depict two different types of machines.

Figure 7.4: Salmon filleting machine

Figure 7.5: Heading, gutting and roe recovery machine

Most fish processing machinery installations, used during preliminary processing, depend for their operation on using large quantities of water. Beyond this necessary use of water, the flow of water to these installations is often uncontrolled and excessive. The waste is often cut or mashed up and mixed with the water by the action of the machines, which produces a highly polluted effluent. This is a particular problem when processing ungutted and high oil content pelagic fish. The solid waste from the machines is often not effectively separated at source. It often ends up on the floor around the installations. The faults lie not only in the processing machines themselves but also in the systems of catch trays, chutes, conveyors and flumes commonly built around them to transport the fish, products and waste.

7.2.2.2 Freezing/Thawing

The freezing process alone is not a method of preservation. It is merely the means of preparing the fish for storage at a suitably low temperature. In order to produce a good product, freezing is accomplished quickly. A freezer requires to be specially designed for this purpose and thus freezing is a separate process from low temperature storage. The three basic methods of freezing fish are: (i) blowing a continuous stream of cold air over the fish: air blast freezers; (ii) direct contact between the fish and a refrigerated surface: contact or plate freezers; (iii) immersion in or spraying with a refrigerated liquid: immersion or spray freezers. The majority of frozen fish semi products require thawing before further processing.
Thawing is the process of changing a product from frozen to unfrozen. It involves transferring heat to a frozen product to melt the ice that was formed within the flesh during the freezing process. Fish processing industry use a large quantity of frozen fish and shellfish every year. Much of this product requires thawing before further processing or use. Companies typically thaw seafood in-house using a range of different methods. These vary from using water (immersion or spray), air or steam through to microwave and radio frequency systems. After thawing, the fish shall be adequately washed with potable water before processing [205, Nordic Council of Ministers 2015].

The following sections describe some of the most applied thawing processes.

7.2.2.2.1 Thawing using water recirculation and air stirring

The water used for thawing is recirculated in a closed-circuit and used again. Air is used to stir the water during thawing. Level-actuated switches can be installed to control the amount of water fed into the tank. For shrimps and prawns, filtered peeling water can be used [71, AWARENET 2002], [94, Germany 2003].

Achieved environmental benefits
Reduced water consumption. Reduced waste water volume and pollution.

Cross-media effects
Energy consumption.

Environmental performance and operational data
In the fish sector, a water consumption decrease from 5 to 2 m³/t of raw fish is reported, compared to running water.

Technical considerations relevant to applicability
Applicable in the meat sector and in the fish sector for mackerel, shrimps and prawns.

Reference literature

7.2.2.2.2 Thawing in containers filled with warm water with air bubbles at the bottom

Thawing is carried out in containers filled with water at 30–35 ºC, while air is bubbled in at the bottom. Level-actuated switches can be installed to control the amount of water fed into the tank. The water flow also affects the temperature. For shrimps and prawns, filtered peeling water can be used [13, Nordic Council of Ministers 1997], [71, AWARENET 2002].

Achieved environmental benefits
Reduced water consumption. Reduced waste water volume and pollution.

Cross-media effects
Energy consumption.

Environmental performance and operational data
A reduction in water of up to 60 % compared to thawing in running water was achieved in a fish processing installation in Denmark. Water consumption decreased from 5 m³/t of raw fish down to 1.8–2.2 m³/t.

Technical considerations relevant to applicability
Applicable in the meat sector and in the fish sector for whitefish, shrimps and prawns.
**Economics**
In the Danish example, the cost of the equipment with a capacity of 18 t/d of raw fish, which is equivalent to 3,600 t/yr of raw fish, was estimated at about DKK 300,000. The cost saving in water consumption was DKK 10,800.

**Driving force for implementation**
Cost saving in water consumption.

**Example plants**
Used in at least one fish processing installation in Denmark.

**Reference literature**

### 7.2.2.2.3 Thawing by sprinkling

Thawing is achieved by sprinkling the food with water. Compared with thawing by immersion into running water, this technique consumes less water but requires longer times and larger surface areas [71, AWARENET 2002].

**Achieved environmental benefits**
Reduced water consumption. Reduced waste water volume and pollution.

**Cross-media effects**
The food surface may dry and its unsaturated fats, e.g. in pork, may oxidise.

**Environmental performance and operational data**

**Technical considerations relevant to applicability**
Applicable in the meat and fish sectors.

**Reference literature**

### 7.2.2.4 Thawing by 100 % water saturated heated air

Thawing is achieved by exposing the food to 100 % water saturated hot or warm air.

Compared with thawing by immersion into running water, this technique consumes less water but requires longer times and larger surface areas.

Using hot air may cause a rapid growth of microorganisms on the surface layers of the thawed product and hinder reabsorption of thawed water. This creates unsightly and often nutritionally wasteful drip loss. Furthermore, the food surface may dry and its unsaturated fats, e.g. in pork, may oxidise. Energy consumption is higher compared to other thawing techniques, as hot air is used.

When warm humid air is used to thaw blocks of frozen white fish, it can cause problems in maintaining the quality of the finished product because the fish at the edge of the frozen block thaw before the fish in the middle of the block.

Dry thawing is reported to adversely affect the quality of shrimps and prawns [13, Nordic Council of Ministers 1997], [71, AWARENET 2002].

**Achieved environmental benefits**
Reduced water consumption. Reduced waste water volume and pollution.
Cross-media effects
Energy is consumed to produce the air bubbles.

Environmental performance and operational data

Technical considerations relevant to applicability
Applicable in the meat and fish sectors.

Example plants
Commonly used in white fish processing in the Nordic countries.

Reference literature

7.2.2.3 Grading

Processing begins with the grading of raw material according to species and size, as well as isolating the fish, which are unfit for consumption or damaged. Fish grading is an absolute prerequisite for efficient industrial fish processing. Actual catch often contains fish of different sizes and species. Grading by size and separation of species ensures uniform flow for next processes thus increasing capacity and quality.

Fish grading is used extensively for small, pelagic fish e.g. herring, mackerel, sprat and sardines. The material is graded according to maximum thickness, as this is correlated with the length of the fish. Most frequently, the grading takes place in an opening slit formed by some vibrating elements, or between rotating rollers [205, Nordic Council of Ministers 2015].

A vibrating grading machine is shown in Figure 7.6.

![Vibrating grading machine](source: [205, Nordic Council of Ministers 2015])

Figure 7.6: Vibrating grading machine

7.2.2.4 Scaling

For some fish species, hand scaling amounts nearly 50 % of the time of initial processing. Machines used in mechanised scaling should not damage the skin or weaken the texture of the muscular tissue. Two types of scaling machines are used in fish preliminary processing: drum machines in which the material is scaled by grazing past the rough walls of the rotating drum, and machine scrapers in which fish is passed through a system of stationary or moving scrapers [205, Nordic Council of Ministers 2015].
7.2.2.5 Deheading and gutting

The fish head constitutes up to 20% of its weight and is usually considered as an inedible part. The fish can be deheaded manually or mechanically. Manual cutting is easier for small fresh water fish. Larger fish ranging from 20-40 cm can be deheaded using mechanical devices. Fish can be cut in three different ways: round cut, straight cut and contoured cut. In most fish installations, manual deheading is performed because it causes minimal flesh loss. A cut around the operculum is a called a round cut and it results in the lowest meat loss. This cut is mainly used when the final product is a boneless and skinless fillet. Machines with a guillotine cutter are suitable for larger fish under-going round or contour cuts. Machines with a manually operated circular saw are suitable for larger fish undergoing straight cuts. The amount of deheaded waste produced from fish processing is 27-32%.

Gutting of the fish is the removal of internal organs and optionally cleaning the body cavity of the peritoneum, kidney tissue and blood. In the gutting process, the fish is cut longitudinally to remove the internal organs on a table made of special material, which is easy to wash and does not absorb fluids. The table is rinsed and periodically disinfected. There are some mechanical gutting machines used for trout, eel and other fish, but their use increases the fish processing cost. The internal organs constitute around 5-8% of the fish weight [205, Nordic Council of Ministers 2015].

7.2.2.6 Filleting and skinning

Filleting can involve a number of unit operations: pretreatment, fish filleting, trimming of fillets, packing and storage. The fillet is the block of meat composed of the dorsal and abdominal muscles and the most popular forms of fish-obtained culinary raw material on the market. The technological yield of filleting depends of the fish species, its sex, size, alimentation etc. Hand filleting is labour-intensive and high productivity requires much skill and experience from the workers. For this reason, filleting machines have been implemented in fish processing on a wide scale. Different species can be processed in these devices as long as they are in the same size range and similar body shape. The simplest filleting machine for gutted and deheaded fish has two disc knives set from each other at a distance equal to the thickness of the fish's backbone.

Following the wide application of filleting machines, skinning machines were introduced. The fish skinning machines are designed to scrape the fish skin from fish fillets and ensure high output and effectiveness of the operation. A correctly skinned fillet should not be damaged on the skinned side, where the silvery pellicle connecting monomers are left [205, Nordic Council of Ministers 2015].

7.2.3 Fish preservation methods

7.2.3.1 Canning

The canning process is a sterilisation technique that kills microorganisms already present on the fish, prevents further microbial contamination, and inactivates degradable enzymes. In this process fish are hermetically sealed in containers and then heated to high temperatures for a given amount of time. The fish canning production process begins after filleting, when the fish is pre-cooked in the cans; then brine, oil or sauce is added and finally the cans are sealed and autoclaved [205, Nordic Council of Ministers 2015].
7.2.3.2 Salting

Salting is the process that lowers the moisture or water content of fish and other fishery products to a point where microorganisms cannot live and grow. Sodium chloride, or salt, improves fish texture because it firms up the fish. Salt partially dehydrates the fish and kills the bacteria. Three basic methods of applying salt to preserve fish:

- pickle salting—cover the fish with salt and pack them in layers in watertight containers. This forms the pickle that serves as the saturated brine solution that covers the fish completely;
- brine salting—immerse the fish in a saturated solution made up of 25 parts of salt and 100 parts of water. Brine salting is done only as a temporary way to preserve fish before they are dried, smoked, or processed;
- dry salting—run granular salt on the fish. The proportion of salt to fish varies from 10% to 35% of the fish weight.

7.2.3.3 Smoking

Smoked seafood is prepared with two basic procedures. Hot smoking cooks the product; cold smoking does not. Cold smoking devices have one basic function: to apply smoke to the product. Hot smoking devices have the added function of applying heat. And because preservation of fish usually requires moisture removal, systems designed for hot or cold smoking fish may have the added function of dehydration. Modern fish smoking equipment is usually designed to produce either hot or cold smoked products, but in either case they are usually designed to have adequate airflow and exchange to remove large quantities of water from the product (and eject it from the system).

Before smoking, fish shall be dry-salted or brined in a manner that will ensure an adequate and consistent water phase salt content of the finished product. After removal from a brining solution, fish shall be rinsed with potable water. Immediately after the thermal process, the smoked fish shall be cooled to a temperature ca. 3.3 degrees Celsius or below and shall remain at or below that temperature at all times, including through all storage, marketing, and sales channels [205, Nordic Council of Ministers 2015].

The exhaust from the smoking kilns is treated using incineration. Energy consumption can be reduced using catalytic incineration and heat recuperation.

Tar is deposited on smoking sticks and in the smoking chamber. The sticks are cleaned in a constantly moving drum, which ensures that the sticks rub hard on each other to remove the deposits. The tar is then removed by a controlled water supply and not running water. Tar deposited in kilns or troughs is collected and handled as chemical waste and not via the WWTP.

Smoking frames are often cleaned manually with a pressure cleaner. A washing cabinet which collects and recirculates water containing detergents, is used. The drain may automatically be changed over to the WWTP at the final rinse. As an alternative, a washing tunnel could be used with water from the second stage reused for the initial rinse.

Table 7.2 shows the environmental impact of the different methods for smoke generation.
### Table 7.2: Environmental impact of the different methods for smoke generation

<table>
<thead>
<tr>
<th>Method</th>
<th>Emissions to air</th>
<th>Air treatment</th>
<th>Tar deposits</th>
<th>Cleaning (water consumption/waste water pollution)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burning wood</td>
<td>Large content of VOCs</td>
<td>Needed</td>
<td>Large content</td>
<td>Water consumed and waste water produced due to cleaning</td>
</tr>
<tr>
<td>Smouldering wood</td>
<td>Up to 200 chemical components</td>
<td>Needed</td>
<td>Large content</td>
<td>Water consumed and waste water produced due to cleaning</td>
</tr>
<tr>
<td>Liquid</td>
<td>Reduced to a large extent, e.g. odour/VOCs</td>
<td>Reduced considerably</td>
<td>No deposits</td>
<td>Reduced</td>
</tr>
<tr>
<td>Friction</td>
<td>Reduced</td>
<td>Unnecessary</td>
<td>Reduced</td>
<td>Reduced, powerful detergents are not needed</td>
</tr>
<tr>
<td>Superheated steam</td>
<td>Reduced</td>
<td>Reduced</td>
<td>Reduced</td>
<td>Reduced</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

### 7.2.3.4 Drying

Like the salting method, it lowers the water content of the fish to a point where microorganisms, bacteria, enzymes, and yeasts cannot grow and multiply. The most popular fish preservation method is solar drying (natural dehydration). It is done in combination with salting. Fish dried under the sun looks and tastes better.

### 7.2.4 Fish meal/oil production

Fishmeal and fish oil are produced by a continuous process called wet pressing method, which involves cooking, pressing, drying and milling. Fishmeal factories use raw material fully. The following summary is a step-by-step guide to the production process [205, Nordic Council of Ministers 2015]:

- intake raw fish is sampled and analysed on intake to check for freshness;
- cooking: the raw fish is conveyed through a steam heated continuous cooker, where it is heated to 90–95° C. This sterilises the fish, coagulates the proteins and disrupts the cell membranes, to facilitate the separation of the solubles and the oil from the dry matter;
- pressing: the cooked raw material is fed to a screw press where much of the liquid is squeezed out to form a presscake which is conveyed to the dryer;
- separator: the press liquid contains, apart from water, most of the oil from the fish, and also dissolved proteins, salts and fine particles. The latter are removed in a decanter and transported to the dryer to be mixed in with the presscake. The liquid from the decanter is fed to separators where the oil is removed and subsequently stored for export;
- evaporator: the water phase from the separators is fed to the evaporators where it is concentrated before being blended with the presscake during the drying stage;
- dryer: the water in the presscake, sludge and concentrate is removed by rapid hot air drying after which the fishmeal is cooled, milled and stored for export.

Frozen processed fish/moulded fish products and fish fingers

During processing, frozen fish blocks, made from either layered fillets, jumbled or minced fish, are cut into the required dimensions. With moulded products, the fish off-cuts, seasoning and binding materials are fed into a moulding machine and formed into the required shape. The product then passes through a series of enrobing machines, which cover the fish with batter
and/or breadcrumbs, with the type and number of enrobers being dependent upon the desired product. After enrobing, the product is fried in an edible oil. Temperatures vary, but around 190 °C is typical. The fryers may be heated by thermal oil, gas or by electrical means. The fried product then travels into a freezing unit where it is subjected to a stream of cold air to reduce the product to a predetermined target temperature. –18 °C is typical.

Canned fish/shellfish products

Raw fish are washed, cut into fillets and then steamed in cooking/cooling tunnels. After head removal, white fish are filleted in machines with two sets of rotating knives that cut the fillets from the bone and cut off the collar bones. The knives are watered to cool them and to clean off fish meat and scale.

Next, the two fillets are conveyed skin-side down to the skinning phase. Fatty fish are orientated in a forward direction and held into position, using water jets, until aligned with a stop plate. They are de-headed and the tails and guts are taken out before entering the filleting machine. The two fillets then proceed to the skinning stage. Filleting and skinning may be carried out manually. Descaling is sometimes achieved using caustic baths. Fish off cuts are normally transported to the waste collection area via chutes, water flumes or conveyor belts.

After steaming, the fish are filled into cans, which contain either brine, oil or sauce. The cans are sealed by passage through a can seamer. Precooking, skinning and cutting are carried out if medium size or large fish are processed. Small fish are put in cans whole and are cooked directly in the can.

After seaming, the cans pass into a retort for sterilisation. Here, the product is heated at a sufficient temperature to inactivate any food poisoning microorganisms. The product is then cooled with chlorinated water. Shellfish are processed in a similar manner but are often transported under a rocking motion through a scalding system to open the shells and dislodge the flesh. Additional washing and trimming steps may also be incorporated to remove sand and mud.

The curing and smoking of fish and during processing of shellfish, may also be carried out.

Crustaceans

Once headed and washed, shrimps and prawns are preserved by icing or brine-freezing before being transported to the processing installation. Chemicals, e.g., sodium bisulphite, are used to prevent black spots. After cooking, they are peeled and cooled with large amounts of water. Crabs are transported alive. Crab meat is picked, either manually or mechanically.

Molluscs

The types of molluscs processed and consumed in Europe mainly comprise cephalopods (cuttlefish, squid, octopus) and bivalves (oyster, mussel, clam and scallop). Processing includes freezing, canning and pickling. After cooking and shell removal, washing is often carried out by blowing air at the bottom of washing tank to agitate the meat, while the grit and shell particles settle down. Some molluscs, such as oysters or mussels are pickled with vinegar and spices. Here, the meat is dipped in 3% salt brine, drained and covered for three days with a 3% vinegar solution containing 3% salt. They are then drained, packed and covered with spiced vinegar.

Waste water treatment

Fish processing waste water primary treatment applies to the following techniques:
• screening (see Section 2.3.6.1.1)
• sedimentation (see Section 2.3.6.1.5)
• DAF (see Section 2.3.6.1.6)
• centrifugation (see Section)
• precipitation (see Section 2.3.6.1.8).

After primary treatment, if the waste water quality is not suitable for discharge to a MWWTP, secondary treatment is needed. Removal efficiency using aerobic treatment (see Sections 2.3.6.2.1) is high for waste water with BOD/COD <3000 mg/l. For highly polluted waste water, e.g. BOD/COD >3000 mg/l, anaerobic treatment (see Section 2.3.6.2.2) is used.

Tertiary treatment in the fish sector includes, e.g. membrane separation (see Section 2.3.6.3.7) and disinfection and sterilisation (see Section 0).

The use of landspreading has been reported in this sector.
7.3 Current consumption and emission levels

7.3.1 Overview

Major environmental impacts associated with fish processing operations are the high consumption of water, consumption of energy and the discharge of a waste water with a high organic concentration due to the presence of oils, proteins and TSS. Waste water can also contain high emission levels of phosphates, nitrates and chloride. Noise, odour and solid wastes may also be concerns for some installations. In addition to this, due to its highly perishable nature when compared to other FDM products, if not properly refrigerated, product yield decreases and product losses contribute to the solid and liquid waste loads. These solids may be used in fish-meal production. The consumption and emission of the utilities (water, energy) varies in wide range, depending on the process technology, product characteristics, installation location, equipment characteristics and source of utilities. Table 7.3 summarises the environmental impact of the processes applied in this sector.

Table 7.3: Environmental impact in processes of fish processing industry

<table>
<thead>
<tr>
<th>Process</th>
<th>Water consumption</th>
<th>Waste water generation</th>
<th>Energy consumption</th>
<th>Waste generation</th>
<th>Odour</th>
<th>Noise</th>
<th>Chemical consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preliminary processing</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Thawing/frizzing</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Grading</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Scaling</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Deheading and gutting</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Filleting and skinning</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Canning</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Salting</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Smoking</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Drying</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fish meal/oil production</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cleaning</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

NB: + = potential environmental impact  
- = non existing/no relevant environmental impact

Source: [205, Nordic Council of Ministers 2015]

Table 7.4 shows the inputs and outputs of different types of fish production.
### Table 7.4: Inputs and outputs of the different fish production (per 1 000 kg of fish)

<table>
<thead>
<tr>
<th>Process</th>
<th>Inputs</th>
<th>Outputs</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy (kWh)</td>
<td>Waste water (m³)</td>
<td>BO D (kg)</td>
<td>COD (kg)</td>
<td>Nitrogen (kg)</td>
<td>Phosphorus (kg)</td>
<td>Solid waste (kg)</td>
</tr>
<tr>
<td></td>
<td>Freezing: 50–70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Filleting: 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oily fish filleting</td>
<td>Ice: 10–12</td>
<td>5–8</td>
<td>50</td>
<td>85</td>
<td>2.5</td>
<td>0.1–0.3</td>
<td>400–450</td>
</tr>
<tr>
<td></td>
<td>Freezing: 50–70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Filleting: 2–5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frozen fish thawing</td>
<td>NI</td>
<td>5</td>
<td>NI</td>
<td>1–7</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>De-icing and washing</td>
<td>0.8–1.2</td>
<td>1</td>
<td>NI</td>
<td>0.7–4.9</td>
<td>NI</td>
<td>NI</td>
<td>0–20</td>
</tr>
<tr>
<td>Grinding</td>
<td>0.1–0.3</td>
<td>0.3–0.4</td>
<td>NI</td>
<td>0.4–1.7</td>
<td>NI</td>
<td>NI</td>
<td>0–20</td>
</tr>
<tr>
<td>Scaling of white fish</td>
<td>0.1–0.3</td>
<td>10–15</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>Scales: 20–40 Head and debris: 270–320</td>
</tr>
<tr>
<td>Deheading of white fish</td>
<td>0.3–0.8</td>
<td>1</td>
<td>NI</td>
<td>2–4</td>
<td>NI</td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Filleting of deheaded white fish</td>
<td>1.8</td>
<td>1–3</td>
<td>NI</td>
<td>4–12</td>
<td>NI</td>
<td>NI</td>
<td>Frames and off cut</td>
</tr>
<tr>
<td>Filleting of ungutted oily fish</td>
<td>0.7–2.2</td>
<td>1–2</td>
<td>NI</td>
<td>7–5</td>
<td>NI</td>
<td>NI</td>
<td>Scales: 400 Entrails, tails, heads and frames: 400</td>
</tr>
<tr>
<td>Skinning white fish</td>
<td>0.4–0.9</td>
<td>0.2–0.6</td>
<td>NI</td>
<td>1.7–5</td>
<td>NI</td>
<td>NI</td>
<td>Skin: 40</td>
</tr>
<tr>
<td>Skinning oily fish</td>
<td>0.2–0.4</td>
<td>0.2–0.9</td>
<td>NI</td>
<td>3–5</td>
<td>NI</td>
<td>NI</td>
<td>Skin: 40</td>
</tr>
<tr>
<td>Trimming and cutting of white fish</td>
<td>0.3–3</td>
<td>0.1</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Packaging of fillets</td>
<td>5–7.5</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Freezing and storage</td>
<td>10–14</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Handling and storage of fish</td>
<td>10–12</td>
<td>NI</td>
<td>NI</td>
<td>130–140</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Unloading of fish</td>
<td>3</td>
<td>2–5</td>
<td>NI</td>
<td>27–34</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
</tbody>
</table>

NB: NI = no information provided

**Source:** [205, Nordic Council of Ministers 2015]

### 7.3.2 Energy consumption

Fish processing facilities need energy to produce hot water, steam and electricity for process and cleaning applications. Electricity is used for electrical equipment, air conditioning, cooling, freezing, and ice production. Energy consumption can be divided into two parts: approximately
80 % energy consumption depends on production and 20 % is constant and independent of production [205, Nordic Council of Ministers 2015].

The consumption of energy depends on the installation, the equipment and the fish manufacturing processes that take place. Processes, e.g. canning, that involve heating, cooling, production of ice, drying, evaporation and oil production consume more energy than those that do not, e.g. filleting, where energy consumption is low. On average, filleting consumes 65–87 kWh/t of fish and canning consumes 150–190 kWh/t of fish [192, COM 2006].

7.3.3 Water consumption

Fish processing requires large amounts of water, primarily for washing and cleaning purposes, but also as a media for storage and refrigeration of fish products before and during processes. Water is also an important medium for transportation in the particular handling and processing steps. The processing industry for marine species often uses seawater in part of the cleaning process, and cleaning the fish filet with seawater is considered important to improve the quality of the finished product. Seawater used for this purpose is normally filtered and treated with UV disinfection to inhibit spreading of bacteria.

To meet quality and hygiene standards, the fish sector uses high quantities of water. It is mainly consumed for cleaning operations and washing, cooling, and transportation of fish. Fish canning and fish filleting consume large quantities of water, e.g. to clean and lubricate the filleting machinery. Typical figures for fresh water consumption are for thawing, about 1 m³/t fish; for filleting 5 to 11 m³/t fish, and for canning, 15 m³/t fish. Water is used for transporting fish and viscera, for cleaning the installation and the equipment, for washing raw materials and products, and for thawing. Reported water consumption and specific COD loads for traditional fish processing are summarised in Table 7.5.

Table 7.5: Specific water consumption and organic load in Nordic countries

<table>
<thead>
<tr>
<th>Production</th>
<th>Water consumption (m³/t raw fish)</th>
<th>COD (kg/t raw fish)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herring filleting</td>
<td>3.3–10</td>
<td>Up to 95</td>
</tr>
<tr>
<td>Mackerel</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Cleaning and head cut</td>
<td>20</td>
<td>270</td>
</tr>
<tr>
<td>Thawing included</td>
<td>26–32</td>
<td>NI</td>
</tr>
<tr>
<td>White fish processing</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Fresh fish</td>
<td>4.8</td>
<td>5–36</td>
</tr>
<tr>
<td>Thawing included</td>
<td>9.8</td>
<td>NI</td>
</tr>
<tr>
<td>Shrimp processing</td>
<td>23–32</td>
<td>100–130</td>
</tr>
</tbody>
</table>

NB:NI = no information provided
Source: [13, Nordic Council of Ministers 1997.]

7.3.4 Emissions to water

Water consumption in fish processing industry and the production of highly polluted waste water are of great concern worldwide. In fact, in this type of industries, a huge amount of water is used throughout all steps, including cleaning, cooking, cooling, sanitization and floor washing. Most of the water consumed during fish processing becomes waste water. The process related waste water is produced in different processing steps, e.g. thawing, washing, head cutting, filleting, skinning and trimming, and in cleaning the equipment and the installation.
Fish processing waste water are known to contain organic contaminants in soluble, colloidal and particulate form. The biodegradable organic matter is mainly in the form of proteins and lipids. The concentration and volume of waste water from fish processing varies widely, depending on the fish to be processed, the additives used (e.g. brine, oil, tomato sauce), the unit processes involved and the source of the water, among other factors.

When frozen fish is used as a raw material, a thawing step is needed. The organic pollution of the waste water is relatively small. Scaling normally takes place in rotating perforated drums. Scales are flushed away using large amounts of water – 10 to 15 m$^3$/t fish. Large volumes of waste water and organic pollution are generated. If the fillets are to be skinned, scaling is not necessary. In automated filleting and eviscerating processes, water is used to lubricate fish while passing through the machine. For some species such as mackerel, a warm caustic bath is necessary to remove the skin and the waste water needs to be neutralised before it is discharged.

Water is used for washing and rinsing the fish, giving rise to waste water carrying fish scraps and viscera. Viscera from oily fish contain high emission levels of oil and soluble matter, thus waste water from their filleting normally has higher COD emission levels (3 000–60 000 mg/l) than those from white fish filleting (2 000–6 000 mg/l). The highly polluted waste water is generated due to the time that solid wastes are in contact with the water which contains blood and fat. In automated skinning, the fillet is pulled over a freezing drum. Water is used to clean and lubricate the machine. The skinning of fatty fish releases large quantities of oil to the waste water. The skinning process contributes about one third of the overall organic pollution in the waste water of filleting installations.

As the evisceration of fatty fish takes place at the processing installation, and white fish are eviscerated at sea, this also adds to the reason for the waste water having higher COD and TSS emission levels. Table 7.6 shows the reported waste water characteristics from fish filleting.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Filleting of herring</th>
<th>Filleting of cod</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (kg/m$^3$)</td>
<td>Range (kg/m$^3$)</td>
</tr>
<tr>
<td>BOD$_2$</td>
<td>10 000</td>
<td>5 000–20 000</td>
</tr>
<tr>
<td>Fat</td>
<td>12 000</td>
<td>2 500–16 000</td>
</tr>
<tr>
<td>Dry matter</td>
<td>20 000</td>
<td>5 000–28 000</td>
</tr>
<tr>
<td>Protein</td>
<td>6 000</td>
<td>NI</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Water consumption (m$^3$/t)</td>
<td>NI</td>
<td>5</td>
</tr>
</tbody>
</table>

NB:NI = no information provided

Table 7.6: Waste water characteristics from fish filleting

In precooking, water is reused several times and recovery can be made. About 3–4 g oil/kg fatty fish, protein and pieces of fish are released into the water with oil forming a layer on the surface. If the fish is made in brine, there is a high salt concentration in the waste water. Skin is removed from some species, such as mackerel, with the help of a warm caustic bath. Waste water is consequently alkaline and is treated by neutralisation.

The waste water contains blood, flesh, guts, soluble protein and waste material and is high in BOD, COD, TSS, FOG, and phosphates, as well as detergents and other cleaning agents.

Table 7.7 shows the characteristics of untreated waste water from the fish sector and its primary treatment efficiencies.
Table 7.7: Characteristics of untreated fish industry waste water and primary treatment efficiencies

<table>
<thead>
<tr>
<th>Treatment method</th>
<th>BOD (mg/l)</th>
<th>Total N (mg/l)</th>
<th>Total P (mg/l)</th>
<th>FOG (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>2000–28000</td>
<td>400–1000</td>
<td>80–150</td>
<td>500–25000</td>
</tr>
<tr>
<td>Centrifugation</td>
<td>1500–5000</td>
<td>NI</td>
<td>NI</td>
<td>500–2000</td>
</tr>
<tr>
<td>DAF</td>
<td>1500–6000</td>
<td>200–600</td>
<td>40–90</td>
<td>400–2000</td>
</tr>
<tr>
<td>Precipitation (H₂SO₄) and DAF</td>
<td>800–3000</td>
<td>150–300</td>
<td>30–50</td>
<td>100–500</td>
</tr>
<tr>
<td>Precipitation (Fe/Mo) and polyelectrolyte</td>
<td>600–3000</td>
<td>150–300</td>
<td>5–10</td>
<td>100–500</td>
</tr>
<tr>
<td>Two step DAF with precipitation (Fe/Mo) and polyelectrolyte</td>
<td>500–1500</td>
<td>100–200</td>
<td>5–10</td>
<td>50–300</td>
</tr>
</tbody>
</table>

NB: NI = no information provided
Source: [71, AWARENET 2002]

Waste water production rates and characteristics depend highly on the production lines. Data for Germany are presented in Table 7.8.

Table 7.8: Typical waste water production rates and characteristics for fish processing in Germany

<table>
<thead>
<tr>
<th>Production</th>
<th>Waste water production (m³/t)</th>
<th>TSS (mg/l)</th>
<th>BOD₅ (mg/l)</th>
<th>Fats* (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herring</td>
<td>17–40</td>
<td>220–1 520</td>
<td>2 300–4 000</td>
<td>190–450</td>
</tr>
<tr>
<td>Fresh fish</td>
<td>About 8</td>
<td>170–3 650</td>
<td>1 000–6 250</td>
<td>46–2 500</td>
</tr>
<tr>
<td>Smoking of fish</td>
<td>About 8</td>
<td>14–845</td>
<td>1 000–1 700</td>
<td>24–180</td>
</tr>
<tr>
<td>Salting of salmon</td>
<td>About 35</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Deep frozen fish</td>
<td>2–15</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Thawing</td>
<td>NI</td>
<td>0–70</td>
<td>30–1 800</td>
<td>4–46</td>
</tr>
</tbody>
</table>

*expressed as petrolether extract.
NB: NI = no information provided.
Source: [12, ATV 2000]

Fish processing waste water is generally treated using physical-chemical methods (primary treatment) biological methods (secondary treatment), or a combination of both. Within the primary treatment, can be listed processes as equalisation, screening, sedimentation, pH adjustment, flocculation, flotation, and microfiltration. The biological processes (aerobic and anaerobic) are known to be the more appropriate for removal of dissolved organics and nutrients.

A stepwise approach to waste water treatment commonly yields the best results in the most economical way. The primary treatment deals with the removal of suspended solids, colloidal materials and large screenable and settleable solids. In the treatment of fish processing waste water solids and colloids, they should be removed fast and with low shear technologies in order to avoid dissolution of oil and organics (COD) into the water. Waste water treatment is a provision to collect the substances lost during the process as the last possibility of pollution control and a good opportunity for recovering valuable substances.
7.3.5 Emissions to air

Particulate matter (PM), carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAH), organic acids, acrolein, acetaldehyde, formaldehyde, nitrogen oxides, and most importantly volatile organic compounds (VOC) have been identified as pollutants associated with smokehouses.

7.3.5.1 Odour

Odour is often a significant form of air pollution in fish processing. Major sources include storage sites for processing waste, cooking by-products during fish drying processes, and odour emitted during filling and emptying of bulk tanks and silos. Fish quality may deteriorate under the anaerobic conditions found in on-board storage on fishing processing facilities. This deterioration causes the formation of odorous compounds such as ammonia, mercaptans, and hydrogen sulphide gas.

The largest odour source in the fish by-products segment is the fishmeal dryers. Odorous gases from reduction cookers consist primarily of hydrogen sulphide (H$_2$S) and trimethylamine [(CH$_3$)$_3$N], but are emitted from this stage in appreciably smaller volumes than from fishmeal dryers. The canning processes also release some odours. Fish cannery and fish by-product processing odours can be controlled by means of afterburners, chlorinator–scrubbers, or condensers [205, Nordic Council of Ministers 2015]. The vented smoke also contains VOCs. Some installations remove odours from the smoke before it is emitted to the air.

7.3.6 Residues

The amount of waste from fish varies with fish species, size, season and fishing ground. The solid waste is generated when the fish is gutted, headed and further processed into fillets. Depending on the efficiency of the production process, only 50–60% of total fish catch goes for human consumption. The waste includes heads, viscera, skin, trimmings and fish rejects. They are often dumped, used as animal feed or as fertiliser. Due to the worldwide decline of fish stocks, a better use of by-catch and by-products is important. These biomasses have great potential as a source of high valued products due to their high protein content, high levels of essential nutrients such as vitamins, minerals, and fish oils.

The solid wastes generated during fish processing range between 20–60% of the catch, comprising skin, guts, bones, heads, cephalopods, feathers and shells. For example, when the fish quality is poor, soft fillets can get caught in the skinning knife. This decreases the yield and increases the production of by-products and waste.

Part of the waste water and almost all of the solid output may be used for different purposes. Fatty acids and flavours may be recovered from cooking water. Rejected fish are used in animal feed or for production of fish-meal and fish-oil and used afterwards in foodstuff, animal feed and coatings.

By-products from the filleting, skinning, cutting and canning steps are used for:

- production of foodstuffs, e.g. fish-meal, ingredients, surimi, polyunsaturated fatty acids, gelatine and collagen
- production of animal feed, e.g. fish protein, fish silage, fish protein hydrolysate, pet food, fish-oil and solubles
- production of fertilisers such as fish solubles and fish protein hydrolysate
- production of pharmaceuticals such as gelatine and collagen
- production of coatings, e.g. fish-oil and pearl essence, and adhesives such as fish glue
- production of leather.
Fluid lost from the fish may be treated anaerobically to produce biogas. Heads, shells, intestines and scraps have different applications, such as:

- production of animal feed, e.g. fish-meal, crustacean meal for cats and antaxanthin for aquaculture
- production of foodstuff, e.g. fish-meal, chitin and chitosan
- production of flocculants for waste water treatment, e.g. chitin and chitosan
- production of pharmaceuticals, e.g. chitin and chitosan.

Solid by-products of the filleting, curing, salting and the smoking of fish have similar uses as mentioned above for the canning of fish. Ash from shavings is generally disposed of with municipal solid waste. Figure shows the consumption and emission levels of the process steps in filleting and preserving fish.

![Figure: Consumption and emission levels of the process steps in filleting and preserving fish](image)

The main crustaceans processed and consumed in Europe comprise shrimps, prawns, lobsters, crayfish crabs and crabs. The main processing steps together with consumption and emission levels are presented in Figure.
Figure: Consumption and emission levels of the process steps in crustaceans processing [134, AWARENET, 2002]

Sand and shell particles generated during the shell removal and washing steps of mollusc processing are used in the production of chemicals such as plastics and paints, construction materials and fertilisers. Fluid lost from the fish, e.g. clam juice, may be used in foodstuffs. Figure shows the consumption and emission levels of the process steps in mollusc processing.

Figure: Consumption and emission levels of the process steps in mollusc processing [134, AWARENET, 2002]
7.4 Techniques to consider in the determination of BAT

7.4.1 Techniques to increase energy efficiency

7.4.1.1 Friction smoke

Description
Smoke is generated from the friction between wood and a rapidly rotating rough roller which creates pyrolysis.

Technical description
Smoke is generated from the friction between wood and a rapidly rotating rough roller which creates pyrolysis. The smoke is mild and contains hardly any carcinogenic compounds. The process can be carried out in a closed system with recirculation, so that use of an afterburner or other smoke cleaning system is unnecessary. This method claims to enable a more precise control of the volume of smoke produced, by altering the pressure between the wheel or disc and the wood.

Achieved environmental benefits
Reduced energy and water consumption. Reduced waste water pollution. Reduced tar production.

Environmental performance and operational data
It is reported that the energy saving is often 50 % of the energy consumption. As a result of the mild smoke, the deposits in the smoking chamber are less than 10 % of the deposits created with wood chip smoke. Cleaning is, therefore, much easier, and the use of powerful detergents is avoided. There are fewer organic compounds in the waste water, and water is saved due to longer intervals between cleaning.

Technical considerations relevant to applicability
Applicable in the processing of fish and seafood, meat, cheese, and fruit and vegetables.

Example plants
Used in fish processing.

Reference literature
[20, Nordic Council of Ministers 2001]

7.4.2 Techniques to reduce water consumption

7.4.2.1 General processing techniques

7.4.2.1.1 Removal and transport of fat and viscera by vacuum

Description
Using a vacuum, fat and viscera are removed from the fish.

Technical description
In skinning and cutting, enclosed systems are applied for transporting fat and viscera to collection facilities. The fat and viscera are removed from the fish by vacuum and not with water. The sucking equipment consists of a vacuum ending in a specially designed sucking nozzle placed immediately after the head cut.

Achieved environmental benefits
Reduced water consumption. Reduced waste water pollution. Waste minimisation, e.g. by-products can be sold for fish-meal production.
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Environmental performance and operational data
Reductions of 30 to 50% of the pollution load are achieved. The energy consumed is higher than for the traditional removal of the head by cutting and washing out the viscera.

Technical considerations relevant to applicability
Applicable in the fish sector, e.g. during cutting, eviscerating and filleting. The technique was applied in herring filleting, but abandoned due to the energy consumption and noise.

Cross-media effects
Energy consumption and noise pollution.

Economics
Savings in waste water treatment. As the by-product has a lower water content, it can be sold at a higher price.

Example plants
Used in mackerel processing in the Nordic countries.

Reference literature
[13, Nordic Council of Ministers 1997], [71, AWARENET 2002]

7.4.2.1.2 Using the filtered recirculated scaling waste water for preliminary fish rinsing

See also Section 2.3.3.1.1.

Description
Scaling waste water is filtered and recirculated for preliminary fish rinsing.

Technical description
Scaling equipment consists of a perforated rotating drum onto which water is applied to flush scales away. Using the filtered recirculated scaling waste water for preliminary fish rinsing minimises overall water consumption. Proper adjusting of the scaler operation, by weighing the amount of scales for a specific water flow, is also carried out.

Achieved environmental benefits
Reduced water consumption.

Environmental performance and operational data
Water savings of up to 70% are reported.

Cross-media effects
Energy consumption for reusing the scaling water.

Technical considerations relevant to applicability
Applicable in the fish sector.

Example plants
TWG, please provide information.

Reference literature
[71, AWARENET 2002]
7.4.2.1.3 Avoiding scaling if the fish is subsequently skinned

Description
Scaling equipment consists of a perforated rotating drum onto which water is applied to flush scales away. If the fish is subsequently skinned, scaling is not carried out.

Achieved environmental benefits
Reduced water consumption. Reduced energy consumption.

Environmental performance and operational data
Water savings of 10–15 m$^3$/t are achieved.

Technical considerations relevant to applicability
Applicable in the fish sector.

Example plants
TWG, please provide information.

Reference literature
[71, AWARENET 2002]

7.4.2.1.4 Dry transport of fat, viscera, skin and fillets, incorporating mesh conveyors

Description
Use of conveyors or a vacuum instead of using transport water.

Technical description
Instead of using transport water in filleting, skinning and fat and viscera removal, a conveyor can either be set up under each line or a single filtering conveyor can serve all the machines. The dry transport is carried out by a chute with approximately 20% slope mounted under the gutting wheel. Here viscera, fatty belly strips and the water from the wheel are caught. The method used on a filleting machine is shown in Figure 7.7. From the chute, viscera strips and water slide on to a fine meshed synthetic cloth conveyor belt, through which the water is drained. The viscera are transported to a container.

In filleting of white fish, dry transport is carried out by a filter conveyor with a mesh size of 0.25 mm. The water from the machines and small particles pass through the filter, while solids, e.g., fat and viscera, are retained. To keep the equipment clean and preserve filter capacity, it may be necessary to mount a water spray system. The filtrate can be used as spray water.
Achieved environmental benefits
Reduced waste water pollution load. Waste minimisation, e.g. a large amount of saleable by-product is collected, which can be sold for fish-meal production.

Cross-media effects
Water consumption, e.g. for cooling the equipment’s knives and wheels, for cleaning the filter belt, and for cleaning the belly cavity. Energy is consumed.

Environmental performance and operational data
The pollution load of the waste water is reduced by 29–52 %, as shown Table 7.9.

Table 7.9: Discharge data before and after introduction of dry removal and transport of viscera

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wet (kg/t raw herring)</th>
<th>Dry (kg/t raw herring)</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total nitrogen</td>
<td>1.4</td>
<td>0.99</td>
<td>30</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>0.17</td>
<td>0.12</td>
<td>29</td>
</tr>
<tr>
<td>COD</td>
<td>26.3</td>
<td>15.0</td>
<td>43</td>
</tr>
<tr>
<td>Dry material</td>
<td>17.8</td>
<td>10.9</td>
<td>39</td>
</tr>
<tr>
<td>Oil</td>
<td>7.3</td>
<td>3.5</td>
<td>52</td>
</tr>
</tbody>
</table>

Filter conveyors under filleting machines are estimated to decrease the total COD discharge by about 5–15 % if the installation has a central filter conveyor or about 15–25 % if it has a drum sieve.

Technical considerations relevant to applicability
Applicable in the fish sector, e.g. during skinning, evisceration, filleting and cutting.
**Economics**
As the by-product has a lower water content, it can be sold at a higher price.

**Driving force for implementation**
Economic savings in waste water treatment.

**Example plants**
Used in the Danish herring industry, in whitefish processing in the Nordic countries and in the fish processing industry in the UK.

**Reference literature**
[13, Nordic Council of Ministers 1997], [28, Envirowise (UK) 1999]

**Transport of skin and fat from the skinner drum by vacuum**

**Description**
This technique consists of Water is only used to moisten the drum to maintain the sucking effect.

**Achieved environmental benefits**
Reduced water consumption. Reduced waste water pollution.

**Cross-media effects**
Energy consumption.

**Environmental performance and operational data**
Both COD load and water consumption are reduced by 95–98%. The need for water for both transport and routine rinsing is removed.

**Technical considerations relevant to applicability**
Applicable in the fish sector, e.g. during skinning.

**Economics**
Savings in waste water treatment.

**Example plants**
Used in the Danish herring industry.

**Reference literature**
[13, Nordic Council of Ministers 1997]

**7.4.2.2 Techniques related to cleaning**

**7.4.2.2.1 Dry cleaning**

This technique is described in Section 2.3.3.2.1.

**Environmental performance and operational data**
Dry systems for collecting solid waste from crustaceans and molluscs, such as screens and efficient recovery systems prevents it from entering the WWTP and can reportedly lead to BOD₅ level reductions of up to 35%.

Other example is to use of a suction device which sucks the skinner drum clean of skin and fat.
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Technical considerations relevant to applicability
Applicable to all fish and seafood processing installations.

Reference literature
[ 71, AWARENET 2002 ]

7.4.3 Techniques to reduce waste

7.4.3.1 Segregation Separation of residues outputs, to optimise use, reuse, recovery, recycling and disposal (and minimise water use and waste water contamination)

This technique is described in Section 2.3.5.3.

Reported example of where the technique is applied
There are likely to be many other opportunities to apply this technique within the sector.

- apply dry collection of all solid wastes by means of trays or baskets to prevent them from falling on the floor and entering the WWTP.

Technical considerations relevant to applicability
Applicable to all fish and seafood processing installations.

Reference literature
[ 71, AWARENET 2002 ]

7.4.3.2 Use only high quality fish

Description
High quality fish can be selected for fillets to increase the process yield.

Technical description
When the fish quality is poor, soft fillets can get caught in the skinning knife. This decreases the yield of the process and increases the generation of by-products and waste production. Skinning of fatty fish releases large quantities of oil to the waste water, amounting to about 1/3 of the overall TOC or COD load. Water is used to clean and lubricate the machinery. Maintaining the sharpness of skinning knives also makes a significant contribution to efficient skinning and waste minimisation.

Fish can deteriorate under the anaerobic conditions present during storage on the fishing vessel, so ensuring rapid delivery and processing, as well as providing storage conditions which maintain quality, contributes to maintaining high quality. The fish are stored in ice, while at sea. On land, they may be stored on ice and sometimes in refrigerated storage. The method of storage may depend on the time interval between the fish being caught and subsequent processing. High quality fish can be selected for fillets and lower quality fish can be used, e.g. in fish-meal and fish-oil production. Broken fish may be used for food which does not require the appearance of whole fillets, such as moulded products and soups.

The successful application of this technique depends on collaboration with the operators of the fishing vessels and intermediary holders of the fish, such as wholesalers and hauliers.

Achieved environmental benefits
Reduced waste generation.
Cross-media effects
Energy may be required for storage.

Technical considerations relevant to applicability
Applicable in fish processing.

Driving force for implementation
Reduced waste generation.

Reference literature
[13, Nordic Council of Ministers 1997], [71, AWARENET 2002]

Smoke from burning wood

Description
The equipment for generating smoke from burning wood consists of a chamber with a smoke generator. In the simplest operation, the products are hung on racks in the chamber with a fire of wood dust or chips ignited on the floor. This fire is suitably dampened to maximise the smoke production and to avoid flame production. The product increases in temperature to about 30 ºC. The smoking period may last for up to 48 hours.

Cross-media effects
Exhaust air with a large VOC content. Large quantities of tar are deposited in the smoking chamber.

Environmental performance and operational data
It is reported that burning sawdust produces smoke with a large content of VOCs. An open or semi-open system is used and a supply of air is necessary, i.e. a surplus of air is used which will require cleaning before it is released to the air.

When wood chips are used in the smoke generator, the air supply, and thus also the temperature, are both normally higher. More tar compounds are formed and the need for cleaning is, therefore, greater. Smoke cleaning is also normally required in this case.

In a Norwegian investigation, the control programme for the smoking process was altered to take account of the need for smoke. The smoke generator was thus closed down before the smoking process was completed. This reduced the consumption of wood chips from 8.9 to 3.6 kg per tonne of sausages without changing the product quality.

Technical considerations relevant to applicability
Applicable in the processing of fish and meat.

Reference literature
[20, Nordic Council of Ministers 2001]

Smoke from smouldering wood

Description
Smoke from smouldering wood consists of two phases, i.e. a disperse liquid phase, e.g. droplets, and a vapour phase. The former contains particles of smoke, which are not regarded as important in the smoking process. The vapour phase is more important in imparting flavour.

Smoking can take place at two temperature levels, i.e. ambient, up to 30 ºC, and at elevated temperatures, between 50 and 90 ºC. The heat from the smouldering wood is not enough to raise the temperature up to between 50 and 90 ºC, so extra heat is added by means of steam or a heat-
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exchanger. The duration of the smoking depends on the product. Some products require pre-drying or drying or maturing between smoking steps. Conditioned air, which is temperature and moisture heated by steam-pipes or electrical heaters, is used to control the drying of the product. The time the product is in the chamber varies from hours to days. The period the product is smoked can range between 15 minutes to 4 hours per phase.

Cross-media effects

The vapour phase contains up to 200 chemical components, not all of which have been identified. They include a range of organic acids, aldehydes, ketones, alcohols and polycyclic hydrocarbons. Tar is deposited in the smoking chamber.

Environmental performance and operational data

It is reported that the smoke generator can be a small oven where hardwood chips or sawdust are slowly added onto a bed of already smouldering wood or onto an electrically heated grid. Air is blown through the small oven and carries the smoke into the smoking chamber where the product is located. The smoke exiting the chamber is vented to the air or partially recirculated. In more sophisticated systems, the equipment may also include an air conditioning unit to, e.g. ventilate, cool, heat or moisturise the air. In older types of cold smoking kilns, the sawdust is often burned directly on the floor.

Technical considerations relevant to applicability

Applicable in the processing of fish and seafood, meat, cheese, and fruit and vegetables.

Reference literature

[20, Nordic Council of Ministers 2001]

Case studies

Herring processing in Denmark

Description

Before early 1990, the Danish fishing industry was characterised by a large consumption of water and a large discharge of organic material to the waste water. From early 1990 until 1997, the industry applied cleaner technology techniques, as shown in Table, and achieved a water consumption and organic discharge reduction of up to 20–30% of the original load.

<table>
<thead>
<tr>
<th>Process</th>
<th>Measure</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorting</td>
<td>Exchange of water nozzles (see Section 2.3.1.3/3)</td>
<td>Water consumption</td>
</tr>
<tr>
<td>Eviscerating</td>
<td>Dry process for removal and transport of fat and viscera (see Section)</td>
<td>Energy, organic and nutrient pollution of waste water, reuse of waste</td>
</tr>
<tr>
<td>Filleting</td>
<td>Better use, removal and/or replacement of water nozzles (see Section 2.3.3.1.2)</td>
<td>Water consumption</td>
</tr>
<tr>
<td>Skinning</td>
<td>Transport of skin and fat from skinner drum by vacuum (see Section 4)</td>
<td>Water consumption, organic pollution of waste water</td>
</tr>
</tbody>
</table>

Table: Techniques applied in the herring filleting industry to reduce water consumption and waste water pollution.

Furthermore, in the period from 1997 to 2000, the installations involved in the study increased their product refinement and shifted from discharging waste water directly to receiving waters to being connected to a MWWTP. In 2000, only three of the companies in the study still operated a separate discharge to receiving waters.
The results from earlier projects on introducing cleaner technologies in this sector have been sustained and, in most cases, further increased through the introduction of environmental management programmes (see Section 2.3.1.1). Some installations have been certified according to ISO 14001, while others have applied non-certified environmental management schemes. In addition, all the installations have employed specialist environmental staff and, in some cases, also a manager.

**Achieved environmental benefits**
Reduced water consumption. Reduced energy consumption. Reduced pollution of waste water. Waste minimisation, e.g., waste is used as a by-product.

**Environmental performance and operational data**

In 1989, the water consumption was about 2.5–9 m³/t of raw material and the pollution load was about 20–120 kg COD/t of raw material. By the year 2000, both water consumption and COD loads had been reduced to about 1.3–3.1 m³/t raw material and 10–24 kg COD/t raw material, respectively. Earlier environmental performance variations among the companies have also been reduced significantly. The remaining difference in environmental performance is mainly due to various levels of product refinement, the different application of abatement technologies and the practising of different types of production planning.

Though the results achieved from implementing the above measures in herring processing are positive and to the benefit of the general environment, it is evident that end-of-pipe treatment still needs to be applied. The pollution level, e.g., measured as COD or nutrients, is still high in the untreated waste water, i.e., between 2000 and 10000 mg COD/l, 200–600 mg N/l, and 40–100 mg P/l.

**Example plants**
Five fish processing installations in Denmark.

**Reference literature**
[147, Lehman N. and Nielsen E.H, 2002]

**Fish processing in the UK**

**Description**
A fish food company produces 12000 t/yr of frozen and chilled fish products at its two sites in Hull, in the UK. Their major products are hot smoked mackerel and herring, cold smoked haddock, white fish fillets, and battered and breaded frozen fish.

In 1996, the company implemented a waste minimisation project which initially focused on water and waste water issues, but soon expanded to cover raw materials, packaging and energy. A waste minimisation team analysed their water use and waste water generation for different processes and prepared water balances for the company’s two sites.

**Achieved environmental benefits**
Reduced water consumption. Improved energy efficiency and hygiene standards.

**Environmental performance and operational data**
Overall water consumption was reduced by 58% per tonne of product. The measures to improve performance included:
- using new thawing equipment to eliminate water losses from leakages
- improving the cleaning procedures, e.g., reducing the number of hose pipes and encouraging employees to use plastic shovels and rubber blades to sweep up fish waste (see Section 2.3.3.2.1)
- applying dry filleting
• repairing any leaks
• training and raising employees awareness.

Economics
The benefits of the water consumption and waste water minimisation project included:
• cost savings of over EUR 150000/yr
• payback period of 36 weeks for the new thawing equipment.

Driving force for implementation
In November 1996, the company learnt that its waste water charges would increase significantly in January 2001.

Example plants
A fish processing industry in Hull, UK.

Reference literature
[58, Envirowise (UK), 1999]

7.4.4 Techniques to reduce emissions to air

7.4.4.1 Techniques to reduce TVOC emissions from smoke kilns and odour

7.4.4.1.1 Liquid smoke

Description
Treatment of fish (or meat) by exposing it to smoke under the time and temperature conditions similar to those for hot or cold smoking.

Technical description
Smoking in liquid smoke is a process of treating fish (or meat) by exposing it to smoke which is regenerated by atomizing smoke condensate in a smoking chamber under the time and temperature conditions similar to those for hot or cold smoking.

Liquid smoke is produced by condensation of the smoke, followed by fractional distillation to reduce the content of tarry matter and other contaminants. The resulting solution is diluted with water and sprayed onto the product. In some cases, it is incorporated into a curing brine and injected into the product for flavouring purposes.

The advantage is that the smoke flavour can be achieved without smoking and, therefore, the components in the smoke, which are suspected to be damaging to health, are, to a large extent, avoided. In liquid smoking, the harmful substances contained in the smoke have already been filtered out during production of the smoke condensate. As there is no emission of smoke, the need for air treatment is considerably reduced.

Achieved environmental benefits
Reduced emissions to air, e.g. odour/VOCs. Tar is not produced during this method of smoking.

Environmental performance and operational data
TWG, please provide information.

Technical considerations relevant to applicability
Applicable in the processing of fish and seafood, meat, cheese, and fruit and vegetables.

Liquid smoke results in a smoke flavour which is different from the flavour achieved with conventional smoking; this might not necessarily be acceptable to the customers, on the grounds
of taste or smell. It will thus not always be possible to choose liquid smoke for processed fish and meat products.

**Example plants**
Used in fish and meat processing, e.g. in the production of Vienna sausages.

**Reference literature**
[20, Nordic Council of Ministers 2001], [205, Nordic Council of Ministers 2015]

### 7.4.4.1.2 Smoke from superheated steam

**Description**
Superheated steam is passed over chips of wood, and transfers the smoke and flavour to the products.

**Technical description**
The pyrolysis of wood chips/shavings can also be carried out by passing superheated steam over chips of wood, which transfers the smoke and flavour to the products. This reduces the number of compounds in the smoke and also allows the air surplus to be reduced to a minimum. As the surplus steam can be condensed, the exhaust is therefore low. Cleaning is also easier due to a lower level of tar deposits in the smoking chamber.

**Achieved environmental benefits**
Reduced emissions to air. Reduced tar production.

**Environmental performance and operational data**
TWG, please provide information.

**Technical considerations relevant to applicability**
Applicable in the processing of fish and seafood, meat, cheese, and fruit and vegetables.

**Example plants**
TWG, please provide information.

**Reference literature**
[20, Nordic Council of Ministers 2001]

### 7.4.4.1.3 Biofilter

For general information, see Section 2.3.7.3.4.

**Environmental performance and operational data**
In a Norwegian salmon installation a biofilter dimensioned for 3,000 m$^3$ air/h is installed inside an insulated cassette. The biomedia consists of non-degradable compounds and after the biofilter application no bad smell was detectable in local environment [224, Denmark 2015].

**Reference literature**
[224, Denmark 2015]
7.4.4.1.4 Non-thermal plasma

A general description of the technique is given in Section 2.3.7.3.8

Environmental performance and operational data
Table 7.10 shows data for some fish-meal example installations.

Table 7.10: Odour reduction using non-thermal plasma treatment

<table>
<thead>
<tr>
<th>Industry</th>
<th>Number of samples</th>
<th>Odour in (average) (OU₄/m³)</th>
<th>Odour out (average) (OU₄/m³)</th>
<th>Average (range) reduction efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish-meal</td>
<td>3</td>
<td>15 833</td>
<td>3 233</td>
<td>80 (± 4)</td>
</tr>
<tr>
<td>Fish-meal</td>
<td>3</td>
<td>16 350</td>
<td>1 600</td>
<td>90 (± 1)</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

Reference literature
[192, COM 2006]

7.4.4.1.5 Thermal oxidation of waste gases

A general description of the technique is given in Section 2.3.7.3.6.

Environmental performance and operational data

At an example smokehouse with an annual production of around 3 000 tonnes of smoked products, waste gases from smoking are burned using a direct flame thermal oxidiser. The waste gas from the smokeless process phases, which does not require emission abatement, is not treated. The system is regarded as a robust waste gas treatment requiring little maintenance.

The thermal oxidiser is heated to its operating temperature before the smoke generators are operated. During smoking, the exhaust gas fan force-feeds the smoke-laden waste gas through a waste gas bypass flap to a preheater. Here, the dirty gas is heated to 300–350 °C before it enters the combustion chamber, where it is mixed with the hot gases from the gas burner. After treatment, the clean gas is used to preheat the dirty gas by using an integrated heat exchanger and it is cooled to 400–450 °C before it is discharged to air via a flue stack.

Table 7.11 shows technical data for direct flame thermal oxidation in the example smokehouse. A flow diagram of the origin and process management of flue-gas from this smokehouse is illustrated in Figure 7.8.
Table 7.11: Technical data of a direct flame thermal oxidiser applied in a smokehouse

<table>
<thead>
<tr>
<th>Dimensions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total length including burner</td>
<td>4 250 mm</td>
</tr>
<tr>
<td>Total length excluding burner</td>
<td>3 750 mm</td>
</tr>
<tr>
<td>Diameter</td>
<td>1 150 mm</td>
</tr>
<tr>
<td>Dirty gas connection</td>
<td>200 x 200 mm or 200 mm diameter</td>
</tr>
<tr>
<td>Clean gas connection</td>
<td>300 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>approximately 1250 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rated connections</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>Oil</td>
</tr>
<tr>
<td>Electrical connection</td>
<td>220 V/50 Hz (approximately 1 kW)</td>
</tr>
<tr>
<td>Exhaust gas fan</td>
<td>380 V/50 Hz (approximately 4 kW)</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]
Figure 7.8: Flow diagram showing the origin and process management of the flue-gas from the waste gas cleaning system of a smokehouse
In the example smokehouse, all smoke units, regardless of their size, are equipped with a smoke generator. The smoking intensity is determined by the smoking time which is approximately 60–120 minutes/batch. The flowrate for one smoke generator is 200 Nm³/h, resulting in a total flowrate for 11 smoke chambers of approximately 2300 Nm³/h. Applying a realistic parallel operating factor of 75%, the actual flowrate is 1650 Nm³/h. Table 7.12 shows technical data for the direct flame thermal oxidiser used.

Table 7.12: Technical data for a direct flame thermal oxidiser applied in a smokehouse

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste gas flowrate</td>
<td>2300 m³/h</td>
<td>Normal state (i.e. 0 ºC, and 1013 mbar, dry)</td>
</tr>
<tr>
<td>Burner capacity</td>
<td>600 kW</td>
<td>The capacity is continuously modulated</td>
</tr>
<tr>
<td>Substance concentration in waste gas</td>
<td>Achieved level not reported (&lt;50 mg/Nm³ TOC &lt;0.115 kg/h)</td>
<td>2300 Nm³/h x 50 mg/Nm³ = 0.115 kg/h</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

It is reported that at 620 to 660 ºC, complete removal of odour emissions is achieved and as a general rule, TOC is emitted at an unspecified level below 50 mg/Nm³. Direct flame thermal oxidation can be run at temperatures of up to 1000 ºC. The effectiveness of the technique depends on several parameters such as operating temperature, residence time and mixing conditions in the combustion chamber. TOC emission levels of less than 10 mg/Nm³ are readily achieved.

Figure 7.9 shows the balance of substances as an input/output diagram for the waste gas treatment system.

![Figure 7.9: Mass balance of a waste gas treatment system with direct flame thermal oxidation](source: [192, COM 2006])

Reference literature
[192, COM 2006]
7.5 Emerging techniques

TWG, please provide information.
8 FRUIT AND VEGETABLES

8.1 General information about the sector

The EU produces a broad range of fruits and vegetables thanks to its varied climatic and topographic conditions. It is one of the main global producers of tomatoes for example. Open-air production is typical in southern EU Member States and is complemented by all-season greenhouses production which is typical of countries such as the Netherlands or Belgium. The EU-28 produced an estimated 16.8 million tonnes of tomatoes in 2014, of which approximately two thirds came from Italy and Spain.

The EU-28 also produced an estimated 5.5 million tonnes of carrots and 6.4 million tonnes of onions in 2014. Carrot production was relatively high in Poland and the United Kingdom; these two countries accounted for more than one quarter (14.2 % and 14.9 % respectively) of EU-28 output in 2014. The production of carrots in these two EU Member States remained relatively stable during the period 2000–2014, at around 0.7–0.8 million tonnes. The Netherlands and Spain are the EU’s principal onion producing countries, accounting together for a little over two fifths (46.0 %) of EU-28 output in 2014.

Around 14 million tonnes of apples were produced in the EU-28 in 2014. Apples are produced in almost all EU Member States, although Poland, Italy and France are by far the largest producers. Citrus fruit production in the EU is much more restricted by climatic conditions; the vast majority of citrus fruits (59.8 %) are produced in Spain [218, Eurostat 2015].
8.2 Applied processes and techniques

The characteristic features of fruit and vegetables are that they are soft edible plant products which, because of their relatively high moisture content, are perishable in their fresh state. A summary of the possible processing routes of some fruit and vegetables is shown in Table 8.1.

Table 8.1: Summary of the possible processing routes of some fruit and vegetables

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Processing</th>
<th>Preservation method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Garden vegetables</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peas, beans, spinach, potatoes, asparagus, maize and lentils</td>
<td>Put in packaging, in water</td>
<td>Thermal treatment</td>
</tr>
<tr>
<td>Olives, cabbage, artichokes, mushrooms, onions, peppers, carrots and cucumbers</td>
<td>Put in oil, pickling/brining, sulphited</td>
<td>Natural or artificial thermal treatment</td>
</tr>
<tr>
<td>Cabbage and cucumbers</td>
<td>Lactic acid fermentation</td>
<td>Microbial treatment</td>
</tr>
<tr>
<td>Various garden vegetables</td>
<td>Juice</td>
<td>Thermal treatment</td>
</tr>
<tr>
<td>Various garden vegetables</td>
<td>Dried</td>
<td>Drying</td>
</tr>
<tr>
<td>Various garden vegetables</td>
<td>Freezing, deep-frozen and ready to use vegetables</td>
<td>Cooling</td>
</tr>
<tr>
<td><strong>Tomato</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tomato</td>
<td>Paste</td>
<td>Dehydration and heat treatment</td>
</tr>
<tr>
<td></td>
<td>Whole peeled</td>
<td>Thermal treatment</td>
</tr>
<tr>
<td></td>
<td>Non-whole, peeled (diced or crushed)</td>
<td>Thermal treatment</td>
</tr>
<tr>
<td></td>
<td>Juice, strained, passata</td>
<td>Thermal treatment</td>
</tr>
<tr>
<td></td>
<td>Powder and flakes</td>
<td>Drying</td>
</tr>
<tr>
<td><strong>Fruit</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berries, pears, apples, peaches, apricots, plums, pineapple, cherries and grapes</td>
<td>Put in water, in syrup</td>
<td>Thermal treatment, with optional synergetic action of sugar (reduction of a&lt;sub&gt;n&lt;/sub&gt;)</td>
</tr>
<tr>
<td>Peaches, apricots, plums, cherries, berries and figs</td>
<td>Jam and jellies</td>
<td>Thermal treatment, with optional synergetic action of sugar (reduction of a&lt;sub&gt;n&lt;/sub&gt;)</td>
</tr>
<tr>
<td>Citrus</td>
<td>Marmalade</td>
<td>Thermal treatment, with optional synergetic action of sugar (reduction of a&lt;sub&gt;n&lt;/sub&gt;)</td>
</tr>
<tr>
<td>Pears, apples, peaches, apricots, plums, tropical fruits and undergrowth fruits</td>
<td>Juices and nectars</td>
<td>Thermal treatment</td>
</tr>
<tr>
<td>Various fruits</td>
<td>Candies</td>
<td>Action of sugar (reduction of a&lt;sub&gt;n&lt;/sub&gt;)</td>
</tr>
<tr>
<td>Various fruits</td>
<td>Concentrates</td>
<td>Thermal treatment (reduction of a&lt;sub&gt;n&lt;/sub&gt;)</td>
</tr>
<tr>
<td>Various fruits</td>
<td>Put in alcohol</td>
<td>Reduction of a&lt;sub&gt;n&lt;/sub&gt;</td>
</tr>
<tr>
<td>Various fruits</td>
<td>Dried fruits</td>
<td>Drying</td>
</tr>
<tr>
<td>Various fruits</td>
<td>Frozen and deep-frozen fruit</td>
<td>Freezing</td>
</tr>
</tbody>
</table>

*Source: [52, Italy 2001]*

Some common processes applied in the fruit and vegetable sectors are firstly described in the following sections. Then some more details are given for specific products.
8.2.1 Peeling

The objective of peeling is to remove the skin/peel from raw fruit and vegetables. This improves the appearance and taste of the final product. During peeling, the losses need to be minimised by removing as little of the underlying food as possible but still achieving a clean peeled surface. Various methods for peeling are steam peeling, knife peeling, abrasion peeling, caustic peeling and flame peeling.

In most peeling operations, a water spray is used to remove the peeled skin. Waste water is generated which contains TSS. Conventional steam or hot water peeling uses large quantities of water, up to four times that required for caustic peeling, and produces waste water with high levels of product residue. At potato processing installations, the peels can contribute up to 80% of the total BOD. In fruit processing, peeling waste water can account for as much as 10% of the total waste water flow and 60% of the BOD. Dry caustic peeling methods can greatly reduce the volume and pollutant load of the waste water from this operation and allow for the collection of peel as pumpable slurry. The use of caustic in peeling may lead to pH fluctuations in the waste water. Some produce, e.g. tomatoes, requires strong caustic solutions and the addition of wetting agents. Dry caustic peeling tends to have a lower caustic consumption than wet methods. In steam peeling, most of the peeled material is discharged with the steam; this results in the collection of a concentrated waste stream. Remaining traces are sprayed off with water. The process has lower water consumption than other wet peeling methods.

When flame peeling is applied, some dust and odour emissions can occur. The peels are often recovered and used as animal feed, otherwise they are disposed of as waste. Abrasion peeling has a significantly higher product loss than flash steam peeling, 25% loss compared to 8–15% loss, and considerably more waste water is produced. In caustic peeling, product loss is around 17%. Dry caustic peeling reduces water consumption and produces a concentrated caustic paste for disposal.

Flash steam peeling, caustic peeling and flame peeling require heat; the other peeling operations use electrical energy.

The most common peeling processes that are applied in the fruit and vegetable sector, are described more in detail in the following subsections [1, CIAA 2002], [8, Environment Agency of England and Wales 2000], [14, VITO et al. 2001], [15, Van Bael J. 1998], [23, Envirowise (UK) and Ashact 2001], [66, Italy 2002], [94, Germany 2003], [110, CIAA 2003], [116, CIAA–AAC–UFE 2003], [138, Fellows P.J. 2000], [160, Federación Conservas 2005].

8.2.1.1 Steam peeling—continuous process

The continuous steam peeler is a drum with a screw inside. The steam is fed directly into the drum, generally at a lower pressure than the batch process (see Section 8.2.1.2), and the product is heated during an adjustable residence time. Most of the peeled material is discharged with the steam. Any remaining traces are sprayed off with water. This water may be filtered and used to wash raw fruit and vegetables.

With this process, reduced waste production compared to other peeling techniques is achieved, and the peel is often recovered and used as animal feed. Moreover, less water than a combination of abrasion and knife peeling is used.

Increased steam use compared to both wet and dry caustic peeling. High water consumption and waste water contamination. Odour can also be a problem.
Steam peeling uses approximately five times more steam, e.g. for energy, than caustic peeling. Table 8.2 shows energy carriers and consumption for steam peeling, prior to freezing vegetables.

Table 8.2: Energy carrier and consumption for steam peeling, prior to freezing vegetables

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Approximate consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water (kWh/t frozen vegetables)</td>
<td>0</td>
</tr>
<tr>
<td>Steam (t/t frozen vegetables)</td>
<td>0.9</td>
</tr>
<tr>
<td>Steam pressure (bar)</td>
<td>7–15</td>
</tr>
<tr>
<td>Electricity (kWh/t frozen vegetables)</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

Steam peeling uses large quantities of water, up to five times more than the amount required for caustic peeling, but half of that for a combination of abrasion and knife peeling. It also produces waste water with high levels of product residue. At potato processing installations, the peels can contribute up to 80% of the total BOD. In fruit processing, peeling waste water can account for as much as 10% of the total waste water flow and 60% of the BOD. When steam peeling is applied, cold water may be used to condense the steam. If water cooling is not used then less water is used, less waste is produced and there are lower organic loads in the waste water. Product loss in the peeling process is 8–15%.

The waste consists of the solid peel residues as well as dissolved substances such as starch or tissue fluids. The solid material is generally separated by sedimentation, dried and composted. This fraction contains minerals and bioactive phenolic substances, but also, in the case of potatoes, glycoalkaloids which limit the direct nutritional use.

The steam peeling process in an example installation is shown in Figure 8.1. This can be compared with the outputs if abrasion peeling followed by knife peeling is used, as shown in Table 8.3.

![Figure 8.1: Steam peeling process in an example installation in Finland](source)

Source: [192, COM 2006]

Technical considerations relevant to applicability
Applicable for all fruit and vegetables which are peeled, except where the peel is relatively hard compared with the fruit flesh, unless it is further processed to make stewed fruit or juice.

Economies
Steam peeling is reported to be more economical than abrasion, knife and caustic peeling.

**Example plants**
Widely used to peel large quantities of potatoes, sweet potatoes, salsifies, beets, carrots, other tubers and tomatoes.

### 8.2.1.2 Steam peeling—batch process

Batch steam peeling is also called flash steam peeling. The raw materials such as roots and tubers are exposed to high pressure steam, from 1,500 to 2,000 kPa in a rotating pressure vessel. The high temperature causes a rapid heating and cooking of the surface layer within 15 to 30 seconds. The pressure is then instantly released, which causes the cooked skin to flash off. Most of the peeled material is discharged with the steam, resulting in a concentrated waste stream, and water is only needed to remove any remaining traces.

Reduced water consumption and waste water production, when compared to continuous steam peeling is achieved, but with increased levels of product residue. Reduced waste production compared to other peeling techniques is achieved and the peel is often recovered and used as animal feed. A lower waste water pollution load compared to the use of abrasion peeling followed by knife peeling. Table shows energy carriers and consumption for steam peeling.

The process has lower water consumption and waste water production than continuous steam peeling. With tomatoes, the pressure used ranges from 200 to 350 kPa. This type of peeler is reportedly gaining in popularity due to the lower water consumption, minimum product loss, good appearance of the peeled surfaces and the possible high throughput of up to 4,500 kg/h, with automatic control of the peeling cycle.

The waste consists of the solid peel residues as well as dissolved substances such as starch or tissue fluids. The solid material is generally separated by sedimentation, dried and composted. This fraction contains minerals and bioactive phenolic substances, but also, in the case of potatoes, glycoalkaloids which limit the direct nutritional use.

**Cross-media effects**
Higher energy consumption than caustic peeling. Odour can also be a problem.

**Technical considerations relevant to applicability**
Applicable for all fruits and vegetables which are peeled, except where the peel is relatively hard compared with the fruit flesh, unless it is further processed to make stewed fruit or juice.

**Economics**
Steam peeling is reported to be more economical than abrasion, knife and caustic peeling.

**Example plants**
Widely used to peel large quantities of potatoes, sweet potatoes, salsifies, beets, carrots, other tubers and tomatoes.

### 8.2.1.3 Abrasion peeling

In abrasion peeling, the material to be peeled is fed onto carborundum rollers or fed into a rotating bowl, which is lined with carborundum. The abrasive carborundum surface removes the skin, which is then washed away with a copious supply of water. The process is normally carried out at ambient temperature.

Energy is not required for heating water or producing steam, but is needed for the operation of the rollers or rotating bowl.
The relatively low throughputs are due to all of the pieces of food needing to contact the abrasive surfaces. The hygiene quality is sometimes a problem because, as no peeling water is added, the cooling function of water is not fulfilled, and there can be localised high temperatures. Nevertheless, the quality of potatoes can reportedly be maintained during peeling using carborundum.

Large quantities of water are consumed. There is high product loss and high production of waste water. Odour emissions can be a problem. A combination of abrasion peeling and knife peeling produces a higher waste water pollution load than steam peeling.

The peel can be recovered and used as animal feed.

This technique is used for peeling onions, potatoes, carrots and beets, as the skin is easily removed and the quality of the product can be maintained. Sometimes abrasion peeling is used as a pre-peeling step before knife peeling.

**Achieved environmental benefits**
Reduced energy consumption.

**Cross-media effects**

**Environmental performance and operational data**
This technique has significantly higher product loss than steam peeling, i.e. a 25% loss compared to 8–15% loss. If the vegetables are sorted and peeled in uniform sizes, the proportion of flesh removed as peeling waste may be reduced. There is also considerably more waste water produced than from steam peeling. This dilute waste water contains the high product loss and it is expensive and difficult to treat.

**Technical considerations relevant to applicability**

**Economics**
The capital and energy costs are low. Steam peeling is reported to be more economical.

**Example plants**
Widely applied for peeling potatoes and onions.

### 8.2.1.4 Knife peeling

In knife peeling, the material to be peeled is pressed to against rotating blades, or is itself rotated against stationary blades. Although water is not used during the actual peeling operation, it is used for the continuous cleaning of rollers and blades, so contaminated waste water is produced.

The peel can be recovered and used directly as animal feed or for recovery of its components. Less energy consumption than steam peeling is achieved.

The product loss after knife peeling is 16–17%. Maintaining the knife sharp reduces damage to the product and consequent waste. After cutting, defective pieces, e.g. which are too dark or too small, can be separated and used as animal feed. In carrot processing, several valuable substances such as vitamin C, fibre, phenolic compounds and carotenoids, can be recovered as by-products.

Table 8.3 shows the effect of a combination of abrasion pre-peeling and knife peeling on water pollution in the production of half pears in syrup.
Table 8.3: The effect of a combination of abrasion pre-peeling and knife peeling on water pollution loads in the production of half pears in syrup

<table>
<thead>
<tr>
<th></th>
<th>BOD (kg/t)</th>
<th>COD (kg/t)</th>
<th>SS (kg/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abrasion pre-peeling plus knife peeling</td>
<td>21.6</td>
<td>36.5</td>
<td>21.5</td>
</tr>
</tbody>
</table>

Water consumption if the water is not reused for cooling cans after sterilisation 29.6 m³/t
Water consumption if the water is reused for cooling cans after sterilisation 6.2 m³/t

Source: [192, COM 2006]

Figure 8.2 shows a flow diagram of potato and carrot processing showing the outputs if abrasion peeling followed by knife peeling is used. This can be compared to the outputs if steam peeling is used, as shown in Figure 8.1.

Figure 8.2: Flow diagram of potato and carrot processing in a Finnish installation

Cross-media effects
Odour emissions and noise pollution. A combination of abrasion peeling and knife peeling produces a higher waste water pollution load than steam peeling and uses twice as much water.

Technical considerations relevant to applicability
Knife peeling is particularly used for citrus fruits where the skin is easily removed and little damage is caused to the fruits and for small quantities of, e.g. potatoes, carrots, beets and apples, or when vegetables are used for catering or in institutional kitchens. Peaches and pears can be peeled using very small blades mounted on rollers.

Economics
Knife peeling is reportedly more expensive than steam peeling.
8.2.1.5  Wet caustic peeling

The material to be peeled is either placed in or passed through a dilute solution, e.g. 1 to 2 %, but as high as 20 %, of caustic, heated to 80–120 ºC. This softens the skin which can then be sprayed off by high pressure water sprays. The caustic concentration and the temperature depend on the type of fruit or vegetable and the degree of peeling required. Although water is not used during the actual peeling operation, it is used for the continuous cleaning of rollers and blades, so contaminated waste water is produced.

Reduced water and energy consumption compared to steam peeling is achieved.

The use of caustic peeling may cause pH fluctuations in the waste water. Furthermore, caustic peeling causes higher solubilisation of material and consequently high COD, BOD and TSS loads. The BOD and COD emission levels are higher than for abrasion peeling followed by knife peeling, but the TSS load is lower. Caustic peeling needs less energy, both in terms of electricity consumption and steam consumption, than steam peeling, but creates a greater load for the WWTP.

Wet caustic peeling uses four times less water than steam peeling. Some products, e.g. tomatoes, require strong caustic solutions and the addition of wetting agents. In the case of gherkins, the concentration of the caustic is approximately 2 %, in the case of carrots approximately 10 % and in the case of pumpkins up to 20 %. Product loss is around 17 %.

Table 8.4 shows the effect of caustic peeling on water pollution in the production of half pears in syrup. This can be compared with the same operation using abrasion peeling followed by knife peeling in Table 8.5 shows energy carriers and consumption data for caustic peeling, prior to freezing vegetables.

Table 8.4:  The effect of caustic peeling on water pollution in the production of half pears in syrup

<table>
<thead>
<tr>
<th>Operation</th>
<th>BOD (kg/t)</th>
<th>COD (kg/t)</th>
<th>SS (kg/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caustic peeling</td>
<td>39.7</td>
<td>66.3</td>
<td>11.4</td>
</tr>
</tbody>
</table>

Water consumption if the water is not reused for cooling cans after sterilisation 29.6 m³/t

Water consumption if the water is reused for cooling cans after sterilisation 6.2 m³/t

Source: [192, COM 2006]

Table 8.5:  Energy carriers and consumption for caustic peeling, prior to freezing vegetables

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Approximate consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water (kWh/t frozen vegetables)</td>
<td>0</td>
</tr>
<tr>
<td>Steam (t/t frozen vegetables)</td>
<td>0.16</td>
</tr>
<tr>
<td>Steam pressure (bar)</td>
<td>7</td>
</tr>
<tr>
<td>Electricity (kWh/t frozen vegetables)</td>
<td>2</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

At an example installation, water use and the resulting waste water were compared for wet and dry caustic peeling (see Section) at a site processing 72 t/d of table beet. For the same quantity of product processed, dry caustic peeling reduced water use by 75 % and solid waste by 90 % compared to wet caustic peeling. In addition, the waste water generated during dry caustic peeling contained 88 % less TSS, 94 % less COD and 93 % less BOD than that from wet caustic peeling. Nevertheless, it is reported that the peel contaminated with caustic is, at least in some cases, disposed of to the WWTP in small amounts, after buffering. Dry caustic peeling tends to have a lower caustic consumption than wet methods.
Cross-media effects
Waste water with high pH and organic load produced. Highly alkaline or salty solid waste is produced, which is difficult to dispose of. The use of chemicals may limit the use of the nutrients the peel contains. If the peel is used for nutrition, separate waste water treatment is needed. Odour is emitted and there is noise pollution. The product can become decolourised.

Technical considerations relevant to applicability
Applicable for all fruit and vegetables which are peeled. It can be used where the peel is relatively hard compared with the fruit flesh and where steam peeling cannot be applied.

Economics
Wet caustic peeling produces waste with a very high pH and organic loading, which then adds to the water treatment costs. Caustic peeling is reportedly more expensive than steam peeling.

Example plants
Used for peeling potatoes, carrots, beets, salsifies, peaches, apricots, apples, pears, tomatoes, peppers, pumpkins, gherkins and citrus fruits. It is reportedly used for peeling apples because steam peeling (see Section) damages the fruit’s flesh.

8.2.1.6 Dry caustic peeling
In dry caustic peeling, the material is dipped in a 10 % caustic solution heated to 80–120 °C, to soften the skin, which is then removed by rubber discs or rollers. This reduces water consumption and produces a concentrated caustic paste for disposal. Peeling is followed by washing to remove the peel and any residual caustic.

In the case of peeling peaches and apricots, the skin is very fine and soft and not as easily distinguishable from the fruit flesh as that of e.g. tomatoes, peppers and potatoes, so it clings to the flesh. The skin clings to the flesh of less ripe fruit more strongly than it clings to ripe fruit. Peaches and apricots are immersed into the caustic solution and the skin is decomposed. The residue is then removed by spraying the fruit with water. In practice, fruits of varying ripeness are peeled together and the process is prolonged to ensure that the least ripe fruit are peeled. In the case of e.g. peeling peaches and apricots for subsequent preservation either whole or in halves, the mechanical removal of the softened skin would cause unacceptable damage to the surface of the fruit.

Reduced water consumption compared to steam peeling and wet caustic peeling and reduced solid waste and waste water production compared to wet caustic peeling is achieved. Moreover, lower caustic consumption than wet caustic peeling and reduced energy consumption compared to steam peeling is achieved.

Dry caustic peeling methods can greatly reduce the volume and pollutant load of the waste water compared to steam peeling and wet caustic peeling. The peel can be collected as a pumpable slurry, which needs to be disposed of. It is reported that the peel contaminated with caustic is, at least in some cases, disposed of to the WWTP in small amounts, after buffering. Dry caustic peeling tends to have a lower caustic consumption than wet caustic peeling.

As an example installation, water use and the resulting waste water were compared for wet and dry caustic peeling at a site processing 72 t/d of table beet. For the same quantity of product processed, dry caustic peeling reduced water use by 75 % and solid waste by 90 % compared to wet caustic peeling. In addition, the waste water generated during dry caustic peeling contained 88 % less TSS, 94 % less COD and 93 % less BOD than that from wet caustic peeling.

Cross-media effects
Highly alkaline or salty solid waste is produced. The use of chemicals may restrict the nutritional exploitation of the separated peel mass. Odour is emitted. Noise pollution can also be a problem. The product can become decolourised.

**Technical considerations relevant to applicability**

Applicable for all fruits and vegetables which are peeled. It can be used where the peel is relatively hard compared with the fruit flesh and steam peeling cannot be applied.

**Economics**

Dry caustic peeling produces waste with a very high pH, which adds to the water treatment costs. Dry caustic peeling is reportedly more expensive than steam peeling.

**Example plants**

Used for the peeling of potatoes, carrots, salsifies, apples, peaches and apricots.

### 8.2.2 Blanching

Blanching is designed to expose the entire product to high temperatures for a short period of time. The primary function of this operation is to inactivate or retard bacterial and enzyme action, which could otherwise cause rapid degeneration of quality. Two other desirable effects of blanching include the expelling of air and gases in the product, and a reduction in the product volume.

Before blanching, the food is preheated. Blanching may be accomplished by direct or indirect heating systems. This may depend on the product. Direct heating is normally made by immersion into hot water, at 80 to 100 °C, or by exposure to live steam. The operation is normally carried out in horizontal chambers. The residence time in the blancher can vary from approximately 1 to 5 minutes depending on the fruit or vegetable being blanched. For some products, direct contact with water is to be avoided so heat exchangers working with hot water or vapour are applied. After blanching, the food is cooled using either water or air.

The most common blanching processes that are applied in the fruit and vegetable sector, are described more in detail in the following subsections [1, CIAA 2002], [14, VITO et al. 2001], [15, Van Bael J. 1998], [51, Ullmann 2001], [138, Fellows P.J. 2000].

Blanching generally comprises three steps, i.e. preheating, blanching and cooling and is followed by further processing such as the manufacture of preserves or freezing. Blanching is described in Section 0.

Table 8.6 shows a qualitative comparison of energy and water consumption levels within the different blanching techniques.

**Table 8.6: Comparison of the energy and water consumption levels within the different blanching techniques**

<table>
<thead>
<tr>
<th>Blanching technique</th>
<th>Energy</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam blanching with air cooling</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Belt blanching with water cooling</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Belt blanching with air cooling</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Drum blanching with countercurrent water cooling</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

1: Lowest consumption  
4: Highest consumption  

Source: [192, COM 2006]

### 8.2.2.1 Steam blanching with air cooling
Steam blanching is a continuous process where the food is moved on one long perforated conveyor belt. During preheating, the food is sprinkled with water from above and sprayed by water from below. The preheating water is maintained at 60 ºC using steam.

During the blanching step, the food is further heated by direct steam injection from below. To minimise water and energy consumption, the steam is recycled and the process takes place in sealed equipment, designed to minimise steam consumption.

Finally, the food is cooled with air using heavy duty fans. The air is cooled further, to a lower temperature, by spraying water into the airflow. This water prevents the food from drying. If necessary, the food can be further cooled down with water in the last cooling compartment. Reusing this cooling water in the preheating section is not useful, as the water does not hold much energy. Air cooling is less energy efficient than water cooling as the heat cannot be reused and the fans for blowing the air across the food have high energy consumption.

The optimal temperature and time of blanching depend on the type of food and the size of the pieces being blanched. Typical blanching conditions are 65 to 95 ºC, for one minute or more. Steam blanching produces waste water with high BOD emission levels.

The energy efficiency can depend on the method of retaining the steam pressure. Food can enter and leave the blancher through rotary valves and seals to reduce steam losses and increase energy efficiency, or steam can be reused by passing it through venturi valves. Using a combination of hydrostatic and venturi valves can improve the efficiency further.

Steam blanchers reportedly lead to smaller losses of water soluble components and nutrients, but blanching can be uneven if the food is piled too high on the conveyor or if spots of the product have touched each other they may not be blanched.

**Achieved environmental benefits**
Lowest water consumption and waste water volume, compared to the other blanching techniques. Moreover reduced energy consumption compared to belt blanching with air cooling.

**Cross-media effects**
Higher energy consumption than the belt blancher with water cooling and the drum blancher with countercurrent water cooling. High BOD load in the waste water.

**Technical considerations relevant to applicability**
Applicable for blanching fruit and vegetables.

### 8.2.2.2 Belt blanching with water cooling
Belt blanching with water cooling is a continuous process where the food is moved on one long perforated conveyor belt. The food is preheated with water sprinkled from above and sprayed from below, flowing countercurrently with the food. The temperature of the preheating water is maintained at 60 ºC using steam. The cooled preheating water can be reused in other processes, e.g. washing and cutting and pre-rinsing of, e.g. freezing tunnels.

In the blanching section, the food is also sprinkled with water from above and sprayed by water from below. For this step the water temperature is maintained at, e.g. 80–95 ºC, by steam injection.

Finally, the food is cooled with water. Cooling is undertaken in a series of different compartments. In each compartment, water is sprayed over and under the food. Fresh cooling water at, e.g. 2–15 ºC, enters the last compartment of the cooling section and is reused in the preceding compartments. The water from the first compartment of the cooling section, i.e. immediately after blanching, which is warm, is reused in the preheating section, leading to heat
recovery and a reduction in water consumption. If the coldest water available is used for cooling, this also reduces the energy consumption, for both the cooling step after blanching and if the food is destined for low temperature storage or processing, e.g. freezing.

The optimal temperature and time of blanching depend on the kind and size of food. Hot water blanching produces waste water with high BOD emission levels.

If a belt blancher is combined with water cooling, 2–8 kWh/t frozen product are consumed. Belt blanching with water cooling is the most energy efficient blanching technique. The reason is that the heat released by the cooling of the food in the cooling zone is used to preheat the vegetables before blanching. Also, the water consumption is minimised by reusing it within the cooling compartments and for preheating.

Table 8.7 shows the energy carriers and consumption for the belt blancher with water cooling expressed in terms of the amount of frozen product, i.e. assuming the product will be frozen after blanching.

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Approximate consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water (kWh/t frozen vegetables)</td>
<td>0</td>
</tr>
<tr>
<td>Steam (t/t frozen vegetables)</td>
<td>0.09</td>
</tr>
<tr>
<td>Steam pressure (bar)</td>
<td>7</td>
</tr>
<tr>
<td>Electricity (kWh/t frozen vegetables)</td>
<td>2–9</td>
</tr>
</tbody>
</table>

NB: *Hot water is 0 because water is heated by steam injection*

Source: [192, COM 2006]

Achieved environmental benefits

Lowest energy consumption compared to all the other blanching techniques. Reduced water consumption compared to the drum blancher with countercurrent water cooling.

Cross-media effects

Higher water consumption compared to steam blanching with air cooling and belt blanching with air cooling. High BOD load in the waste water.

Technical considerations relevant to applicability

Applicable for blanching fruit and vegetables.

8.2.2.3 Belt blanching with air cooling

This is a continuous process where the food is moved along on one long perforated conveyor belt. The food is preheated with water sprinkled from above and sprayed from below, flowing countercurrently with the food. The preheating water is maintained at 60 °C using steam. The cooled preheating water can be reused in other processes, e.g. washing and cutting processes and pre-rinsing of, e.g. freezing tunnels.

In the blanching section, the food is sprinkled with water from above and sprayed by water from below. The water temperature is maintained at, e.g. 80–95 °C, by steam injection.

The blanched food is cooled with air using heavy duty fans. The air is cooled further, to a lower temperature, by spraying water into the airflow. This water prevents the food from drying. If necessary, the food can be further cooled down with water in the last cooling compartment. Reusing this cooling water in the preheating section is not useful, as the water does not hold much energy. This technique is less energy efficient, because with air cooling the heat cannot be reused and the fans for blowing the air across the food have high energy consumption.
The optimal temperature and time of blanching depend on the kind and size of food. Hot water blanching produces waste water with high BOD emission levels.

When a belt blancher is used combined with air cooling, 7–28 kWh/t frozen product are consumed. Heavy duty fans consume 60 kWh. Table 8.8 shows the energy carriers and consumption for the belt blancher with air cooling, expressed in terms of the amount of frozen product.

Table 8.8: Energy carriers and consumption for a belt blancher with air cooling

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Order of magnitude indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water (kWh/t frozen vegetables)</td>
<td>0*</td>
</tr>
<tr>
<td>Steam (t/t frozen vegetables)</td>
<td>0.16</td>
</tr>
<tr>
<td>Steam pressure (bar)</td>
<td>7</td>
</tr>
<tr>
<td>Electricity (kWh/t frozen vegetables)</td>
<td>7–30</td>
</tr>
</tbody>
</table>

NB: *Hot water is 0 because water is heated by steam injection

Source: [192, COM 2006]

When processing preserves, cooling of the food to about 40 ºC is sufficient, because it is subject to further processing involving heat which prevents the development of bacteriological problems. Preserves undergo heat treatment at a later stage, e.g. during sterilisation and pasteurisation. This means that less energy is used when applying this technique for preserves, compared to other uses of the fruit and vegetable sector which would need to be cooled further, e.g. prior to freezing.

**Achieved environmental benefits**
Reduced water consumption compared to belt blanching with water cooling and drum blanching with countercurrent water cooling.

**Cross-media effects**
Highest energy consumption compared to the other blanching techniques. Higher water consumption than steam blanching with air cooling. High BOD load in the waste water.

**Technical considerations relevant to applicability**
Applicable for blanching fruit and vegetables.

### 8.2.2.4 Drum blancher with countercurrent water cooling

This is a batch process where the food enters the system via a trough and a rotating screw. The water for the blancher is heated by steam injection. The food leaves the system via a perforated paddle. Next, the product is cooled using water running countercurrently to the food. The heated cooling water can be reused in other processes, e.g. to simultaneously preheat the fresh food and transport it to the drum blancher.

The optimal temperature and time of blanching depend on the kind and size of the food. The drum blancher with countercurrent water cooling consumes 1–2.6 kWh/t frozen product. The countercurrent drum cooler consumes 2–4 litres of water per kilogram of food.

Table 8.9 shows the energy carriers and consumption for drum blanching, expressed in terms of the amount of frozen product, assuming that the food will be frozen.

Table 8.9: Energy carriers and order of magnitude indicators of the drum blancher

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Approximate consumption</th>
</tr>
</thead>
</table>

WORKING DRAFT IN PROGRESS
Table 8.10 shows the energy carriers and consumption for countercurrent drum water cooling, expressed in terms of the amount of frozen product, assuming that the food will be frozen.

Table 8.10: Energy carriers and consumption for countercurrent drum water cooling

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Approximate consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water (kWh/t frozen vegetables)</td>
<td>0*</td>
</tr>
<tr>
<td>Steam (t/t frozen vegetables)</td>
<td>0.16</td>
</tr>
<tr>
<td>Steam pressure (bar)</td>
<td>7</td>
</tr>
<tr>
<td>Electricity (kWh/t frozen vegetables)</td>
<td>0.5–1.3</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

Achieved environmental benefits
Lower energy consumption compared to belt blanching with air cooling and steam blanching with air cooling.

Cross-media effects
Highest water consumption compared to the other blanching techniques. High BOD load in the waste water. Higher energy consumption than belt blanching with water cooling.

Technical considerations relevant to applicability
Applicable for blanching fruit and vegetables.

8.2.3 Ready meals that predominantly contain fruit and vegetables

Some fruit and vegetables are preserved. For this purpose, depending on the type of fruit and vegetables, different processes are used, and a variety of products are made, e.g. ready meals. In most installations, a variety of fruit and vegetable types are processed simultaneously and consecutively into different products. The majority of installations process products in bulk and are subject to seasonal variations, in line with crop rotation. However, some have product lines that are not affected by seasonal fluctuations. Further processing of frozen raw materials takes place throughout the year. Processing capacities are increasingly being expanded for such product processing.

8.2.4 Fruit juice

Fruit juices are produced throughout temperate and tropical areas of the world. Orange juice predominates in temperate climates and pineapple juice in tropical climates. The bulk of the European world fruit juice production is from citrus fruits, mostly oranges, pomes; from apple and pear type fruits and from vine fruits. Some stone fruit juices are manufactured but in much smaller quantities.

In a typical citrus juice process, the fruit is sorted, graded and washed to remove extraneous matter such as sticks and leaves, adhering dirt and insects. The fruit is then passed through oil extraction equipment where it is subjected to hundreds of small cuts of the skin to rupture the oil sacs and release the citrus oil, which is removed by washing. Oil extraction may be carried out after juice extraction. The fruit juice is mechanically extracted and screened to remove excess
pulp, pieces of skin and seeds. The screened juice is preserved by a number of methods such as canning, aseptic processing, chemical inhibition, freezing, and membrane separation. It may be concentrated before packaging to reduce transport costs. The juice may be clarified before or after preservation.

A typical pome juice process includes similar processes but without an oil extraction step. The fresh fruits are delivered to the processing installation and unloaded, washed, sorted and then crushed after eventual coring or pitting, e.g. for peaches and apricots. The white fruits are heated to avoid enzymatic browning. The crushed fruits are then strained and refined to extract the juice. For apple juice, the juice is sometimes clarified with an enzymatic treatment and filtration.

Orange, apple and tomato juices are often concentrated, normally by evaporation or in some cases by RO or cryoconcentration. The juice is obtained either from fresh fruits or from reconstituted concentrates from citrus, pineapple and other tropical fruits. It can be packed directly, as it is the case with juices, or mixed with sugar and water, as it is the case with nectars. The juices are then de-aerated and hot filled into bottles or cans.

Because of the low pH, filling with a HTST pasteurisation treatment is sufficient to stabilise the product when followed by bottle sterilisation in a steam tunnel. Aseptic packaging is carried out by pasteurising, cooling and filling, all in aseptic conditions. The filling is carried out in cardboard bricks or preformed bricks.

8.2.5 Heat treated fruit

In typical canned fruit processes, the fruit is ideally used as soon as possible after delivery, although it often has to be stored for a time under chilled conditions, e.g. apple. The fruit is first washed, then sorted and possibly trimmed, then graded or cored before peeling. A variety of methods are used for peeling, including abrasive, caustic, steam or mechanical peeling. Peeled fruit may be blanched or transferred to tanks containing materials such as brine or ascorbic acid solutions to prevent browning. If necessary, the fruit may be sliced. Products such as orange segments are subjected to acid and caustic soaks to remove stringy fibres before canning. The fruit is filled into containers, e.g. cans or glass jars, in syrup or a natural juice. Before sealing, they can be gently heated to remove entrained gases, a process known as exhausting. Filling under vacuum conditions avoids the need for exhausting. The container is then sealed, heat processed and cooled. For fruit, a pasteurising treatment with a temperature under 100 ºC is sufficient.

8.2.6 Frozen fruit and vegetables

The freezing of fruits and vegetables is a major preservation method in its own right and it is widely used to preserve fruits and vegetables which are to be further processed, e.g. for the manufacture of jam. Fruits and vegetables intended for freezing are generally washed and inspected before being individually quick frozen, or packed in syrup or pureed before freezing. Typical fast freezing methods involve direct contact with a cooled solid, e.g. band or drum freezers, direct contact with cooled air or other gaseous mixtures, e.g. blast air, fluidised bed and spiral freezers, direct immersion in a cooled liquid, e.g. brine freezers, or cryogenic freezers. The process for deep-frozen fruit and vegetables is shown in Figure 8.3.
8.2.7 Fruit preserves

Preserving is the manufacture of jams, jellies, marmalades and mincemeat. It is essentially the combining of fruits and sugar with subsequent cooking. It produces a tasty product of a sufficiently high sugar content, low $a_w$ value, and with a satisfactory shelf-life retention quality.

A pasteurising treatment is applied at 85 °C or above. The jams are made using pulp and fruit juice, e.g. citrus for marmalade, and clarified juice for jellies. The basic ingredients of a preserve are fruit, sweetening agents, typically sucrose and/or various sugar syrups; acids, typically citric or malic acid; buffers such as trisodium citrate; fats, in curds/mincemeat; citrus peel, for mincemeat and marmalade; gelling agents, usually pectin and anti-foaming agents—when using frozen or sulphited fruits. In a typical process, the fruit usually arrives pre-prepared either frozen or sulphited. The prepared fruit, pectin, sucrose, glucose syrup and other small ingredients are then blended together in a mixing vessel. The mix is boiled either at atmospheric pressure or under vacuum, using batch or continuous methods. After boiling, the jam is filled into containers which vary from individual portions to bulk tank for bakery use.

8.2.8 Dried fruit

Dried fruit processing uses raw materials such as grapes, apricots, pears, bananas and plums. A basic process consists of sorting, grading, washing, drying and packing. Many fruits are sun-dried at source, although some producers use mechanical methods, typically tunnels through which hot air is passed. Some fruits are sulphited before drying to preserve the fruit and soften the fruit tissue, leading to a faster loss of moisture during drying. In some cases, the fruit is sprayed or dipped after harvesting with a potassium carbonate solution which also contains dipping oil. The composition of the dipping oil varies between producers. For example, some producers use olive oil, others may use mixtures of ethyl esters of fatty acids and free oleic acid.
8.2.9 Tomatoes

In the EU, about eight million tonnes of tomatoes were processed in 2000, of which five million tonnes were processed in Italy. Significant quantities are also processed in Spain, Portugal, Greece and France. The tomatoes are made into different forms for different kinds of products. The main product is 28 °brix to 30 °brix tomato paste obtained from the juice by concentration. Other products are whole, diced or crushed peeled tomatoes, tomato juices such as passata, and dried products such as powder and flakes. The basic processes for tomato manufacturing are shown in Figure 8.4.

![Diagram of tomato processing](link)

Source: [54, Italian contribution 2001]

Figure 8.4: Manufacture of various tomato products

8.2.10 Potatoes

Two of the main potato-based products are crisps and chips. The manufacturing of both essentially consists of peeling the raw material, slicing to an appropriate size and blanching, followed by frying to achieve the desired sensory properties. To prevent colourisation of chips, a substance called pyrophosphate is used in the Netherlands. This is a very significant P-source in the waste water from potato processing installations. Sodium metabisulphate may also be used to prevent potatoes from discolouring. Chips are generally sold frozen and may be part fried or fully fried. Crisps are increasingly sold in modified atmosphere packs.

Whether the product is potato chips, mashed potatoes or another potato product, there may be foam formation in the wash bath, which can lead to serious processing difficulties. Starch foam is very stable and difficult to remove. Mechanical methods of foam control have such limited effectiveness, that the addition of foam-control agents may be the most practical solution [51, Ullmann 2001].

The objective of frying is to cook in edible oil at temperatures in the region of 200 °C. Vegetable oil, or a mixture of animal fat and vegetable oil, is normally used. The product is fed
into the fryer on a slatted belt. The fryer is a horizontal chamber containing the oil. The product drops into the oil and if it is coated in batter, this expands and brings the product to the surface of the oil. The slatted belt feeds the product under the main fryer belt, which takes the product through the fryer and controls the frying time. The take-out belt at the end of the fryer lifts the product out of the oil, allows drainage and transfers the product to the inspection and packing belts. Fryers are equipped with a fume extraction fan to eliminate fume leakage. The frying temperature and time vary according to the product being processed. Temperatures range from 190 to 205 °C and residence times in the fryer are normally around 35 seconds, but can be as long as 6 minutes.

8.2.10.1 Potato chips

Potatoes are delivered to the installation and are sorted to remove stones, pebbles and other extraneous matter. The raw material is washed, graded and peeled. A number of peeling methods are available, including mechanical, steam and caustic peeling. Large tubers are generally sorted for use in chip production. Potatoes are cut into the required size using independently driven multiple knives. Off-cuts, slivers and broken pieces are removed before blanching. The chips are blanched using steam or water generally at around 60 °C to 85 °C. Multiple blanching stages may be used.

Excess moisture is removed from the chips both to preserve the life of the frying oil and to lower the moisture content of the chips. This also leads to a reduction in the required frying time. Conveyor dryers are used in large processing installations. The chips are fried, typically at around 160–180 °C, the time of frying varies for completely fried and partially fried products. Excess fat is removed from the chips before freezing. Some manufacturers recover the fat for reuse. Fluidised bed freezing may be used for freezing the finished product, although belt freezing reportedly provides a more energy efficient option.

8.2.10.2 Potato crisps

Processing methods for the manufacture of crisps vary greatly, but generally take the form of washing, peeling, trimming and sorting, slicing, rinsing, partial drying, frying, salting, flavouring, cooling and packing. Potatoes are first washed with drum or flotation washers. Stones, sand, dirt and any extraneous matter are removed. Potatoes are elevated into washers and peeled by abrasion. Peeled potatoes are trimmed to remove eyes, bruises and decaying portions. Slicing is carried out using a series of blades mounted on a circular stationary plate and a rotating drum. Water is supplied to flush starch from the equipment. Sliced potatoes are washed, usually in drum washers, to remove surface starch and sugars.

Some manufacturers blanch crisps prior to frying using steam-jacketed water filled tanks. Typical blanching conditions are 65 °C to 95 °C, for one minute or more. After washing, surface moisture is removed by various methods including compressed air and blower fans, vibrating mesh belts and heated air. Crisp frying may be batch or continuous. Temperatures are in the range of 160 °C to 190 °C and cooking times are typically between 1.5 and 3 minutes. When the crisps leave the fryer, they are agitated to remove excess oil and discharged to a belt running underneath a salter. Flavouring may be mixed with the salt or dusted/sprayed onto the crisps in rotating drums. Finally the crisps are cooled and packed.

8.2.11 Vegetable juice

Significant quantities of juice are produced from vegetable sources such as carrot, celery, beetroot and cabbage. In general, fresh vegetables are first washed and sorted before being coarsely milled and then pressed to extract the juice. Most vegetable juices have low acidity, i.e. a pH >4.5, and therefore, they require a full sterilisation process for preservation. Vegetable juices are sometimes acidified with organic or mineral acids to reduce the pH, so that a milder
Chapter 8

heat treatment such as pasteurisation is then possible. Some low acidity juices are blended with high acid juices such as tomato, rhubarb, citrus, pineapple or cabbage, so that they are acidic enough to only require pasteurisation. Some vegetables may be blanched prior to acidifying and extraction. Root vegetables are usually peeled before maceration and extraction.

8.2.12 Heat treated and frozen vegetables

Process conditions vary depending upon the vegetable type, but preliminary operations for both heat treated and frozen vegetables are similar to those described in Section 8.2.5 for fruits. They usually involve washing, grading and screening to remove extraneous matter such as stones and dirt. After washing, the vegetables are peeled and may be trimmed. After peeling the vegetables may be left whole or cut in a number of ways such as sliced or diced. Some vegetables are washed after slicing to remove the surface starch. Most vegetables require blanching. Steam or water blanching are the most common methods. The product is then cooled rapidly. After cooling, the product may be re-inspected and screened before being quick frozen or filled into cans or glass jars, usually with a hot brine, e.g. sugar, salt or acid, and then heat processed. Vegetables generally undergo a full sterilisation process as the pH is too high to inhibit microbial action.

8.2.13 Pickling of vegetables

In a typical pickling process, raw vegetables are delivered, washed and then screened to remove extraneous matter such as stones. Depending upon the vegetable, the raw material might be steam cooked and then cooled. The product is then peeled, typically using steam, and re-inspected before being cut to the required dimensions, e.g. sliced/diced/shredded, and transported to the filling line. The chopped vegetables are then filled into containers. An acidifying liquor is mixed with spices and transferred to the filling line to be used in the pickling sauce. This liquor typically consists of acetic acid, malt vinegar, spirit vinegar, distilled malt vinegar, liquid sugar and salt, depending upon the formulation. The acidifying liquor is deposited into the container. The container is sealed and typically pasteurised before cooling and packaging.

8.2.14 Vegetable drying

Vegetable drying uses raw materials such as potatoes, tomatoes, mushrooms and onions. The basic process is the same as in fruit processing, i.e. sorting, grading, washing, drying and packing. Many vegetables can be sun dried at source. Mechanical methods can also be used.

Waste water treatment

The following treatment options are not necessarily applicable to potato processing. For specific characteristics see Section 0.

Before waste water treatment, segregation of water streams is typically applied in the fruit and vegetable sector (see Section). After segregation, primary treatment is applied and the following techniques are used:

- screening (see Section 2.3.6.1.1)
- flow and load equalisation (see Section 2.3.6.1.3)
- neutralisation (see Section 2.3.6.1.4)
- sedimentation (see Section 2.3.6.1.5)
- DAF (see Section 2.3.6.1.6)
SS and soil are better separated using sedimentation than DAF. However, if the waste water contains appreciable levels of FOG, then a combination of sedimentation and DAF is typically applied.

For the waste water of peeling operations, the use of chemicals may restrict the nutritional exploitation of the separated peel mass. In fact, if peel mass is used for nutrition, separate waste water treatment is needed. Steam peeling plants may have separate units.

In some instances, waste water after primary treatment can be discharged into the MWWTP. For discharges to watercourses, or for treating waste water to a quality suitable for reuse, secondary treatment is required. Due to the seasonal operation, biological treatment of waste water from the fruit and vegetable sector may represent a problem for the operators.

For waste water with a BOD concentration greater than 1000–1500 mg/l, anaerobic treatment processes (see Section 2.3.6.2.2) can be used. After this treatment, waste water may be discharged to a MWWTP following surface aeration, but not to water bodies. For lower polluted waste water streams, aerobic treatment (see Section 2.3.6.2.1) can be used. The waste water from fruit and vegetable processing is often deficient in nitrogen and phosphorus and may require supplements of these nutrients to support adequate biological activity. Nitrification and dephosphatation processes can be stimulated by controlling aeration. A two-stage biological system (see Section 2.3.6.2.3), anaerobic followed by aerobic, may achieve a quality of waste water suitable for discharge to a watercourse.

If stricter permit conditions are in place due to the receiving water, or if the water is to be recycled in the process, then tertiary treatment (see Section 2.3.6.3) is needed. If the recycled water is to be used in processing areas as drinking water, tertiary treatment, including disinfection and sterilisation, is essential.

Figure 8 illustrates a flow sheet of typical waste water treatment techniques used in the fruit and vegetable sector.

**Potato processing**

Although the organic constituents of the waste water from potato processing are readily biodegradable, problems may arise during waste water treatment largely due to the following factors [35, Germany 2002]:

- pollution loads may fluctuate substantially in the course of the day, week, year
- high concentrations of impurities
- imbalanced composition of waste water, e.g. preponderance of carbohydrates and sometimes imbalanced mineral nutrient supply
- presence of foam producing substances, e.g. protein
- risk of bulking sludge formation
- the temperature of the waste water sometimes exceeds 35–40 °C, which may necessitate the use of evaporation coolers
- the rapid onset of the anaerobic fermentation process may give rise to undesirable odours
- the acids present during the fermentation processes may result in the pH being reduced to between 4 and 4.5. This acidification takes place within about 2 hours.

In anaerobic/aerobic treatment systems, it is necessary to investigate whether, in view of the N_total load, it is possible to treat the entire production waste water or only a substream to ensure that the aerobic stage still has enough carbon for nitrogen elimination. If the above
considerations are taken into account, it is possible to use biological processes to clean the highly concentrated waste water from potato processing facilities. UASB reactors may not be suitable for potato peeling operations.

**Figure:** Flow sheet of typical waste water treatment in the fruit and vegetable sector [8, Environment Agency of England and Wales 2000]

Table shows some waste water treatment combinations reported for the fruit and vegetable sector.
### Combination of techniques

<table>
<thead>
<tr>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary treatments (see Section 2.3.6.1)</td>
</tr>
<tr>
<td>Primary treatments (see Section 2.3.6.1) + Aerobic processes (see Section 2.3.6.2.1)</td>
</tr>
<tr>
<td>Primary treatments (see Section 2.3.6.1) + Anaerobic processes (see Section 2.3.6.2.2) + Aerobic processes (see Section 2.3.6.2.1)</td>
</tr>
<tr>
<td>Primary treatments (see Section 2.3.6.1) + Anaerobic processes (see Section 2.3.6.2.2) + Aerobic processes (see Section 2.3.6.2.1) + Biological nitrification/denitrification (see Section 2.3.6.3.1) + Phosphorus removal by biological methods (see Section 2.3.6.3.3)</td>
</tr>
<tr>
<td>Primary treatments (see Section 2.3.6.1) + Anaerobic processes (see Section 2.3.6.2.2) + Aerobic processes (see Section 2.3.6.2.1) + Biological nitrification/denitrification (see Section 2.3.6.3.1) + Phosphorus removal by biological methods (see Section 2.3.6.3.3) + Precipitation (see Section 2.3.6.1.8) + Filtration (see Section 2.3.6.3.6)</td>
</tr>
<tr>
<td>Primary treatments (see Section 2.3.6.1) + Anaerobic processes (see Section 2.3.6.2.2) + Aerobic processes (see Section 2.3.6.2.1) + Biological nitrification/denitrification (see Section 2.3.6.3.1) + Phosphorus removal by biological methods (see Section 2.3.6.3.3) + Precipitation (see Section 2.3.6.1.8) + Filtration (see Section 2.3.6.3.6) + Carbon adsorption (see Section 0)</td>
</tr>
<tr>
<td>Primary treatments (see Section 2.3.6.1) + Anaerobic processes (see Section 2.3.6.2.2) + Aerobic processes (see Section 2.3.6.2.1) + Biological nitrification/denitrification (see Section 2.3.6.3.1) + Phosphorus removal by biological methods (see Section 2.3.6.3.3) + Precipitation (see Section 2.3.6.1.8) + Filtration (see Section 2.3.6.3.6) + Carbon adsorption (see Section 0) + Membrane separation, i.e. CFM (see Section 2.3.6.3.7)</td>
</tr>
<tr>
<td>Primary treatments (see Section 2.3.6.1) + Anaerobic processes (see Section 2.3.6.2.2) + Aerobic processes (see Section 2.3.6.2.1) + Biological nitrification/denitrification (see Section 2.3.6.3.1) + Phosphorus removal by biological methods (see Section 2.3.6.3.3) + Precipitation (see Section 2.3.6.1.8) + Filtration (see Section 2.3.6.3.6) + Carbon adsorption (see Section 0) + Membrane separation, i.e. RO (see Section 2.3.6.3.7)</td>
</tr>
</tbody>
</table>

**Table:** Some waste water treatment combinations reported for the fruit and vegetable sector [31, VITO, et al., 2001]
8.3 Current consumption and emission levels

8.3.1 Energy consumption

Processes involving heating, cooling, drying, evaporation, sterilisation, pasteurisation and blanching consume significant energy. Almost every process step requires electricity. For steam production, natural gas boilers can be used. The frozen vegetable sector is a large consumer of electricity and natural gas. Deep freezing is the process which uses the most electricity.

Figure 8.5 shows data for specific energy consumption (MWh/tonne of product) from various fruit and vegetables installations.

![Figure 8.5: Specific energy consumption (MWh/tonne of product) in fruit and vegetables](image)

Source: [193, TWG 2015]

During deep freezing, cooling to a very low temperature level, i.e. -30 to -40 °C, is necessary. During this process, energy is consumed at a rate of 80 to 280 kWh/t of frozen vegetables. Other processes, e.g. washing, require less electrical energy, a maximum of 28 kWh/t of frozen product. Deep freezing carrots consumes ±8 kWh/t and freezing salsifies consumes ±20 kWh/t and these require a lot of electrical energy for sorting. Washing spinach for deep freezing consumes ±4 kWh/t and is electricity intensive. The mechanical processing of frozen beans and salsifies consumes ±6 kWh/t and ±9 kWh/t respectively, i.e. much more electricity compared with other vegetables.

The electricity consumption of the belt blancher with air cooling, which produces 7 to 30 kWh/t of frozen product, is significantly higher than that of the belt blancher with water cooling, which produces 2 to 9 kWh/t of frozen product, or the drum blancher with countercurrent water cooling, which produces 1 to 2.6 kWh/t of frozen product. Spinach requires most electricity for intermediate processes such as packing or making of portions.

Steam is used for peeling and blanching. Steam peeling uses approximately five times more steam than caustic peeling. Belt blanching with water cooling consumes approximately half the energy of belt blanching with air cooling or drum blanching with countercurrent water cooling. For storage, electricity consumption is between 20 and 65 kWh/m³ of storage space/year.
8.3.2 Water consumption

Water is used mainly during washing. It is also used during peeling and blanching. The fruit and vegetable canning industry in Greece consumes 7–15 m$^3$ water per tonne of product.

Figure 8.6 shows data for specific water consumption (m$^3$/tonne of product) from various fruit and vegetables installations. Water recycling is usually applied. Higher specific water consumptions have been reported for tomato processing.

![Figure 8.6: Specific water consumption (m$^3$/tonne of product) in fruit and vegetables](image)

Table shows water consumption levels reported by, and achieved in, fruit and vegetable installations.

<table>
<thead>
<tr>
<th>Product category</th>
<th>Water consumption (m$^3$/t-product)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canned fruit</td>
<td>2.5–4.0</td>
</tr>
<tr>
<td>Canned vegetables</td>
<td>3.5–6.0</td>
</tr>
<tr>
<td>Frozen vegetables</td>
<td>5.0–8.5</td>
</tr>
<tr>
<td>Fruit juices</td>
<td>6.5</td>
</tr>
<tr>
<td>Juices</td>
<td>6.0</td>
</tr>
<tr>
<td>Baby food</td>
<td>6.0–9.0</td>
</tr>
</tbody>
</table>

*Source: [193, TWG 2015]*

Water consumption levels reported for some processes in the fruit and vegetable sector are shown in Table 8.11.
Table 8.11: Water consumption for some processes in the fruit and vegetable sector

<table>
<thead>
<tr>
<th>Type of processing</th>
<th>Water consumption (m$^3$/t finished product)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep frozen vegetables</td>
<td></td>
</tr>
<tr>
<td>non-peeled products, e.g. leeks, onions, aubergines, cabbage, blanched celery,</td>
<td>2.5–5.0</td>
</tr>
<tr>
<td>rhubarb and courgettes</td>
<td></td>
</tr>
<tr>
<td>beans, peas, cauliflower, sprouts and flageoleats</td>
<td></td>
</tr>
<tr>
<td>blanched leaf vegetables, e.g. spinach</td>
<td></td>
</tr>
<tr>
<td>peeled products, e.g. carrots, celery and potatoes</td>
<td></td>
</tr>
<tr>
<td>Preserved vegetables (range)</td>
<td>7–11</td>
</tr>
<tr>
<td>well managed</td>
<td>5.9</td>
</tr>
<tr>
<td>Potato processing (range)</td>
<td>4.5–9.0</td>
</tr>
<tr>
<td>well managed</td>
<td>5.1</td>
</tr>
<tr>
<td>Potato peeling company (well managed)</td>
<td>2.4</td>
</tr>
<tr>
<td><strong>Source:</strong> [5, German Dairy Association 1999], [71, AWARENET 2002].</td>
<td></td>
</tr>
</tbody>
</table>

Tomatoes are one of the most processed raw materials. Italy is the second largest producer in the world after the US, and the largest exporter of tomato products. Reported figures for water and energy consumption together with waste water and solid waste production in the different processing steps for canned peeled tomatoes and tomato juice are summarised in Table 8.12 and Table 8.13.

**Canned peeled tomatoes (whole and cut)**

<table>
<thead>
<tr>
<th>Unit operation</th>
<th>Water consumption (m$^3$/t)</th>
<th>Waste water load (kg COD/t)</th>
<th>By-products/solid wastes (kg/t)</th>
<th>Electrical energy (kWh/t)</th>
<th>Thermal energy (kg steam/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1. Materials handling and storage</td>
<td>0.2</td>
<td>1.5</td>
<td>10–15</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>A.2. Sorting/screening, grading, destemming/destalking and trimming</td>
<td>0.1–2</td>
<td>0.1</td>
<td>0.2</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>A.3. Peeling (crushing)</td>
<td>0.5–2</td>
<td>1.5</td>
<td>25–30</td>
<td>2.5</td>
<td>100</td>
</tr>
<tr>
<td>A.4. Washing</td>
<td>2</td>
<td>2</td>
<td>0.2</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>A.5. Cutting, slicing, mincing, pulping and peeling</td>
<td>0.5–2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.1. Cutting, slicing, mincing, pulping and peeling</td>
<td>0.5–2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.2. Blanching</td>
<td>0.5</td>
<td></td>
<td></td>
<td>4</td>
<td>60</td>
</tr>
<tr>
<td>B.3. Pasteurization, sterilisation and UHT</td>
<td>15–25</td>
<td></td>
<td></td>
<td>2</td>
<td>450–500</td>
</tr>
<tr>
<td>Cans and bottles</td>
<td>200–300</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.5. Filtration</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.6. Blanching</td>
<td>0.5</td>
<td></td>
<td></td>
<td>4</td>
<td>60</td>
</tr>
<tr>
<td>C.7. Pasteurisation, sterilisation and UHT</td>
<td>15–25</td>
<td></td>
<td></td>
<td>2</td>
<td>450–500</td>
</tr>
<tr>
<td>Cans and bottles</td>
<td>200–300</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.8. Pasteurisation, sterilisation and UHT</td>
<td>15–25</td>
<td></td>
<td></td>
<td>2</td>
<td>450–500</td>
</tr>
<tr>
<td>Cans and bottles</td>
<td>200–300</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.1. Evaporation (for juice)</td>
<td>10–12</td>
<td></td>
<td></td>
<td>7–8</td>
<td>150–200</td>
</tr>
<tr>
<td>E.2. Pasteurating and filling</td>
<td>0.5</td>
<td></td>
<td></td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>E.4. Cleaning and disinfection</td>
<td>0.5</td>
<td></td>
<td>0.3–4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.5. Vacuum generation</td>
<td>0.5</td>
<td></td>
<td>1–2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall totals of typical installations</td>
<td>35–40</td>
<td>7–10</td>
<td>25–35</td>
<td>19–24</td>
<td>750–850</td>
</tr>
</tbody>
</table>

**Table : Consumption and emission levels for canning tomatoes**

[89, Italian contribution, 2001, 184, Italy, 2003]
## Chapter 8

### Tomato juice, puree and paste (28–30 °Brix puree) \(^{(1)}\)

<table>
<thead>
<tr>
<th>Unit operation</th>
<th>Water consumption</th>
<th>Waste water load</th>
<th>By-products/ solid wastes</th>
<th>Electrical energy</th>
<th>Thermal energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Description</td>
<td>(m(^3)/t)</td>
<td>(kg COD/t)</td>
<td>(kg/t)</td>
<td>(kWh/t)</td>
</tr>
<tr>
<td>A.1</td>
<td>Materials handling and storage</td>
<td>5</td>
<td>6</td>
<td>12</td>
<td>0.4</td>
</tr>
<tr>
<td>A.2</td>
<td>Sorting/screening, grading, dehulling, destemming/destalking and trimming</td>
<td>10</td>
<td>2</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>A.3</td>
<td>Peeling (refining)</td>
<td></td>
<td>150–200</td>
<td></td>
<td>8-12</td>
</tr>
<tr>
<td>A.4</td>
<td>Washing</td>
<td>15</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.1</td>
<td>Cutting, slicing, chopping, mincing, pulping and pressing</td>
<td></td>
<td></td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>B.2</td>
<td>Mixing/blending, homogenisation and conching</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.1</td>
<td>Blanching</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.2</td>
<td>Pasteurisation, sterilisation and UHT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.3</td>
<td>Evaporation (liquid to liquid)</td>
<td>100–150 (^{(2)})</td>
<td>60–80</td>
<td>1500–1800</td>
<td></td>
</tr>
<tr>
<td>E.4</td>
<td>Drying (liquid to solid)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F.1</td>
<td>Evaporation (liquid to liquid)</td>
<td>130–180 (^{(2)})</td>
<td>10–12</td>
<td>90–125</td>
<td>2300–2800</td>
</tr>
<tr>
<td>F.2</td>
<td>Drying (liquid to solid)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H.1</td>
<td>Packing and filling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.1</td>
<td>Cleaning and disinfection</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.4</td>
<td>Vacuum generation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Overall totals of typical installations**

- All figures are referred to 1 t of 28–30 Brix tomato puree. Conversion coefficients for other final products:
  - 7–12 Brix puree multiply by 0.3;
  - 20–22 Brix puree multiply by 0.7;
  - 36–40 Brix puree multiply by 1.3
- Without cooling towers

### 8.3.3 Residues

Large amounts of solid wastes are produced. These are organic materials, including fruit and vegetables discarded during selection, and those from processes such as peeling or coring. These typically have a high nutritional value and can be used as animal feed. Undesired materials discarded from the first processing steps include soil and extraneous plant material, spoiled food stocks, and some trimmings, peels, pits, seeds and pulp.

When caustic agents are used for peeling fruit and soft vegetables, a highly alkaline or salty solid waste is produced. High moisture content solid wastes can be generated by wet cleaning and reuse operations in which the dissolved solids or TSS are concentrated and separated from the waste water.

Up to 50 % of fruit and typically 10 to 30 % of raw vegetable materials are wasted during processing. Part of the waste goes to the waste water and significant amounts of solid wastes are also generated. Some reported figures are shown in Table 8.12

---

\(^{(1)}\) All figures are referred to 1 t of 28–30 °Brix tomato puree. Conversion coefficients for other final products:

- 7–12 Brix puree multiply by 0.3;
- 20–22 Brix puree multiply by 0.7;
- 36–40 Brix puree multiply by 1.3

\(^{(2)}\) Without cooling towers

Table: Consumption and emission levels for manufacturing of tomato juice, puree and paste

[89, Italian contribution, 2001, 184, Italy, 2003]
### Table 8.12: Solid waste produced during fruit and vegetable processing

<table>
<thead>
<tr>
<th>Raw material processed</th>
<th>Solid waste produced per tonne of product (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>40</td>
</tr>
<tr>
<td>Peas</td>
<td>40</td>
</tr>
<tr>
<td>Potatoes</td>
<td>40</td>
</tr>
<tr>
<td>Strawberries</td>
<td>60</td>
</tr>
<tr>
<td>Apples</td>
<td>90</td>
</tr>
<tr>
<td>All vegetables</td>
<td>130</td>
</tr>
<tr>
<td>Peaches</td>
<td>180</td>
</tr>
<tr>
<td>Broccoli</td>
<td>200</td>
</tr>
<tr>
<td>Carrots</td>
<td>200</td>
</tr>
<tr>
<td>Frozen peaches*</td>
<td>200</td>
</tr>
</tbody>
</table>

*Product

Source: [74, World Bank (IBRD) et al. 1998]

The reported types and amount of wastes produced in processing and preservation of fruit and vegetables are shown in Figure.

![Figure](https://example.com/figure.png)

Source: [71, AWARENET 2002]

**Figure 1:** Type and amount of wastes produced in fruit and vegetable processing and preservation

Some reported figures for producing fruit and vegetable juices are shown in Figure.
Chapter 8

If fruit and vegetables are treated with enzymes during juice manufacturing, less waste is produced. Table 1 shows the effects of apple and tomato processing in Hungary.

<table>
<thead>
<tr>
<th>Raw materials</th>
<th>Type of pretreatment</th>
<th>Amount of waste (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>With enzyme</td>
<td>8–18</td>
</tr>
<tr>
<td></td>
<td>Without enzyme</td>
<td>10–25</td>
</tr>
<tr>
<td>Tomato</td>
<td>With enzyme</td>
<td>2–6</td>
</tr>
<tr>
<td></td>
<td>Without enzyme</td>
<td>4–8</td>
</tr>
</tbody>
</table>

Table 1: Fruit and vegetable wastes in juice manufacturing in Hungary

Solid wastes are normally used for the production of animal feed and organic fertilisers. They may also be used for producing food or other marketable products, or disposed of in waste water or to land. Possible reuse and disposal routes for the different solid wastes produced are as follows:

- Non-nutritive fibre from apple pomace, dried citrus peel and lecithin from soybeans, may be used for the production of foods such as fermented foods, drinks, oils and proteins, or for the development of biopolymers for elaboration of biodegradable packing and construction material. Pectin is extracted from apples. Citrus is extracted during juice production;
- Citrus wastes, grape lees, grapes and potato processing wastes, may be used for biosynthesis of natural chemicals such as furfural, xylitol, alcohol, organic acids and...
polysaccharides, and pharmaceuticals such as hycogenin, antibiotics and vitamins. This option is growing as more opportunities are identified:

- production of animal feed from sugar beet pulp, apple and tomato pomace and citrus pulp pellets, without or after treatment (physical, chemical, microbial, ensilage, production of microbial biomass). This use is limited by several factors, including shipping, putrefaction during storage and transport, and the presence of undesirable constituents such as alkalis or salt. Water content is the major contributor to shipping costs and to some extent to the putrefaction rates. Putrefaction reduces the shelf-life and value of the solid wastes and limits its use as animal feed;
- peach and olive pits, rice hulls and straw, may be burnt directly, or converted to produce biogas or alcohol. Incineration is a viable option for solid wastes with a relatively low (<10 %) water content. Catalytic gasification or pyrolysis may also applied;
- composting and land application of organic waste is limited because of odour and possible soil contamination by leaching organics and salts.

Within the unit operations used in the fruit and vegetable sector, peeling is one of the major solid output and waste water producers.

Steam peeling is generally used for large quantities of potatoes, carrots and other tubers. Pre-processing includes the washing and the separation of mud and stones. This solid waste has no value for bioconversion. The waste produced in peeling has solids, mainly peel, which are separated by sedimentation from the aqueous phase, dried and may be composted. They may be further treated to recover minerals, fibre and phenolics. The aqueous phase goes for waste water treatment together with waste water from other processes. Its pollution, before discharge to MWWTP, expressed in COD is about 4 000 mg/l. Soluble vitamins, starch, fibre and tissue fluid may be recovered from this waste water.

Mechanical peeling is used for small quantities of potatoes, carrots, apples, pears, etc. or when vegetables are used for catering or in institutional kitchens. The peeling is often performed outside the main processor. There are numerous peeling companies with varying capacity and equipment. The unit operations are basically the same as in steam peeling. The processing starts with the separation of mud and stones similar to the step for the steam peeling process.

The peeling consists of three consecutive steps: mechanical pre-peeling, using, e.g. carborundum; knife peeling and then washing. Waste water is produced in all three steps. After sedimentation, the aqueous phase goes for waste water treatment. Its pollution expressed in COD is about 5000 mg/l. The separated solid phase is normally composted. Vitamins, starch, fibre and minerals may be recovered.

Knife peeling produces a similar output as steam peeling and it can be used similarly, either directly as animal feed or for recovery of its components. About 60 % of the total organic solid waste produced comes from pre-peeling, by abrasion peeling and the rest is from knife peeling. After cutting, defective pieces which are, e.g. too dark or too small, are separated and used as animal feed. However, especially in carrot processing, several valuable substances such as vitamin C, fibre, phenolic compounds and carotenoids, can be recovered from this by-product. The next step is rinsing, and in the case of potato processing, this is usually combined with the addition of browning inhibitors or sulphites before transporting the peeled product to the main processing facility.

Data comparing outputs from processes using either steam peeling or a combination of abrasion peeling and knife peeling is shown in Figure 8.1 and Figure 8.2.
8.3.4 Emissions to water

Waste water characteristics are affected by various factors. These include the raw material being processed, seasonal and source variations, unit operations, production patterns and operator practice.

Figure 8.7 shows reported data on specific waste water discharges (m$^3$/tonne of product) from fruit and vegetables installations. Higher discharged waste water volumes have been commonly reported for tomato processing.

![Figure 8.7: Specific waste water discharge (m$^3$/tonne of product) in fruit and vegetables](source)

Table shows data reported for canning fruits and vegetables in the US.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fruit</th>
<th>Vegetables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste water volume (m$^3$/raw material)</td>
<td>10.86</td>
<td>22.91</td>
</tr>
<tr>
<td>BOD$_5$ (kg/t raw material)</td>
<td>11.8</td>
<td>13.0</td>
</tr>
<tr>
<td>TSS (kg/t raw material)</td>
<td>2.3</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Table: Average waste water and water pollution generated in the US canning industry in 1975

The leaching of sugars, starches and other soluble organic compounds from the raw fruit or vegetables into the blanching water results in high BOD, TSS and dissolved solids emission levels. As blanching water is normally reused/recycled, the volume of waste water from blanching is normally relatively small. However, this tends to concentrate pollutants in the waste water.

Typically, waste water is high in TSS, sugars and starches. Residual pesticides that are difficult to degrade during waste water treatment may be a concern, especially with produce from countries with less stringent controls on pesticide use.

Reported emission levels of BOD and TSS in the waste water arising from the processing of various fruits and vegetables, are shown in Table 8.13 and Table 8.14.
Table 8.13: BOD and TSS concentrations in waste water from fruit and vegetable processing

<table>
<thead>
<tr>
<th>BOD &lt;500 mg/l</th>
<th>BOD 500–1 000 mg/l</th>
<th>BOD 1 000–2 000 mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>TSS mg/l</td>
<td>Product</td>
</tr>
<tr>
<td>Citrus</td>
<td>130</td>
<td>Apple juice</td>
</tr>
<tr>
<td>Asparagus</td>
<td>43–114</td>
<td>Strawberries</td>
</tr>
<tr>
<td>Broccoli</td>
<td>100–455</td>
<td>Baby foods</td>
</tr>
<tr>
<td>Brussel sprouts</td>
<td>29–1 680</td>
<td>Peeled tomatoes</td>
</tr>
<tr>
<td>Cauliflowers</td>
<td>18–113</td>
<td>Tomato products</td>
</tr>
<tr>
<td>Dehydrated vegetables</td>
<td>168–778</td>
<td></td>
</tr>
<tr>
<td>Leafy greens</td>
<td>19–419</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BOD 2 000–3 000 mg/l</th>
<th>BOD 3 000–5 000 mg/l</th>
<th>BOD &gt;5 000 mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>TSS mg/l</td>
<td>Product</td>
</tr>
<tr>
<td>Carrots</td>
<td>262–1 540</td>
<td>Dried fruit</td>
</tr>
<tr>
<td>Grape juice</td>
<td>216–228</td>
<td>Jams, jellies, preserves</td>
</tr>
<tr>
<td>Peas</td>
<td>79–673</td>
<td>Pears</td>
</tr>
<tr>
<td>Potato crisps</td>
<td>1 450–3 910</td>
<td></td>
</tr>
</tbody>
</table>

Source: [74, World Bank (IBRD) et al. 1998]

Table 8.14: Waste water characteristics from some fruit and vegetable processing

<table>
<thead>
<tr>
<th>Type of operation</th>
<th>SS (mg/l)</th>
<th>COD (mg/l)</th>
<th>BOD₅ (mg/l)</th>
<th>N₉₀ (mg/l)</th>
<th>P₉₀ (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetables, frozen vegetables, preserves, fruit and vegetable juices</td>
<td>700</td>
<td>5 000</td>
<td>3 000</td>
<td>150</td>
<td>30</td>
</tr>
<tr>
<td>Potato processing</td>
<td>700</td>
<td>10 000</td>
<td>3 000</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>Potato peeling</td>
<td>1 100</td>
<td>6 000</td>
<td>2 500</td>
<td>200</td>
<td>30</td>
</tr>
<tr>
<td>Fruit and vegetable juices</td>
<td>16.5²</td>
<td>5 500</td>
<td>2 500</td>
<td>26.5</td>
<td>21</td>
</tr>
<tr>
<td>Apples (without pressing)</td>
<td>33²</td>
<td>5 100</td>
<td>2 500</td>
<td>27</td>
<td>23</td>
</tr>
<tr>
<td>Sour cherries</td>
<td>9</td>
<td>4 000</td>
<td>2 300</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Blackcurrants</td>
<td>4 900</td>
<td>2 600</td>
<td>13.5</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>Blackcurrants without pressing</td>
<td>2 600</td>
<td>2 100</td>
<td>–</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Carrots</td>
<td>2 400</td>
<td>8 600</td>
<td>2 700</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

²Settleable solids after two hours, ml/l

Source: [4, Derden et al. 1999], [35, Germany 2002]

Specific waste water generation and pollution loads are presented in the next two tables. Table 8.15 shows reported loads per unit production that can be achieved by implementing pollution reduction measures, such as procuring clean raw fruit and vegetables, and the use of countercurrent systems for washing and recycling process water, although the specific techniques used for each example and the unit of product are not identified.

Table 8.16 shows the waste water volume and water pollution per unit of product generated in the processing of some fruit.
Table 8.15: Waste water volume and water pollution per unit of product generated in the processing of some vegetables

<table>
<thead>
<tr>
<th>Product</th>
<th>Waste water volume (m³/U)</th>
<th>BOD₅ (kg/U)</th>
<th>TSS (kg/U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asparagus</td>
<td>69.0</td>
<td>2.1</td>
<td>3.4</td>
</tr>
<tr>
<td>Broccoli</td>
<td>11.0</td>
<td>9.8</td>
<td>5.6</td>
</tr>
<tr>
<td>Brussels sprouts</td>
<td>36.0</td>
<td>3.4</td>
<td>11.0</td>
</tr>
<tr>
<td>Carrots</td>
<td>12.0</td>
<td>20.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Cauliflowers</td>
<td>89.0</td>
<td>5.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Maize</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canned</td>
<td>4.5</td>
<td>14.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Frozen</td>
<td>13.0</td>
<td>20.0</td>
<td>5.6</td>
</tr>
<tr>
<td>Dehydrated onions and garlic</td>
<td>20.0</td>
<td>6.5</td>
<td>5.9</td>
</tr>
<tr>
<td>Dehydrated vegetables</td>
<td>22.0</td>
<td>7.9</td>
<td>5.6</td>
</tr>
<tr>
<td>Dry beans</td>
<td>18.0</td>
<td>15.0</td>
<td>4.4</td>
</tr>
<tr>
<td>Lima beans</td>
<td>27.0</td>
<td>14.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Mushrooms</td>
<td>22.0</td>
<td>8.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Onions, canned</td>
<td>23.0</td>
<td>23.0</td>
<td>9.3</td>
</tr>
<tr>
<td>Peas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canned</td>
<td>20.0</td>
<td>22.0</td>
<td>5.4</td>
</tr>
<tr>
<td>Frozen</td>
<td>15.0</td>
<td>18.0</td>
<td>4.9</td>
</tr>
<tr>
<td>Pickles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fresh packed</td>
<td>8.5</td>
<td>9.5</td>
<td>1.9</td>
</tr>
<tr>
<td>Process packed</td>
<td>9.6</td>
<td>18.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Salting stations</td>
<td>1.1</td>
<td>8.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Pimentos</td>
<td>29.0</td>
<td>27.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Potatoes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All products</td>
<td>10.0</td>
<td>18.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Frozen products</td>
<td>11.0</td>
<td>23.0</td>
<td>19.0</td>
</tr>
<tr>
<td>Dehydrated products</td>
<td>8.8</td>
<td>11.0</td>
<td>8.6</td>
</tr>
<tr>
<td>Cabbage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canned</td>
<td>3.5</td>
<td>3.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Cut</td>
<td>0.4</td>
<td>1.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Snap beans</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canned</td>
<td>15.0</td>
<td>3.1</td>
<td>2.0</td>
</tr>
<tr>
<td>Frozen</td>
<td>20.0</td>
<td>6.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Spinach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canned</td>
<td>38.0</td>
<td>8.2</td>
<td>6.5</td>
</tr>
<tr>
<td>Frozen</td>
<td>29.0</td>
<td>4.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Squash</td>
<td>5.6</td>
<td>17.0</td>
<td>2.3</td>
</tr>
<tr>
<td>Sweet potatoes</td>
<td>4.1</td>
<td>30.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Tomatoes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peeled</td>
<td>8.9</td>
<td>4.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Products</td>
<td>4.7</td>
<td>1.3</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Unit of production (U) is not defined in [74, World Bank (IBRD) et al. 1998].

Source: [74, World Bank (IBRD) et al. 1998]
Table 8.16: Waste water volume and water pollution per unit of product generated in the processing of some fruit

<table>
<thead>
<tr>
<th>Product</th>
<th>Waste volume (m$^3$/U)</th>
<th>BOD$_5$ (kg/U)</th>
<th>TSS (kg/U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apricots</td>
<td>29.0</td>
<td>15.0</td>
<td>4.3</td>
</tr>
<tr>
<td>Apples All</td>
<td>3.7</td>
<td>5.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Apples All except juice</td>
<td>5.4</td>
<td>6.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Apples Juice</td>
<td>2.9</td>
<td>2.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Cranberries</td>
<td>5.8</td>
<td>2.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Citrus</td>
<td>10.0</td>
<td>3.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Sweet cherries</td>
<td>7.8</td>
<td>9.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Sour cherries</td>
<td>12.0</td>
<td>17.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Bing cherries</td>
<td>20.0</td>
<td>22.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Cranberries</td>
<td>12.0</td>
<td>10.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Dried fruit</td>
<td>13.0</td>
<td>12.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Grapefruit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grapefruit Canned</td>
<td>72.0</td>
<td>11.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Grapefruit Pressed</td>
<td>1.6</td>
<td>1.9</td>
<td>0.4</td>
</tr>
<tr>
<td>Peaches</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peaches Canned</td>
<td>13.0</td>
<td>14.0</td>
<td>2.3</td>
</tr>
<tr>
<td>Peaches Frozen</td>
<td>5.4</td>
<td>12.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Pears</td>
<td>12.0</td>
<td>21.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Pineapples</td>
<td>13.0</td>
<td>10.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Plums</td>
<td>5.0</td>
<td>4.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Raisins</td>
<td>2.8</td>
<td>6.0</td>
<td>1.6</td>
</tr>
<tr>
<td>Strawberries</td>
<td>13.0</td>
<td>5.3</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Unit of production (U) is not defined in [74, World Bank (IBRD) et al. 1998].

Source: [74, World Bank (IBRD) et al. 1998]

Up to this point in this section, general data on water pollution from fruit and vegetable processing have been reported. In the following paragraphs, there is a breakdown of all unit operations that generate waste water. A reported typical process showing the waste water which arises from the major unit operations is shown in Figure 8.8.
The incoming produce is washed in chlorinated water to remove residual soil, stones and other debris and to reduce the microbial population. Large volumes of chlorinated water are required, especially for root vegetables which carry a lot of earth, and leafy vegetables which have a large surface area. Mechanical or air flotation techniques are used to aid soil removal and reduce the quantity of water used. Some recirculation or reuse of water from other operations is common. Waste water from pre-washing mainly contains field debris and soil particles with small fragments of the fruit or vegetables. If detergents are used to increase cleaning efficiency, they contribute to the COD of the waste water.
Most processes involve some type of grading, trimming and size reduction. Sometimes density graders containing brines of different strength are used. Discharge of significant quantities of brine can adversely affect any biological WWTP. Washing of the produce after these operations creates waste water containing soluble starch, sugars and acids. The use of water fluming to convey both the product and waste material causes additional leaching of these substances. Waste water from citrus fruit processing also contains pectic substances that can interfere with the sedimentation of TSS.

All lines, equipment and process areas that are not in designated dry areas require wet cleaning, which generates waste water contaminated with raw material, product and cleaning chemicals. There are generally fewer requirements for aggressive chemicals in this sector than in others, unless oil or fat is used in processing.

8.3.5 Data for some fruit and vegetable products

8.3.5.1 Fresh-pack

Fresh-pack fruit and vegetables require minimal processing. Water consumption is mainly for produce washing, transport flumes and line cleaning. Processing installations are often close to growing areas, creating opportunities for the use of waste water in irrigation. Some fresh-pack vegetables require peeling.

8.3.5.2 Preserved fruit and vegetables

Fruit and vegetables that are to be preserved undergo further processing. The most common types are discussed below.

Many vegetables and some fruits require peeling, which can be a major source of BOD and TSS and represent a substantial proportion of the total waste water volume. Peeling is usually followed by washing.

Conventional steam peeling uses large quantities of water and produces waste water with high levels of product residue. At potato processing installations, the peels can contribute up to 80% of the total BOD. In fruit processing, peeling waste water can account for as much as 10% of the total waste water flow and 60% of the BOD. Water cooling in steam peeling increases water consumption.

Caustic peeling causes higher solubilisation of material and consequently a higher COD, BOD and TSS load than mechanical peeling, which is a combination of knife and abrasion peeling. Furthermore, the use of caustic in peeling may lead to pH fluctuations in the waste water. Dry caustic peeling tends to have a lower caustic consumption than wet methods and can greatly reduce the volume and pollutant load of the waste water from this operation and allows for the collection of peel as a pumpable slurry.

Blanching is used in most vegetables destined for canning, freezing or drying. Typically, it is carried out using hot water or steam. If the produce is to be frozen, blanching is followed by water or air cooling.

Both water and steam blanching produce waste water high in BOD; in some cases, over half of the total BOD load. The volume of waste water is less with steam blanching than with water blanching. The quantity of waste water from steam blanching can be reduced by steam recycling, effective steam seals and equipment designs that minimise steam consumption. Waste water can be completely eliminated by microwave blanching, which is used in Europe and Japan.
For fruit and vegetable products which can be microbiologically sterilised at temperatures not higher than 100 °C, sterilising, which, in this case, is generally named pasteurisation, can be carried out in installations using hot water or steam at atmospheric pressure. The most traditionally used low temperature process is the open bath. These are metallic cylindrical or parallel piped baths, containing water heated by direct steam injection with a nozzle placed on the bottom. These baths are not generally equipped with automatic thermostats. The operating temperature is the boiling point of water at atmospheric pressure with a continuous flow of excess steam. The packs to be sterilised are loaded into large baskets; the baskets, by means of pulleys, are immersed in the baths and treated by boiling water for the required time. Cooling does not generally take place in the sterilising bath itself, which is thus ready to receive a new load, but in another bath containing cold running water.

For products packaged in glass containers, linear tunnels are used, including the phases of feeding, preheating, heating, precooling, cooling and drying. Heating is by means of saturated dry steam or hot water coming down on the packs from the top from a series of nozzles or by simple percolation from a perforated ceiling. The water is then recovered in recycling baths equipped with direct or indirect steam heating. Cooling is also carried out by sprinkling with water. Precooling water is partially recycled, thus keeping it at around 60 °C. The drying step is indispensable for the prevention of marks on the cap and above all to enable labelling and secondary online packaging. It is carried out by means of hot or cold air blowers. To sterilise low acidity products, which require temperatures greater than 100 °C, various means of heating can be used, although autoclaves are predominantly used. All high temperature sterilisers operate at pressure higher than atmospheric.

Single-phase acid products or products with small pieces, such as fruit juices, vegetable juices and purees, tomato purees, jams, marmalades and jellies, can be hot-filled. Heat sterilisation may be carried out before packaging because of the low pH and/or a of these products. The hot product itself sterilises the metal or glass container, so that only the caps and necks of bottles, and lids of small containers, need to be sterilised separately. Filling and hermetic closure of the container need to be carried out before the product cools down. The filling temperatures are kept between 85–92 °C. In all cases, the subsequent cooling is undertaken with sterilised chlorinated water.

Finally, aseptic packaging is undertaken. It is a combination of sterilising plants for the product and for the containers of various types, with an isolated system of filling and sealing. The aseptic packaging of liquid products involves the following sequence of operations: heating at pre-fixed temperatures; transfer to a holding section; cooling at a temperature of around 35 °C; filling of the pre-sterilised pack, opening and kept in conditions of perfect asepsis; and closure of the pack. The type of heat exchanger is selected according to the rheological properties of the fluid. They can be tubular of the circular crown type or scraped-film exchangers for products with high Re values and tube-in-tube-in-tube exchangers or plate exchangers for products with low Re values [ 66, Italy 2002 ].

Pickling is also an important operation for the preservation of fruit and vegetables. Pickling can be carried out by adding organic acids until the pH is below 4.3. In the process of making sauerkraut, salt is added (brining/curing) to promote the growth of lactic acid bacteria, for taste reasons and for conservation. The following process phases produce brine; fresh brine after slashing and salting (100–150 kg/t of white cabbage) and sour brine in the course of lactic fermentation (150–180 kg/t of white cabbage). The blanching process is carried out in sour brine, which produces blanching brine. Table 8.17 shows the waste water values of brine during the production of cabbage.
### Table 8.17: Waste water values of brine during the production of Sauerkraut

<table>
<thead>
<tr>
<th>Brine</th>
<th>pH</th>
<th>Concentration in waste water (mg/l)</th>
<th>COD (mg/l)</th>
<th>Chloride (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh brine</td>
<td>6.0–6.2</td>
<td>10 000–30 000</td>
<td>15 000–40 000</td>
<td>12 000–15 000</td>
</tr>
<tr>
<td>Fermentation brine</td>
<td>3.8–4.2</td>
<td>17 000–50 000</td>
<td>25 000–75 000</td>
<td>2 500–20 000</td>
</tr>
<tr>
<td>Blanching brine</td>
<td>3.8–4.0</td>
<td>40 000–55 000</td>
<td>65 000–85 000</td>
<td>–</td>
</tr>
</tbody>
</table>

**Source:** [192, COM 2006]

### 8.3.5.3 Frozen vegetables

**Materials handling and storage**

In manufacturing frozen vegetables, transportation and storage operations require energy as follows [15, Van Bael J. 1998]:

- the transportation of frozen vegetables requires 2–14 kWh/t frozen vegetables. For most production lines, the electrical rating of the belts is between 5–30 kW,
- the storage of vegetables needs 20–65 kWh/m³ storage/year electricity and about 26 389 kWh/m² (95 MJ/m²) storage/year is needed in the form of hot water.

Data from the literature show that the average energy balance is made up as follows [15, Van Bael J. 1998]:

- 11% for the evaporator fans;
- 5% for the condenser fans;
- 7% for peripheral equipment;
- 77% for compressors, of which 21% is used for heat input via doors/hatches, 48% used due to losses via the building shell, and 8% through the product.

**Sorting/screening, grading, dehulling, destemming/destalking and trimming**

The sorting operation has an electrical energy consumption of 0–20 kWh/t frozen vegetables [15, Van Bael J. 1998]. Table 8.18 shows the electricity consumption during the sorting of vegetables.

### Table 8.18: Electricity consumption during the sorting of vegetables

<table>
<thead>
<tr>
<th>Product</th>
<th>Electricity consumption (kWh/t frozen vegetables)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinach</td>
<td>0</td>
</tr>
<tr>
<td>Cauliflowers</td>
<td>1</td>
</tr>
<tr>
<td>Peas</td>
<td>4</td>
</tr>
<tr>
<td>Sprouts</td>
<td>4</td>
</tr>
<tr>
<td>Beans</td>
<td>5</td>
</tr>
<tr>
<td>Carrots</td>
<td>8</td>
</tr>
</tbody>
</table>

**Source:** [15, Van Bael J. 1998]

### Peeling

In frozen vegetable processing, salsifies and carrots are peeled before being mechanically processed. Caustic peeling and steam peeling are two methods used. Caustic peeling needs less energy, both in terms of electricity consumption and steam consumption, than steam peeling, but creates more load for the WWTP. Table 8.19 shows the energy carrier and consumption for the caustic peeling of vegetables and Table 8.20 shows the energy carrier and consumption for the steam peeling of vegetables.
### Table 8.19: Energy carrier and consumption for the caustic peeling of vegetables

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Approximate consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water (kWh/t frozen vegetables)</td>
<td>0</td>
</tr>
<tr>
<td>Steam (t/t frozen vegetables)</td>
<td>0.16</td>
</tr>
<tr>
<td>Steam pressure (bar)</td>
<td>7</td>
</tr>
<tr>
<td>Electricity (kWh/t frozen vegetables)</td>
<td>2</td>
</tr>
</tbody>
</table>

*Source: [15, Van Bael J. 1998]*

### Table 8.20: Energy carrier and consumption for the steam peeling of vegetables

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Approximate consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water (kWh/t frozen vegetables)</td>
<td>0</td>
</tr>
<tr>
<td>Steam (t/t frozen vegetables)</td>
<td>0.9</td>
</tr>
<tr>
<td>Steam pressure (bar)</td>
<td>4–15</td>
</tr>
<tr>
<td>Electricity (kWh/t frozen vegetables)</td>
<td>3.5</td>
</tr>
</tbody>
</table>

*Source: [15, Van Bael J. 1998]*

Washing

Washing, as used in the production of frozen vegetables, needs 0–5 kWh/t frozen vegetables. Certain vegetables, e.g. sprouts and cauliflowers, do not require any washing and thus do not consume energy.

Table 8.21 shows the electricity consumption for the washing of vegetables.

### Table 8.21: Electricity consumption for the washing of vegetables

<table>
<thead>
<tr>
<th>Product</th>
<th>Electricity consumption (kWh/t frozen vegetables)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprouts</td>
<td>0</td>
</tr>
<tr>
<td>Cauliflowers</td>
<td>0</td>
</tr>
<tr>
<td>Beans</td>
<td>0.5</td>
</tr>
<tr>
<td>Carrots</td>
<td>2.5</td>
</tr>
<tr>
<td>Salsifies</td>
<td>3</td>
</tr>
<tr>
<td>Peas</td>
<td>3</td>
</tr>
<tr>
<td>Spinach</td>
<td>5</td>
</tr>
</tbody>
</table>

*Source: [15, Van Bael J. 1998]*

Cutting, slicing, chopping, mincing, pulping and pressing

Some vegetables are cut before deep freezing. The electrical energy consumption is up to 9 kWh/t frozen vegetable. Table 8.22 shows the electricity consumption of mechanical processing of vegetables before freezing.

### Table 8.22: Electricity consumption of mechanical processing of vegetables before freezing

<table>
<thead>
<tr>
<th>Product</th>
<th>Electricity consumption (kWh/t frozen vegetables)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peas</td>
<td>0</td>
</tr>
<tr>
<td>Sprouts</td>
<td>0</td>
</tr>
<tr>
<td>Spinach</td>
<td>0</td>
</tr>
<tr>
<td>Carrots (sliced)</td>
<td>1</td>
</tr>
<tr>
<td>Carrots (diced)</td>
<td>2.5</td>
</tr>
<tr>
<td>Salsifies</td>
<td>6</td>
</tr>
<tr>
<td>Beans</td>
<td>9</td>
</tr>
<tr>
<td>Peas</td>
<td>0</td>
</tr>
</tbody>
</table>

*Source: [15, Van Bael J. 1998]*
Carrots, salsifies and beans require a reasonable amount of electrical energy for mechanical processing. Other vegetables examined do not require any electricity at all.

**Blanching**

Drum and belt blanchers are used in manufacturing deep frozen vegetables. Energy consumption depends on, not only the type of blanching device, but also the type of subsequent cooling step. Typical energy consumption levels are shown in Table 8.23 and Table 8.24.

**Table 8.23: Energy source and consumption for drum blanching in the deep freezing of vegetables**

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Approximate consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water (kWh/t frozen vegetables)</td>
<td>0</td>
</tr>
<tr>
<td>Steam (t/t frozen vegetables)</td>
<td>0.16</td>
</tr>
<tr>
<td>Steam pressure (bar)</td>
<td>7</td>
</tr>
<tr>
<td>Electricity (kWh/t frozen vegetables)</td>
<td>0.5–1.3</td>
</tr>
</tbody>
</table>

*Source: [15, Van Bael J. 1998]*

**Table 8.24: Energy source and consumption for countercurrent water cooling of vegetables processing**

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Approximate consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water (kWh/t frozen vegetables)</td>
<td>0</td>
</tr>
<tr>
<td>Steam (t/t frozen vegetables)</td>
<td>0</td>
</tr>
<tr>
<td>Steam pressure (bar)</td>
<td>0</td>
</tr>
<tr>
<td>Electricity (kWh/t frozen vegetables)</td>
<td>0.5–1.3</td>
</tr>
</tbody>
</table>

*Source: [15, Van Bael J. 1998]*

Furthermore, the electricity consumption for the production of ice-water is included in the electricity consumption shown for deep freezing. For example, in terms of energy consumption, the belt blancher with water cooling has the lowest total consumption. The heat released by the cooling of the product in the cooling zone is used to preheat the vegetables. In this way, less steam is necessary for blanching. Table 8.25 shows the energy carrier and consumption for belt blancher with water cooling in vegetable processing and Table 8.26 shows the energy carrier and order of magnitude indicators of the belt blancher with air cooling in vegetable processing.

**Table 8.25: Energy carrier and consumption for a belt blancher with water cooling in vegetable processing**

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Approximate consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water (kWh/t frozen vegetables)</td>
<td>0</td>
</tr>
<tr>
<td>Steam (t/t frozen vegetables)</td>
<td>0.09</td>
</tr>
<tr>
<td>Steam pressure (bar)</td>
<td>7</td>
</tr>
<tr>
<td>Electricity (kWh/t frozen vegetables)</td>
<td>2–9</td>
</tr>
</tbody>
</table>

*Source: [15, Van Bael J. 1998]*

**Table 8.26: Energy carrier and order of magnitude indicators of a belt blancher with air cooling in vegetable processing**

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Order of magnitude indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water (kWh/t frozen vegetables)</td>
<td>0</td>
</tr>
<tr>
<td>Steam (t/t frozen vegetables)</td>
<td>0.16</td>
</tr>
<tr>
<td>Steam pressure (bar)</td>
<td>7</td>
</tr>
<tr>
<td>Electricity (kWh/t frozen vegetables)</td>
<td>7–30</td>
</tr>
</tbody>
</table>

*Source: [15, Van Bael J. 1998]*
With regard to electricity consumption, the drum blancher for countercurrent water cooling has the lowest consumption. The water consumption for such an installation is rather high. The use of heavy duty fans (60 kW) in the belt blancher with air cooling, make the electricity consumption high for this type of operation.

8.3.5.4 Juices

Energy is consumed when the juice is concentrated by evaporation and during pasteurisation. Waste water is produced from the condensate during evaporation and during start-up, product changeover and cleaning of pasteurisers. Solid wastes are produced during the pressing of fruit and vegetables. For example, 2% of tomatoes and 30% of citrus fruits may be lost as solid wastes during pressing [96, Italy 2003].

8.3.5.5 Other products

Jams, jellies and preserves are based on the production of fruit gels, which come from extracted juices, purees or the whole fruit respectively. Fruit gels are composed of pectin, acid, sugar and water. The use of sugar and additional cooking tends to increase the BOD of waste water compared with most other fruit processing. The presence of natural or added pectin in the waste water may have an adverse effect on solids settling.
8.4 Techniques to consider in the determination of BAT

8.4.1 Techniques to increase energy efficiency

Peeling of fruit and vegetables
Peeling is described in Section. The objective of peeling is to remove the skin/peel from raw fruit and vegetables, by removing as little of the underlying food as possible but still achieving a clean peeled surface. Peeling is applied on an industrial scale to fruit and vegetables. Various methods for peeling exist and are described in the following sections. The removal of unwanted or inedible material from raw fruit and vegetables, e.g. from leeks and artichokes, is considered to be trimming (see Section 19.2.1.2). Reportedly, the cleaning water from cans and jars can be reused in peeling.

8.4.1.1 Cooling fruit and vegetables before freezing

Description
The temperature of the fruit and vegetables is lowered to around 4 °C before they enter the freezing tunnel by bringing them into contact with cold water. Water is removed from the food and then collected for reuse in the cooling process.

Technical description
The temperature of fruit and vegetables as they enter the freezing tunnel is an important factor that also determines the energy consumption of the system. The lower the temperature, the lower the cooling load and the lower the energy consumption.

The temperature of the fruit and vegetables can be lowered by bringing them into contact with sufficiently cold water for a sufficient time. This is generally the cooling step after blanching. If the ambient temperature of the water is above 4 °C, an ice-water trough can be used to cool the fruit and/or vegetables to 4 °C. Additionally, the circulating water in the ice-water trough can be continually cooled by fitting an additional water cooler in the ice-water trough (see Figure 8.9) or by placing an evaporator plate under the ice-water trough (see Figure 8.10). This evaporator plate is connected into the freezer system in a similar way as the heat exchanger for ice-water production. If the water is carried into the freezing tunnel it becomes frozen and adds an additional energy burden. This can be prevented by passing the food over a vibrating mesh or perforated belt which enables the water to be removed from the food and then collected for reuse in the cooling process.
**Achieved environmental benefits**
Reduced energy consumption in the freezing process.
Chapter 8

Cross-media effects
Energy consumption in the cooling process before freezing.

Environmental performance and operational data
It is reported that a reduction of the product temperature by 10 ºC results in:

- a reduction of the compressor load for cooling at -30 to -40 ºC, which reduces electricity consumption by 5 to 7 kWh/t;
- an increase in the compressor load for cooling at 0 ºC, which reduces electricity consumption by 1.5 to 2 kWh/t;
- a total reduction of the electrical load by 3 to 5.5 kWh/t.

It is also reported that, when a freezing tunnel is operating at a product flowrate of 10 t/h, then the electrical load will fall by 30 to 55 kW if the fruit or vegetable temperature is reduced from 30 to 20 ºC before entering the freezing tunnel. Furthermore, the heat transfer when the cooling is carried out with water is an order of magnitude higher than when the cooling is carried out with air. In addition, fruit and vegetables are best transported as cold and dry as possible in the freezing tunnel, in order to reduce the freezing load, and this is facilitated by draining the fruit or vegetables after immersion in the cold water.

Technical considerations relevant to applicability
Applied in the deep freezing of fruit and vegetables.

Reference literature
[ 14, VITO et al. 2001 ], [ 15, Van Bael J. 1998 ]

8.4.2 Techniques to reduce water consumption

8.4.2.1 Dry cleaning
This technique is described in Section 2.3.3.2.1.

Technical description
A reported example of where the technique is applied is to clear up spilt vegetables manually as far as possible and avoid rinsing away with water.

Technical considerations relevant to applicability
Applicable to all fruit and vegetable processing installations.

Reference literature
[ 14, VITO et al. 2001 ]

8.4.2.2 Water recycling
See also Section 2.3.3.1.1.

Technical description
In new and existing installations opportunities may exist for the reuse of water, either directly in a unit operation or indirectly as a source, e.g. either heat or cold. In existing installations in particular, such opportunities vary depending, e.g. on the unit operations undertaken, the waste water treatment facilities available on the site and the hygiene requirements for the water used on the site. It may be possible to reuse water in the same unit operation either without any treatment, or after a simple filtration.
The segregation of rainwater, wash-water, e.g. water that arises from washing raw materials and from cleaning operations, and process water, e.g. water that arises from peeling, sorting and canning, has been reported. Furthermore, water that has only been used for washing incoming products and has low emission levels of BOD can be just screened rather than undergoing full treatment. The same applies to freezer defrost water.

For example, in belt blanching with water cooling the water from the first compartment of the cooling section, i.e. immediately after blanching, which is warm, can be reused in the preheating section before blanching. In this example, heat is recovered and less water is used due to the recirculation. It is also reported that for some fruit and vegetables blanching water can be used for preliminary cleaning of freezing tunnels.

Water used for blanching and water used for cooling after blanching can be used for washing raw materials, without treatment. Water used for boiling fruit and vegetables can also be used for washing raw materials, without treatment.

Water from cooling cans and jars in fruit and vegetable preservation can be reused for cooling water after sterilisation of the cans and jars, for washing raw materials, for washing peeled fruit and vegetables, to heat cold water for use in blanching or as cleaning water.

Water from sterilisation processes can be used to prewash raw materials. If this water is heated it may affect the shelf-life of the food, by encouraging bacterial growth. Reuse of heated water for washing may depend on whether the fruit and vegetables are subjected to heat treatment later.

After biological waste water treatment and chlorination, water can be reused for cleaning floors. After biological treatment, RO and UV disinfection water can be used for uses which require drinking water standards. A reported example describes water being reused to wash salads (see Section).

**Achieved environmental benefits**
Reduced water consumption and, where heated water is reused, reduced energy consumption.

**Environmental performance and operational data**
A total of 1200 m³/day of vegetable washing waste water can be produced by a UK vegetable processing installation with up to 815 m³/day being pumped forward to an advanced MBR. Following the RO and UV disinfection stages, up to 650 m³/day can be returned back to the factory as salad washing and process water. The influent COD that is received at the balancing tank is up to 1440 kg/day, depending on the production rate [61, UK 2002].

The intensive aerobic environment created in the bioreactors, each with a design MLSS level of 15000 mg/l, combined with the high relative sludge age means that a high-quality final waste water can be achieved with a much smaller footprint. The bioreactor volume is reduced as low as 20 % of the size of a conventional treatment.

About half of the waste water after full treatment reaches drinking water quality and can be reused within the installation. The original COD of about 1500 mg/l was reduced to almost zero. The ultrafiltration biomass separation system also provides a permeate suitable for feeding directly into the RO/UV post treatment stage

**Cross-media effects**
If treatment is required before reuse, energy is consumed and chemicals may also be consumed.

**Technical considerations relevant to applicability**
Applicable in new and existing installations. Improving water reuse in existing installations, using equipment that will later be replaced with BAT, may be able to reuse water to minimise the environmental impact of the existing equipment.
Driving force for implementation
Reduced costs associated to waste water treatment and energy consumption. Water consumption and, in some cases, reduced energy consumption.

Reference literature
[14, VITO et al. 2001], [61, UK 2002], [110, CIAA 2003]

Water recovery in a vegetable processing company—A case study

Description
Because of the water shortage in groundwater resources, and due to a lack of alternative water sources, e.g., no surface water resource was available and the drinking water supply was too expensive, the following water-saving techniques were applied in a vegetable processing company:

- Reuse of treated waste water for processing operations where drinking water quality was not needed. The aerobic treatment of waste water was supplemented by a polishing step, i.e., sand filtration. As a result, the specific water consumption was reduced to 3–3.5 m³/t of product.
- Reduction of the salt content in the waste water by steam stripping.
- Increased capacity of the aerobic waste water treatment and the use of anaerobic pretreatment.

Achieved environmental benefits
Reduction in the use of water resources, reuse of waste water and reduction in the water pollution load.

Cross-media effects
High energy demand for the waste water treatment.

Environmental-performance and operational data
The installation achieved an increase in its production capacity from 17000 to 55000 t/yr in ten years. The final aim was to replace at least 50% of the raw water demand, thereby decreasing the specific water consumption below 2 m³/t of product.

The waste water treatment of the installation consists of an anaerobic pretreatment (reactor volume of 5000 m³, load of 30 t COD/d and specific load of 6 kg COD/m³/d) followed by an aerobic activated sludge plant. After sedimentation, the waste water is treated in a two-step sand filtration process with a maximum capacity of 100 m³/h. After pH correction and/or the addition of flocculants, the water is fed to the UF unit with a capacity of 40 m³/h. The UF unit is operated at low pressure (0.5–1 bar) and has hollow fibre membranes. The water is finally treated by a two-step RO technique. The retentate of the first step is fed to the second step. The RO equipment has a capacity of 20 m³/h, an operating pressure of 8–10 bar and an efficiency of 70%. Although the water is free of salts and bacteria, the water is still sterilised by UV radiation. Backwash water from the sand filters and the UF unit is recycled to biological treatment.

The typical water quality parameters of the waste water in the different treatment steps and that of fresh groundwater are included in Table.
Table: Water quality parameters of treated waste water, raw water and process water

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Waste water</th>
<th>After biological treatment</th>
<th>After polishing filtration</th>
<th>After sterilisation</th>
<th>Ground water</th>
<th>Process water*</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>mg·O₂/l</td>
<td>12000</td>
<td>114</td>
<td></td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>8.5</td>
<td>8.3</td>
<td>8.2</td>
<td>5.5</td>
<td>8.3</td>
<td>2</td>
</tr>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>16</td>
<td>4.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>mg/l</td>
<td>34</td>
<td>34</td>
<td>≤0.5</td>
<td>≤0.5</td>
<td>≤0.5</td>
<td>0</td>
</tr>
<tr>
<td>Conductivity</td>
<td>mS/cm</td>
<td>4.3</td>
<td>4.3</td>
<td>4.2</td>
<td>0.15</td>
<td>2.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Ammonia-N (NH₄⁺)</td>
<td>mg/l</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>0.17</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Iron</td>
<td>mg/l</td>
<td></td>
<td>0.03</td>
<td>0.23</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Hardness</td>
<td>mmol/l</td>
<td>1.0</td>
<td>1.0</td>
<td>≤0.3</td>
<td>≤0.3</td>
<td>≤0.3</td>
<td>≤0.3</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>mg/l</td>
<td>2.9</td>
<td>2.9</td>
<td>≤0.3</td>
<td>≤0.3</td>
<td>≤0.3</td>
<td>≤0.3</td>
</tr>
<tr>
<td>Total bacteria</td>
<td>CFU</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>E. coli</td>
<td>CFU/ml</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*1:1 mixture of groundwater and sterilised water

Table: Quality of groundwater source for a vegetable processing installation compared to WHO guidelines

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Groundwater</th>
<th>WHO guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td>8.3</td>
<td>6.5–8.5</td>
</tr>
<tr>
<td>Sulphate</td>
<td>mg/l</td>
<td>126</td>
<td>400</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>mg/l</td>
<td>552</td>
<td>250</td>
</tr>
<tr>
<td>Chloride</td>
<td>mg/l</td>
<td>550</td>
<td>250</td>
</tr>
<tr>
<td>Conductivity</td>
<td>mS/cm</td>
<td>2.5</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Economics
The drinking water cost varied between EUR 0.99–1.54/m³ and it was expected to increase because of the great demand. The cost of the process water was EUR 1.03/m³.

Driving forces for implementation
The company was using groundwater as it was bacteriologically safe. However, there were some difficulties such as:

- it had to be drawn from a depth of 300 metres
- the local groundwater levels were dropping, leading to shortages
- the groundwater had growing salt concentrations and some parameters were not meeting quality standards. Some parameters compared to WHO guidelines are shown in Table.

Example plants
A vegetable processing installation in Belgium.

Reference literature
[35, OECD, 2001]

Reuse of vegetable washing waste water after treatment—a case study

Description
A systems manufacturer has designed, built and commissioned a turnkey WWTP which enables the reuse of up to 55% of the waste water at a UK vegetable processing installation. The WWTP is based on pretreatment and aerated flow balancing, followed by an advanced MBR.
RO and UV disinfection. To effectively separate the biomass, UF is used, fed by a recirculation system from the two bio-reactor tanks. The operation is fully automated with PLC control and data logging of key process parameters, e.g. flows, dissolved oxygen, pH and temperature. An aeration and mixing system is incorporated to achieve the necessary high rates of oxygen mass transfer into the concentrated biomass.

Figure shows a diagram of a WWTP at a vegetable processing installation.

![Diagram of WWTP at a vegetable processing installation for water reuse](102, UK, 2002)

**Achieved environmental benefits**
Reduced water consumption, e.g. water is reused. Reduced waste water pollution.

**Environmental performance and operational data**

**Example plants**
A UK vegetable processing installation.

**Reference literature**
[61, UK 2002]

**Reuse of water during pea processing, after chlorination**

Microbial contamination can be controlled by the use of chlorine dioxide which is effective against biofilm at a concentration approved for drinking water, i.e. 0.5 ppm. Figure shows a diagram of a four-stage water reuse scheme at a pea cannery. The chlorination of water used for washing incoming fruit or vegetables, is not allowed in some countries. Reusing of water in processes where the water may be in direct contact with the product is also not always permitted.
8.4.3 Techniques to reduce waste

8.4.3.1 Segregation Separation of residues outputs, to optimise use, reuse, recovery, recycling and disposal (and minimise water use and waste water contamination)

This technique is described in Section 2.3.5.3.

Reported examples of where the technique is applied

There are likely to be many other opportunities to apply this technique within the sector.

- remove fine organic material when, e.g. potatoes are brought into the installation;
- restrict sorting, spillage and splash losses by fitting collecting trays, flaps and screens;
- use dry separation and collection of solids, semi-solid residues and rejected raw material, e.g. in sorting, trimming, extraction and filtration;
- separate solid organic material from the waste water of the peeling process using, e.g. sieves, filters and centrifuges, to restrict leaching;
- fit flaps and screens on conveyor belts.

Technical considerations relevant to applicability

Applicable to all fruit and vegetable processing installations.

Reference literature

[14, VITO et al. 2001]

Protected outdoor storage of fruit and vegetables

Technical description

Waste is minimized if fruit and vegetables and organic waste, such as peel and cutting waste are stored in a clear courtyard in the shade and sheltered from rain, or totally enclosed in containers. This minimises contamination and protects the food materials from harm from wet weather conditions.
Achieved environmental benefits
Reduced waste.

Cross-media effects
Storage outside can attract insects, birds and rodents.

Environmental performance and operational data
Some fruit and vegetables may be susceptible to harm from ambient high or low temperatures.

Technical considerations relevant to applicability
Applicable in all installations where raw materials and outputs need to be stored.

Driving force for implementation
Full use of the product and reduced waste.

Reference literature
[14, VITO et al. 2001]

Flame peeling

Technical description
This technique was developed for onions. A flame peeler consists of a conveyor belt which transports and rotates the material through a furnace heated to temperatures above 1000 ºC. The skin or root hairs are burned off and then removed by high pressure water sprays.

Achieved environmental benefits
Flame peeling requires heat, in contrast to other peeling operations which require electrical energy.

Cross-media effects
When flame peeling is applied, some dust and odour emissions occur.

Environmental performance and operational data
Average product losses are 9%. It is reported that red peppers used for the Spanish recipe “piquillo peppers” can only be peeled using flame peeling.

Technical considerations relevant to applicability
Flame peeling is used for peeling onions and peppers.

Reference literature
[71, AWARENET 2002]

8.4.4 Techniques to reduce emissions to air

8.4.4.1 Techniques to reduce odour

TWG, please provide information.
8.5 Emerging techniques

8.5.1 Water recycling at washing step after a O₃/UV treatment

Description
Recycling of water at washing step after an O₃/UV treatment.

Technical description
This technique describes the recycling of water in the washing step after a treatment to reduce the microbial and organic load using a sequential treatment with ozone and UV irradiation. Washing is one of the first steps of processing fresh cut vegetables in which salad is transported to a first washing tank or to a shower line where vegetables are washed with drinking water to remove debris and then directed to the disinfection tank. In the washing step, additionally to the water contained in the washing tank, there is a continuous input of drinking water to maintain the quality of the washing water, mainly in terms of microorganisms and organic load, in a way to prevent the cross-contamination along the processing period. The consumption of continuous drinking water can be between 3-6 m³/h, or even more than 12 m³/h if there the disinfection step with chlorine does not exist, as it happens in some EU countries (for example The Netherlands).

The technique involves the complete or partial recirculation of water in the washing step of processing fresh cut vegetables after an O₃/UV treatment, in order to reduce the water consumption. Washing water from recirculation tank is treated firstly with ozone, which destroys microorganisms by the oxidation of vital cell components, so that preventing microbial growth. Beside, ozone oxidizes the organic matter dissolved in the washing water, so that the organic load concentration can be maintained/reduced over time. A final treatment with UV irradiation increases the global hygienic efficiency of the system and it removes the remained dissolved ozone in the water in order to prevent any damage on minimally processed vegetable (MPV) quality and labour risks when working with open tanks. The main products of the reaction with ozone are oxygen, water and carbon dioxide. As ozone decomposes rapidly, it does not accumulate. Additionally, ozone treatment is also beneficial for the subsequent waste water treatment since it oxidizes the most part of the organic matter, reducing the COD of the final waste water. Electricity is the only input necessary for O₃/UV. Chemicals addition is not necessary for the process.

The treatment of water with O₃/UV system requires the consumption of electricity in several steps: O₂/O₃ production, O₃ dissolution in water, destruction of O₃ excess, UV treatment. Energy consumption for ozone production and effective dissolution in water is 4.59 MJ/m³ of ozonated water. However, a comparative LCA assessment developed by SUSCLEAN project showed that the increase of energy consumption due to O₃/UV treatment is compensated by a reduction of the electricity consumption associated to the supply of process water consumption (pumping of water, water treatment, water cooling) and reduction of energy consumption in waste water treatment.

Achieved environmental benefits
Reduction of water consumption.

Environmental performance and operational data
This technique was tested in the SUSCLEAN project at pilot plant scale obtaining good environmental results.

The recirculation of water at the washing step of processing fresh cut vegetables after an O₃/UV treatment achieved a reduction in water consumption around 22 %, while the hygienic level of the washed water remained in a time period of 90 min.

Ozone reduces the organic matter content in the washing waste water (analysed as COD) in 35 %. Ozone and UV treatment also has effect on the degradation of pesticides. In the...
Experimental test, the concentration of orthophenylphenol was reduced to values lower than 0.1 mg/l.

**Technical considerations relevant to applicability**

Due to its oxidant properties, ozone may react with some materials and lead to corrosion on equipment and facilities. The compatibility of the existing materials should be checked to allow for changes if necessary.

**Economics**

The investment for a complete system (ozone generator, hydrokinetic mixer, contact tower, ozone in air destructor, UV system, ozone monitoring) of O$_3$/UV for treating 4 m$^3$/h of water with an ozone concentration of 12 ppm with a retention time of 2.5 min can be around EUR 70 000.

Operational costs will depend on the local price of electricity, supply water and the cost of waste water treatment and waste water taxes.

**Reference literature**

[ 231, SUSCLEAN 2015 ]

8.5.2 Using NEOW as an alternative to conventional sodium hypochlorite for disinfection of salads

See also Section 2.4.2.

**Description**

Application of neutral electrolyzed oxidizing water (NEOW) as an alternative to conventional sodium hypochlorite for disinfection of salads.

**Technical description**

This technique involves the implementation of NEOW in the decontamination step of food products to replace the conventionally used sodium hypochlorite aimed to efficiently reduce the microbial load on food products with focus on the minimally processed vegetable (MPV) industries while minimising the chlorine input as well as the residue free available chlorine in the waste water.

NEOW is obtained by electro dialysis of a diluted salt solution. This electro dialysis results in the formation of two streams. At the anode side an acid solution consisting of hypochlorous acid and hydrochloric acid is being produced whereas an alkaline solution forms at the cathode side consisting of sodium hydroxide. Additionally, depending on the applied voltage, oxygen and chlorine gas (anode side) as well as hydrogen gas (cathode side) may occur.

The effective component of the electrolyzed oxidizing water is the hypochlorous acid (HOCl), which is generated at the anode side (acid solution) and mainly known for its good disinfectant properties. As a strong oxidizing agent, HOCl penetrates the cell wall of the microorganisms and disrupts the membrane transport proteins, the consequence being that the protein synthesis inside of the cell is disrupted.

**Achieved environmental benefits**

The main potential environmental benefits to be gained through the implementation of NEOW in decontamination and sanitation processes in the MPV industry is the decomposition of the NEOW back into sodium hydroxide. Thus an additional activated carbon treatment of the waste water can be omitted and the waste water may be fed directly into a municipal sewage treatment plant.
NEOW is expected to exhibit easier control and measurement possibilities, allowing a more efficient dosage and thus decrease the material input.

**Cross-media effects**
Due to the production by electrolysis, the application of NEOW has a higher electrical energy demand in comparison to the application of sodium hypochlorite.

The NEOW production requires the consumption of salt (NaCl). The non-optimized feed rate of salt used in the initial industrial scale test conducted in the framework of SUSCLEAN project was 0.21 kg NaCl/l NEOW. However this rate needs to be optimized with further industrial tests. The addition of NaCl for NEOW production increases the electrical conductivity of the waste water, which depends on the rate of salt consumed.

Furthermore there is the risk of the occurrence of chlorine gas at the cathode of the electrolysis cell if an incorrect voltage is applied.

**Environmental performance and operational data**
Operational data have been reported from the NEOW tests in the framework of SUSCLEAN project:

- Electrical consumption of the NEOW generator per day: 4.32 kWh
- Maximum free available chlorine concentration reached: 29 ppm
- Production rate: 0.7 l/min
- Sodium chloride intake: 0.21 kg NaCl/l NEOW

**Economics**
Operational cost could be such as EUR 850 per month. Operational cost generally depends on the local price of electricity, supply water but also the cost of waste water treatment and waste water taxes.

**Reference literature**
[231, SUSCLEAN 2015]
Chapter 9

9 GRAIN MILLING

9.1 General information about the sector

Leading food European industry in grain processing is the flour milling industry, using around 45 million tonnes of soft wheat and rye a year to produce around 35 million tonnes of flour on an annual basis (EU-27). The number of flour milling company exceeds 3 800, of which a large majority are small and medium-sized companies. The industry employs about 45 000 people and represents a turnover of EUR 15 billion. The average use of capacity is about 65% [221, European Flour Millers 2016].
9.2 Applied processes and techniques

There are a number of cereals important as food sources. These include wheat, barley, maize, oats, rye and rice. Wheat and rye grain is milled into flour. Durum wheat is milled into semolina and is generally used to make pasta. Wheat is the prime ingredient used in the manufacture of products such as bread and biscuits. In some countries, rye is used for bread. Barley is mainly used for animal feed. Barley of a certain quality is processed to malt and then used, e.g. in brewing and distilling. Maize is used as a source of starch but also as an ingredient in breakfast cereals and snack foods. Oats are used for cereals, cakes, biscuits, and also for making crispbread. Rice, along with wheat and maize is one of the major cereals of the world and is the basic food for much of the world’s population. Rice is pearled and sometimes precooked.

The wheat grain has three main components, the skin or bran, the embryo or germ, and the endosperm, which makes up the majority of the grain. The object of the milling process is to separate the endosperm with minimal contamination from the bran and germ. The main operations associated with flour milling are cleaning, conditioning, breaking, scalping, purification, reduction and dressing.

The incoming grain is transferred to bulk silos prior to further processing. Gas or heat treatment may be applied to prevent insect infestation. The grain is first washed by passing through a series of screening, scouring, brushing and aspiration operations. These processes remove extraneous matter such as other cereals, stones, metal contaminants, chaff, loosened bran layers, seeds and dust. After washing, the grain is conditioned to optimise the milling process. This involves dampening the grain by the measured addition of water, which immediately binds the kernels. Conditioning may be made by using steam. Conditioning has a number of functions, such as toughening the bran, and thereby improves the separation of the bran from the endosperm, allowing the endosperm to be reduced more effectively in subsequent stages of the process.

The conditioned grain enters the break system of the mill, which consists of pairs of corrugated rollers which revolve in opposite directions and at different speeds. Five sets of break operations are common, with the aperture gradually decreasing and the corrugation becoming finer between subsequent sets. The grain is split by the break-rollers and the endosperm is scraped from the bran. A screening operation known as scalping or grading is carried out after each break-roller. This operation separates:

- coarse particles which contain the remains of the grain and some endosperm which is yet to be recovered
- particles of intermediate size which contain chunks of endosperm which are called semolina or middlings, depending on their particle size and purity
- flour.

The semolina or middlings pass through a purification system consisting of sieving and air classification. This removes particles of endosperm with bran adhering for further treatment by finely fluted rollers elsewhere in the process. The semolina or middlings are then transferred onto reduction rollers, which are smooth and whose purpose is to crush the endosperm. As in the break section of the mill, there are a series of rollers and screening operations, so that flour is screened off whilst the coarser endosperm, retained on the sieves, passes to another set of reduction rollers to be further reduced in size. At the end of the reduction process, most of the endosperm will have been converted to flour, the coarse bran will have been removed and there will be a third stream of endosperm consisting of material containing fine bran which cannot be practically separated. There could be as many as 12 reduction stages in the process. Flour is normally passed over a final redresser at the end of the milling process or after bulk storage to remove any residual foreign bodies. Flour may be dried and classified by sieves into fractions. Practice varies in different MSs, e.g. in the UK, 25 % is bagged for delivery to bakers and other food manufacturers and 70 % is delivered in bulk, whereas in Portugal, the proportions are almost identically opposite.
Grains such as oats and barley, with a tightly adhering husk cannot simply be separated in a traditional wheat mill and are usually subjected to an abrasion process called pearling prior to milling.
Chapter 9

9.3 Current consumption and emission levels

9.3.1 Energy consumption

Figure 9.1 shows data on specific energy consumption (MWh/tonne of product) in various grain milling installations.

![Energy Consumption Chart]

Source: [193, TWG 2015]

Figure 9.1: Specific energy consumption (MWh/tonne of product) in grain milling

9.3.2 Water consumption

Figure 9.1 shows data on specific water consumption (m³/tonne of product) in various grain milling installations. It should be noted that no related techniques have been reported.

![Water Consumption Chart]

Source: [193, TWG 2015]

Figure 9.2: Specific water consumption (m³/tonne of product) in grain milling
9.3.3 Emissions to air

9.3.3.1 Dust emissions

Bag filters are predominantly used for the treatment of dust emissions to air from the grain milling process. The most relevant emissions sources are the milling process itself, raw materials cleaning and transportation. A general overview of the data received for dust emission from the grain milling process is shown in Figure 9.3.

Figure 9.3: Total dust emissions to air from the grain milling process

The meaning of the symbols used in Figure 9.3 is indicated in Table 3.5.
9.4 Techniques to consider in the determination of BAT

9.4.1 Techniques to reduce emissions to air

9.4.1.1 Techniques to reduce dust emissions from the grain milling process

9.4.1.1.1 Bag filter

A general description of the technique is given in Section 2.3.7.2.2.

Environmental performance and operational data
Table 9.1 shows installation-specific performance data related to the application of bag filters for abating emissions to air from grain milling processes.

Table 9.1: Total dust emissions to air the grain milling process after treatment in a bag filter

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>O₂ content (%) dry basis</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>263-12</td>
<td>&lt;0.30</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Wheat processing</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Milling process</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Tubular filter</td>
</tr>
<tr>
<td>432-12</td>
<td>0.10</td>
<td>NI</td>
<td>Micro dust meter</td>
<td>Yearly</td>
<td>Wheat processing</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Milling process</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Medium Pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reverse Jet Filter</td>
</tr>
<tr>
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<td>NI</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Wheat processing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Milling process</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tubular filter</td>
</tr>
<tr>
<td>333-3</td>
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<td>20.9</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Wheat processing</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Debraining</td>
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<td></td>
<td></td>
<td></td>
<td>general aspiration</td>
</tr>
<tr>
<td>432-6</td>
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<td>NI</td>
<td>Micro dust meter</td>
<td>Yearly</td>
<td>Wheat processing</td>
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<td></td>
<td></td>
<td></td>
<td>Flour blending</td>
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<td></td>
<td>Medium Pressure</td>
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<td></td>
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<td>Reverse Jet Filter</td>
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<td>Once every three years</td>
<td>Wheat processing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Wheat cleaning</td>
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<td>Tubular filter</td>
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<td>334-1</td>
<td>0.90</td>
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<td>Wheat cleaning</td>
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<td>Yearly</td>
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<td></td>
<td>Wheat cleaning</td>
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<td>20.90</td>
<td>EN 13284-1</td>
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<td>Wheat processing</td>
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<td></td>
<td></td>
<td>Wheat cleaning</td>
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<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Wheat processing</td>
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<td></td>
<td>Flour transfer</td>
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<td>21.00</td>
<td>NI</td>
<td>Twice a year</td>
<td>Wheat processing</td>
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<td></td>
<td>Reception silo</td>
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<td>2.00</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>Wheat and rye</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>processing</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Milling process</td>
</tr>
</tbody>
</table>
### 9.4.1.1.2 Cyclone

A general description of the technique is given in 2.3.7.2.3.

#### Environmental performance and operational data

The application of cyclones to abate emissions to air from the grain milling process is not reported so often in comparison to the application of bag filters. Moreover, dust emission levels from a cyclone are generally higher those from a bag filter.

Table 9.2 shows installation-specific performance data related to the application of bag filters for abating emissions to air from grain milling processes.

**Table 9.2: Total dust emissions to air from the grain milling process after treatment in a cyclone**

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>O₂ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
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<td>7.70</td>
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<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Wheat processing flour transfer moist waste gas</td>
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<td>218-4</td>
<td>12.81</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>Wheat processing semolina mill cleaning</td>
</tr>
<tr>
<td>218-6</td>
<td>15.39</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>Wheat processing pruning machine</td>
</tr>
</tbody>
</table>

NB: NI = no information provided

Source: [193, TWG 2015]
9.5 Emerging techniques

TWG, please provide information.
10 MEAT PROCESSING

10.1 General information about the sector

Processed meat (cooked, cured, canned, etc.) constitutes the largest and most dynamic part of EU meat consumption. It is a market with added-value and opportunity for marketing and innovation in product development, packaging and branding. The products are convenient (many do not require cooking), they can be present at most meal occasions and they can appeal to both the older and the younger consumer.

Modern retail is the main outlet for processed meat distribution. It represents nearly 84% of European processed meat retail sales. However, products, brands and merchandising differ enormously from one retail chain and one country to another. Counter-service sales can vary from as little as 6% of sales in the UK to around 70% in Italy. While the presence of fresh-prepack is growing, traditional stores are still important outlets for processed meat in many countries.

The meat processing sector represents the downstream part of the meat production value chain. It consists of all the activities related to the production of meat preparations and meat products. The sector is composed of more than 24,000 companies in the EU-28 for a total production value of EUR 86 billion. It employs more than 421,000 people, being one of the largest number for the whole EU food processing industry [253, Clitravi-Avec 2016].

The EU meat processing sector is characterized by a majority of SMEs (90%) with a high level of specialisation operating independently at different stages of the supply chain. This is particularly the case for the pig meat and beef meat sectors. Larger vertically integrated companies (owning slaughterhouses, processing facilities and storages), in terms of numbers, represent a small share of all companies operating in the EU meat processing industry and tend to be more prevalent in the poultry sector.

The EU-28 meat production based on the 2014 slaughtering statistics was as follows: pig meat was the most significant meat category, over 22.1 million tonnes were produced, 51% of annual production of all meats; followed by poultry meat with 13.0 million tonnes (30%). Bovine meat production totalled 7.3 million tonnes (17%) and the meat from sheep and goats together accounted for only 0.8 million tonnes, around 2% of all meat [239, Eurostat 2016].

Growth in world meat consumption is driving changes in EU meat production, which is expected to increase only slightly in the next 10 years, to 46.5 million t. Population and economic growth in developing countries, albeit slower than in the previous decade, are expected to support higher meat demand and contribute to growth of EU meat exports. World meat consumption is expected to increase by 1.4% a year between 2015 and 2025, slower than in the previous decade (2.1%), to 358 million t. In 2014, EU meat consumption was 66.3 kg per capita. Figure 10.1 shows the total meat consumption in the EU for the period 2000–2024 [219, COM 2015].
Chapter 10

The consumption of meat products is not expected to rise over the coming years, due to growing social concerns (animal welfare and carbon footprints), health concerns and an ageing European population (eating less meat per capita). Some of these factors serve to favour poultry over other meats [219, COM 2015].

In the following lines some further data are given by type of processed meat [253, Clitravi-Avec 2016].

**EU poultry meat processing industry**

In 2013 the production of poultry meat in EU-27 was almost 12.9 million tonnes. In the poultry meat supply chain, different companies are involved in supplying and slaughter/processing. Poultry is slaughtered in slaughterhouses and the meat is further processed into consumer products in processing companies.

In 2012, the total production of poultry meat was 12.9 million tonnes with a value of EUR 24.6 billion. However, this is the economic output of the primary sector and slaughterhouses only. No official data is available on the total production value of poultry after further processing, however, according to estimations the value is 30 % higher after processing. Based on that, the total production value of poultry meat in the EU-27 in 2012 would amount EUR 32 billion, meaning that the EU further processing poultry meat sector can be estimated at EUR 7.4 billion.

**EU bovine meat processing industry**

In terms of value, bovine animals represent 8.1 % of total agricultural output and 18.8 % of animal output, without taking animal products (e.g. milk) into account. In Europe, more than two third of the bovine meat is supplied by the dairy herd.

The EU consumes about 7.8 million tonnes of beef each year (both fresh meat and processed meat), with the key high value cuts segment of the market amounting to about 500 000 tonnes. Currently imports into the EU amount to over 300 000 tonnes and the import requirement in the coming years is not predicted to go much beyond 400 000 tonnes.
EU Pig meat processing industry

Pig meat represents 9.0 % of the total EU agricultural output. As already highlighted, pig meat is the major type of meat produced in the EU-28.

The EU pig meat sector has the largest share of processing compared to other meat sectors. In total, an estimated 70% of the EU processed meat production volume is made of pig meat.

EU sheep and goats meat processing industry

Sheep and goat meat represents 1.4 % of the total EU agricultural output. The overall contribution of goat meat to the EU-28 meat production is modest (0.1 %) and is concentrated in seven EU Member States representing 95.6 % of the total EU goat meat production. The EU sheep sector has witnessed downward pressure on production over recent years with reductions in flocks and pressure on income. However, it is expected that over the coming years, demand on the European market will outstrip production levels, which could provide opportunities for exporting countries.

While the main consumer demand is oriented to fresh meat, added-value product areas include irradiated products for microbial safety, precooked products for convenience, portioned and institutional items for uniformity, and nutritionally enhanced meat for healthfulness.
10.2 Applied processes and techniques

10.2.1 General overview

Pork, poultry and beef are the main types of meat processed in Europe. The activities of the meat sector can be divided into three areas, slaughtering (covered by the Slaughterhouses and animal by-products BREF [93, COM 2005]), meat cutting and further processing. For the scope of this BREF the slaughtering activity is considered to end with the making of standard cuts for large animals and cuts for poultry.

Meat processing technology comprises the steps and procedures in the manufacture of processed meat products. These treatments go beyond the simple cutting of meat into meat cuts or meat pieces with subsequent cooking for meat dishes in order to make the meat palatable and involves a wide range of methods. Table 10.1 shows a brief description of the typical processes applied in the meat sector.

Table 10.1: Typical processes applied in FDM meat processing installations

<table>
<thead>
<tr>
<th>Process</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boning</td>
<td>Separation of meat, bones and fat—typical done at the slaughterhouse as a manual or a semi-manual process. In the boning-process, primary cuts are separated in muscles and meat/fat mixes (mixes with different meat/fat content e.g. 50/50 (%)). Typical a meat processing installation buys the specific cuttings/muscles and meat/fat mixes needed for the planned production.</td>
</tr>
<tr>
<td>Cut, trimming</td>
<td>Cutting / dicing / trimming of meat/muscles according to the size and shape needed for the specific product. Cut off parts are used in other products / for minced meat etc.</td>
</tr>
<tr>
<td>Fat standardization</td>
<td>Measuring of fat content of meat/fat and mixing of different batches to obtain the fat content required according to the recipe for the product.</td>
</tr>
<tr>
<td>Mixing</td>
<td>Mixing of meat and auxiliary materials. Typical mixing of minced meat and auxiliary materials.</td>
</tr>
</tbody>
</table>
| Salting, dry salting, vessel salting, injection | Adding salt to the product:  
• Dry salting; storing meat pieces I dry salt until the needed degree of salting is obtained.  
• Vessel salting; storing the meat in brine until the needed degree of salting is obtained.  
• Injection of brine to the product, typical followed by tumbling to obtain uniform distribution of salt in the product. |
| Marinating                       | Adding marinade to the product.                                                                                                                                                                                    |
| Tumbling                         | Tumbling of the product to ensure a uniform distribution of salt/marinade in/at the product.                                                                                                                          |
| Mincing                          | Mincing/chopping of the meat using meat grinders / meat mincers reducing the size of the meat particles from 1 to 2 centimetres, and bowl choppers / meat cutters for further reduction of the particle size. In bowl-choppers and meat-cutters, auxiliary materials can be added during the process. |
| Emulsification, production of minced meat | Final mixing of the minced meat and auxiliary materials using meat emulsifier. Grinder function can be included for further reduction of the size of the meat particles.                                                                 |
| Forming                          | Forming of minced meat to meatballs, burgers etc.—a continuous and automated process. Putting products into forms, typically a manual or semi-automated process.                                                            |
| Filling cans and autoclaving     | Comprises the following process steps:  
• Cleaning of cans before filling  
• Filling of cans                                                                                                                                                                                                   |
<table>
<thead>
<tr>
<th>Process</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filling sausages/ Stuffing sausages</td>
<td>Filling of sausage meat into casings.</td>
</tr>
<tr>
<td>Breading</td>
<td>Coating the product with breading or batter typically before deep-frying.</td>
</tr>
<tr>
<td>Wrapping</td>
<td>Wrapping of products in sausage meat e.g. Scottish eggs or wrapping of the filling/stuffing in spring rolls etc.</td>
</tr>
<tr>
<td>Baking</td>
<td>Heat treatment of products in an oven the baking process can be either a batch process, or a continuous process in a tunnel oven.</td>
</tr>
<tr>
<td>LTLT/sous vide heat treatment</td>
<td>LTLT: Long Time Low Temperature Sous vide: (vacuum) Vacuum packing of product followed by heat treatment in hot water bath. Packed meat/products are immersed into hot water of approx. 55 to 70°C for a long time (hours / several hours). Using of the LTLT/sous vide-process reduces product loss during heat treatment compared to normal heat treatment. Heating and the following chilling can be performed in the same vessel or in two vessels one for cooking and one for cooling.</td>
</tr>
<tr>
<td>Cooking</td>
<td>Cooking of products, immersed into water or by saturated air heated by steam. Cooking can be made in batch cookers or in continuous cookers.</td>
</tr>
<tr>
<td>Deep-fry</td>
<td>Frying in heated oil bath. The products are placed on a conveyor and transported through a bath of heated oil.</td>
</tr>
<tr>
<td>Belt frying</td>
<td>Frying between to heated belts one under and one un top of the product. By using belt-frying equipment the products looks like product produced on a frying pan.</td>
</tr>
<tr>
<td>Hot smoking</td>
<td>Smoking adds flavour and colour to the product. Smoking is done in cabinets (batch process). Smoke can be produced by controlled burning of wood (hardwood) or by friction between the wood and a metal wheel. For some products but only if it is accepted by the market hot smoking can be substituted by liquid smoke added by spraying (liquid smoke is produced on basis of condensed smoke).</td>
</tr>
<tr>
<td>Cold smoking</td>
<td>Smoking by adding cold smoke. Controlled burning of wood (hardwood) typically produces the smoke.</td>
</tr>
<tr>
<td>Fermentation, maturing</td>
<td>Fermentation of meat products using natural starting culture present in the product or starting culture added to the product.</td>
</tr>
<tr>
<td>Drying</td>
<td>Removal of water from the product. The process can take place in a climate camber where temperature and air humidity are controlled.</td>
</tr>
<tr>
<td>Cooling after heat treatment</td>
<td>Cooling–removal of heat from the product. Further description in next chapter.</td>
</tr>
<tr>
<td>Freezing</td>
<td>Freezing – for preservation of the product. Further description in next chapter.</td>
</tr>
<tr>
<td>Shell freezing</td>
<td>Freezing the outer layer of the product before slicing. To optimize the slicing process and to reduce product loss.</td>
</tr>
<tr>
<td>Slicing</td>
<td>Slicing of larger pieces of products. Prior to the slicing shell freezing can be used to ensure uniformity of the slicing and reduce product loss during the slicing. Slicing is typically followed by packing–consumer packing or bulk packing.</td>
</tr>
<tr>
<td>Packing, consumer</td>
<td>Packing and labelling of products for supermarkets.</td>
</tr>
<tr>
<td>Bulk packing</td>
<td>Packing of products to be used in other production installations.</td>
</tr>
</tbody>
</table>

Source: [220, Clitravi-Avec 2016]
More in detail, cutting is a size reduction of large to medium sized parts of food material. For cutting, knives, blades, cleavers and circular or straight saws are used. These are all electrically operated. Carcases are cut into retail cuts of joints by the removal of bone, skin and fat. After cutting the meat, the fresh meat may be stored and dispensed under refrigeration. It can be sold in portions, or it may be combined with other products. Special derinding machines are used for separating rind and fat from pork carcases.

The further processing of meat into, e.g. ham, bacon and sausage, is primarily carried out for preservation purposes but it is also important for taste. In the meat sector, raw meats, either whole muscles or altered meat particles, are restructured to the predetermined product characteristics.

For coarse-ground products, the meat particles are substantially reduced and then restructured back into a different physical form. The goal of muscle product processing is to keep an original intact tissue appearance in the finished product. Products, such as ham, roast beef, and turkey breast, are produced from whole muscles or sectioned muscles. An emulsifying process forms a matrix in which the fat particle is encapsulated with the protein membrane.

Grinding reduces particle size, and mixing assures uniformity of chemical composition as well as protein extraction. Chopping also reduces particle size and produces salt-soluble protein. Major processing equipment includes injectors and massagers for muscle products, grinders and mixers for coarse-ground products, and choppers and emulsifiers for emulsified products. Injecting and massaging processes facilitate brine distribution and protein extraction.

Preservation involving heat, e.g. cooking or frying, and dehydration produces foods that can be packaged and kept for an extended time at appropriate storage conditions. Preservation techniques such as fermentation, smoking, and brining/curing/picking are used to diversify the market selection. All these processes offer a limited extension of the shelf-life by altering the environmental conditions which supports microbial growth.

Smoking is the process of cooking, preserving or flavouring food by exposing it to smoke. There are two types of smoking. Hot smoking is typically carried out at 65–120 °C and can be used to fully cook foods. Hot smoking uses smoke generated from burning and smouldering wood. Cold smoking is typically carried out at 30–55 °C and is generally used to preserve or flavour foods. Cold smoking uses smoke generated from smouldering wood, smoke condensates (liquid smoking), friction and superheated steam. The different methods used for smoke generation are described in Table 7.2. The VOC content in the smoke depends, to a large extent, on the method of smoke generation. The method influences emissions and thus the need for air cleaning. The type of smoke chosen determines the flavour achieved.

The injection under pressure of a solution containing brining/curing/pickling ingredients is a widely used technique for extending the life of meat. The ingredients used are common salt, i.e. NaCl, often with sodium or potassium nitrite and other materials to impart special characteristics. This process is required for whole products such as ham, shoulder, bresaola and turkey. Traditional injection in-vein has ceased and today the technique uses multi-needle injectors, which allow a higher productivity and a major spread of pickle. The injector injects a predetermined dose of pickle containing different additives and ingredients, such as salts, polyphosphates, ascorbate, caseinate, nitrate, nitrite, glutamate and spices inside the ham or shoulder mass.

After the injections, a process which allows complete homogenisation of the ingredients and of the additives into the product takes place. This process also allows the extraction of a pronoucious/saline fluid from the meat with binding effect. It involves massaging the meat inside a container turning around a vertical or inclined axis in a continuous or intermittent way, under vacuum and/or at a refrigerated temperature. Brining/curing by dry salt is required for the production of cured uncooked ham, bacon, and coppa. The latter two products can be also made in the massaging machine.
Raw meats, after these preparation processes, are stuffed into casings to form a defined geometric shape and size. During these processes, rheological properties are critical to the equipment performance and final product quality.

To recover fat from meat residues, wet melting or dry melting is used. In the wet melting process, the raw material is heated in a process kettle by direct steam injection to a temperature of about 90 °C. This results in a watery phase and a fat containing phase. The phases are separated by decantation and centrifugation. In the dry melting process, the raw material is indirectly heated in the processing kettle (a kettle with a steam jacket). All the water which evaporates is removed from the kettle under vacuum. The liquid phase or molten fat and the dry phase or fat-free meat residue are separated by decantation.

The meat sector is very diverse in terms of its products due to specific local tastes and traditions. A typical list of products of FDM meat processing installations is as follows [220, Clitravi-Avec 2016]:

- dried meat;
- dried ham;
- salted meat;
- smoked, salted meat;
- cooked sausages;
- sausages, without heat treatment;
- salami;
- cooked ham, restructured ham etc.;
- canned meat;
- canned minced meat;
- pâtés and liver paste;
- cut out meat, fresh;
- cut out meat, frozen;
- enhanced pieces of meat, fresh;
- enhanced pieces of meat, fried;
- minced meat, fresh;
- meat balls;
- burger patties, fresh;
- burger patties, frozen;
- deep-fried meat balls, cooled;
- deep-fried meat balls, frozen;
- bell fried meat balls, cooled;
- bell fried meat balls, frozen;
- LTLT (Low Temperature Long Time) treated pieces of meat etc.;
- LTLT treated minced meat products;
- soup and bouillon;
- cooled ready-cooked meal;
- frozen ready-cooked meal;
- chicken nuggets;
- pies (pâté en croute etc.);
- other meat preparations fresh;
- ground meat mixture;
- breaded products;

A general overview of the main processes applied for different meat products is shown in Table 10.2.

However, three processes commonly used are canned meat, cooked ham, and cured ham production.
<table>
<thead>
<tr>
<th>Process</th>
<th>Dried meat</th>
<th>Dried ham</th>
<th>Salted meat</th>
<th>Smoked, salted meat</th>
<th>Cooked sausage</th>
<th>Sausages, without heat treatment</th>
<th>Salami</th>
<th>Boiled ham, restructured ham etc.</th>
<th>Canned meat</th>
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<td>Fermentation, maturing</td>
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Table 10.2: General overview of processes applied for different meat products
<table>
<thead>
<tr>
<th>Canned minced meat</th>
<th>Boning</th>
<th>Cutting, trimming</th>
<th>Fat standardisation</th>
<th>Mixing</th>
<th>Salting</th>
<th>Marinating</th>
<th>Tumbling</th>
<th>Mincing</th>
<th>Emulsification, production of minced meat</th>
<th>Forming</th>
<th>Filling cans and auto-claving</th>
<th>Filling sausages</th>
<th>Stuffing sausages</th>
<th>Breeding</th>
<th>Wrapping (in sausage meat)</th>
<th>Baking</th>
<th>TTVL vacuum heat treatment</th>
<th>Cooking</th>
<th>Deep-frying</th>
<th>Belt frying</th>
<th>Hot smoking</th>
<th>Cold smoking</th>
<th>Fermentation, maturing</th>
<th>Drying</th>
<th>Cooling after heat treatment</th>
<th>Freezing</th>
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**Chapter 10**

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"x": process applied
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Source: [220, Clitravi-Avec 2016]
Canned meat (beef muscle in gelatine)

Different raw materials, such as cooked or uncooked, chilled or frozen meat may be used to produce canned meat. A general flow sheet is presented in Figure XX.

**Thawing (A.5)**
Frozen meat is generally transported in plastic bags inside a cardboard secondary packaging. Meat is stored at a temperature below -18 °C. Thawing can be achieved with air at a controlled temperature, or by an intermittent shower, or by immersion into running water. The two first methods allow a reduction in water consumption, but require longer times and larger surface areas. Moreover, the meat surface may be dried and its unsaturated fats, e.g. in pork, may be oxidised. When thawing in a water bath, the unpacked meat is put in iron crates and completely immersed in water at 15 to 18 °C. The water consumption is about 3–5 m³/t.

**Cutting (B.1)**
Fresh meat is trimmed to remove excess fat and may be deboned. About 12 % of by-products are produced in this step.

**Mixing/blending (B.2)**
Gelatine is prepared from industrial powder. It may come from the broth obtained during meat cooking if uncooked raw meat is used in the installation. Cooking one part of meat with one part of water gives 0.7 parts of cooked meat and 1.3 parts of broth. The broth is then filtered, boiled until the insoluble proteins precipitate, centrifuged, and filtered again. Finally, about one part of gelatine is produced. Ingredients, such as thickeners and flavours are added to the gelatine solution.
Packing and filling (H.1)
The gelatine is de-aerated and dosed in cans by a vacuum filler already containing the required part of meat. The cans are then sealed and washed with hot water to remove meat or gelatine residuals.

Sterilisation (E.8)
Cans are put in metal baskets and then sterilised in autoclaves, either in batch or continuous retorts, before being cooled.

Secondary packaging (H.1)
The cooled and dried cans are sent to be secondary packaged using cardboard boxes or bundles with a cardboard base and having a thermo-retractable wrap.

Refrigeration (U.5)
The product has a long shelf-life and does not need special care, apart from a good aeration to avoid condensation on the cans which may damage their external surfaces.

Cooked ham
The preservation of meat by cooking is used for several products, such as sausages, dressed pork and mortadella. The general process is shown in Figure XX.

Source: [54, Italian contribution 2001]

Figure XX: Cooked ham and shoulder production
First the material is received and then sorted.

Thawing (A.5)
This is similar to the canned meat process. In the production of whole hams or shoulders, the meat is held in a coldroom for 18 to 24 hours, to achieve a uniform temperature inside the meat. Losses can occur due to the dripping of meat juice.

Cutting (B1)
Ham and shoulders are manually (in an open or closed way) or mechanically (via a closed way) deboned, and degreased.

Pickling (D.7)
Pickle injection was traditionally made “in-vein”, however, nowadays it is achieved with multi-needle injectors leading to a higher productivity and a more uniformed distribution. The injector injects a predetermined dose of pickle containing different additives and ingredients, e.g. salts, polyphosphates, ascorbate, caseinate, nitrate, nitrite and glutamate, inside the ham or shoulder mass.

Homogenisation (B.2)
Massaging or churning allows the complete homogenisation of the ingredients and of the additives into the product, and it also allows the extraction of a proteinous/saline exudate with a binding effect. This process involves massaging the meat inside a container, which turns round a vertical or inclined axis in a continuous or intermittent way, under vacuum and/or low temperature.

Cooking (E.3)
After moulding, the product is de-aerated and cooked and/or smoked. The cooking can be carried out in a water bath, shower, steam or hot air ovens. Water bath ovens are used for whole meat products. However, a lot of water and energy is needed, major weight loss and water pollution occurs due to the leaching of meat, but the heat transfer is homogenous. Shower ovens provide good heating uniformity and use less water and energy. Steam ovens provide a moist humid heat, where food is cooked in a gentle environment to retain its flavour and moisture. Air ovens require humidity control.

Ham may also be re-moulded and then cooled. Moulds are removed and cleaned. Ham and shoulders are normally trimmed and may be sprinkled with flour to improve the look. Packing is normally carried out under vacuum.

Cured ham
Cured ham products, such as Parma from Italy, or Serrano from Spain have a good reputation because of their high quality. They are normally made of special and standard quality raw meat, e.g. typically Italian cured hams are made from 10 to 12 months old pig haunches of 150 to 180 kg weight. A similar process is used for other products, such as salami, dry sausages, and brawn. The general process is shown in Figure XX.
Sorting, thawing, cutting and trimming, are all similar to the above described processes. Depending on the cuts, a partial peeling may be needed, e.g. for hams and bacon, as well as vein squeezing.

**Brining/curing (D7)**

Curing with dry salt is specific to the production of ham and bacon and can be carried out in the churn. The main component of the curing salt is normally NaCl. Its concentration in end-products has decreased from about 6% to less than 2%. Nitrites may be used as a preservative against *Clostridium botulinum* and other spoilage bacteria but they also impart palatability and appearance characteristics, namely a specific taste, texture, and pink colour. Only a small amount of residual nitrite, usually <10 ppm, remains in modern cured meats.
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**Ageing (D.14)**

Ham spends long periods of time curing under strictly controlled conditions, e.g. temperature and air humidity. In the past, ageing could take one or more years, but today, with improved technology and modern processing installations along with old family secrets, a fully cured country ham can be produced within 6 to 12 months.

**Washing (A.4)**

Salt and meat residuals are removed by brushing and washing. This step produces a significant amount of waste containing fats, proteins and salt. Before washing, it is better to trim the area round the thighbone head and to cut the hip.

**Coating (D.13)**

Before drying, hams are checked and then coated and transported to the drying chambers. Coating comprises covering the muscular part of the pig legs with pork fat or a mixture of fat and salt, pepper and flour, which has been previously sterilised. The ham then remains in these large rooms for several months, up to one year. The humidity and temperature in the room are controlled.

**Packing (H.1)**

With some products, the bones are removed before packaging. Other usually more traditional products are sold with the whole pig leg.

**Gas flushing (H.2)**

As well as traditional methods, gas flushing is also often used for packing hams.

### 10.2.2 Cleaning

Cleaning occurs in three situations at meat processing installations: cleaning during production, cleaning between production batches and cleaning after production [220, Clitravi-Avec 2016].

**Cleaning during production**

Cleaning of production area. Collection of spills on floors to ensure safe working conditions and reduce spreading of spill. Hosing with water if needed.

**Cleaning between production batches**

Cleaning of production equipment. Cleaning to remove product remains from the production line before starting a new production batch to ensure 100% compliance with product specifications. The need for cleaning and the extent of the cleaning is affected by the sensitivity of the succeeding product. Effective planning of the sequence of the individual batches can reduce the need for cleaning between batches—but usually does not eliminate that need.

**Cleaning after production**

Cleaning of the production area and equipment after production. Cleaning starts as soon as production ends. The cleaning procedure consists of the following steps:

- preparation: tidying the area, removing waste, gloves etc. Ideally, operators remove and collect solid waste before applying water;
- first rinse: the area and machines are hosed down in order to take meat waste to the floor and collect this before it goes to the waste water. The purpose is also to pre-soak surfaces;
- application of detergent: operators apply a premixed mixture of detergent and water forming a foam, which clings to surfaces. The detergent should be allowed to work for 15-20 minutes. Most often, the pH of cleaning is alkaline, changing to acid once a week;
- rinsing: operators hose down the area with water to remove foam;
• disinfecting: a disinfectant is applied on the equipment. Most often, a liquid solution containing chloride is used;
• final rinse: water is applied to remove the disinfectant.

10.2.3 Thawing processes

Thawing at ambient temperatures is slow compared to using water or hot air. The latter may cause a rapid growth of microorganisms on the surface layers of the thawed product and hinder reabsorption of thawed water. This creates the unsightly and often nutritionally wasteful drip loss. The use of microwave energy, which is not transferred by conduction through the thawed food layers, is a faster and less damaging thawing process.

The traditional thawing takes place under running water. In this case, the unpacked raw materials are completely immersed in pools with water. They can also be thawed with air at controlled temperatures. Thawing by sprinkling is also applied. Desalting and thawing are carried out simultaneously.

10.2.3.1 Thawing in air

Thawing is carried out in a coldroom at a controlled temperature for 18–24 hours.

It is reported that when meat is thawed in containers filled with water, the meat juice is extracted and the proteins degraded. Thawing meat in a climate chamber at 0 °C is reported to be better for the meat quality, but require longer times and larger surface areas. The meat surface may become dry and unsaturated pork fats may be oxidised. Losses can occur due to the dripping of meat juice [157, Denmark 2005].

10.2.3.2 Thawing using water recirculation and air stirring

See Section 7.2.2.2.1.

10.2.3.3 Thawing in containers filled with warm water with air bubbles at the bottom

See Section 7.2.2.2.2.

10.2.3.4 Thawing by sprinkling

See Section 7.2.2.2.3.

10.2.3.5 Thawing by 100 % water saturated heated air

See Section 7.2.2.2.4.

Waste water treatment

Meat processing waste water is treated using the following primary treatment techniques:

• screening (see Section 2.3.6.1.1)
• fat trap (see Section 2.3.6.1.2)
— flow and load equalisation (see Section 2.3.6.1.3)
— DAF (see Section 2.3.6.1.6)
— diversion tank (see Section 2.3.6.1.7).

Following primary treatment, on-site secondary treatment may be required, either to achieve the required waste water quality or to minimise off-site waste water treatment charges. For waste water streams with a BOD concentration greater than 1000 – 1500 mg/l, anaerobic treatment processes can be used (see Section 2.3.6.2.2). It may be possible to discharge final waste water from the anaerobic process following surface aeration. For lower polluted waste water streams, aerobic treatment is used (see Section 2.3.6.2.1). A two-stage biological system (see Section 2.3.6.2.3.2), anaerobic followed by aerobic, can achieve a quality of waste water suitable for discharge to a watercourse.

If the suspended solids consent limit is low, it may be necessary to use tertiary treatment (see Section 2.3.6.3). For recycling all or part of the final waste water, if the recycled water is to be used in processing areas as drinking water, tertiary treatment, including sterilisation and disinfection, is essential.

Figure shows a typical schematic of a process flow diagram of the waste water treatment applicable to meat and poultry processing of waste water.

![Flow sheet of the treatment used for meat and poultry processing of waste water](Environment Agency of England and Wales 2000)
# Chapter 10

## 10.3 Current consumption and emission levels

### 10.3.1 General information

Table 10.3 shows the potential environmental effects of the typical processes applied in meat processing installations.

**Table 10.3: Potential environmental effects of typical processes applied in meat processing installations**

<table>
<thead>
<tr>
<th>Process</th>
<th>Potential environmental effects</th>
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<td>Boning</td>
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<td>Cut, trimming</td>
<td>Energy consumption for cooling of production facilities (room temperature 5 to 10 °C).</td>
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<td>Fat standardization</td>
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<td>Mixing</td>
<td>Energy consumption for cooling of production facilities (room temperature 5 to 10 °C).</td>
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<td>Salting, dry salting, vessel salting, injection</td>
<td>Energy consumption for cooling of production facilities (room temperature 5 to 10 °C).</td>
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<td>Waste water containing brine/salt and meat juice.</td>
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<td>Marinating</td>
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<td>Waste water containing marinade and meat juice.</td>
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<td>Product loss to waste water caused by difficulties of emptying the equipment before cleaning/shift of production batch.</td>
</tr>
<tr>
<td>Emulsification, production of minced meat</td>
<td>Energy consumption for cooling of production facilities (room temperature 5 to 10 °C).</td>
</tr>
<tr>
<td></td>
<td>Product loss to waste water caused by difficulties of emptying the equipment before cleaning/shift of production batch.</td>
</tr>
<tr>
<td>Forming</td>
<td>Water to lubricate the moulds.</td>
</tr>
<tr>
<td></td>
<td>Waste water containing product residues.</td>
</tr>
<tr>
<td>Filling cans and autoclaving</td>
<td>Water consumption for cleaning of cans prior to filling, washing of filled cans, autoclaving and cooling of finished products.</td>
</tr>
<tr>
<td></td>
<td>Waste water containing product residues and chemicals added to the water to prevent deposition of calcium and the formation of rust on the cans.</td>
</tr>
<tr>
<td>Filling sausages/Stuffing sausages</td>
<td>Energy consumption for cooling of production facilities (room temperature 5 to 10 °C).</td>
</tr>
<tr>
<td></td>
<td>Product loss to waste water caused by difficulties of emptying the equipment before cleaning/shift of production batch.</td>
</tr>
<tr>
<td>Breading</td>
<td>Product loss of breading material (batter) to waste water.</td>
</tr>
<tr>
<td>Wrapping</td>
<td>Energy consumption for cooling of production facilities (room temperature 5 to 10 °C).</td>
</tr>
<tr>
<td></td>
<td>Product loss to waste water caused by difficulties of emptying the equipment handling of sausage meat before cleaning/shift of production batch.</td>
</tr>
<tr>
<td>Baking</td>
<td>Energy consumption for heating and cooling.</td>
</tr>
<tr>
<td>LTLT/sous vide heat treatment</td>
<td>Energy consumption for heating and cooling.</td>
</tr>
<tr>
<td></td>
<td>Water consumption for filling the heating and cooling vats.</td>
</tr>
</tbody>
</table>
### Process Potential environmental effects

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking</td>
<td>Energy consumption for heating. Water consumption for filling of the cooking vat, or water for producing of steam for the cooking in cooking cabinets. Waste water containing product residues from the processed product.</td>
</tr>
<tr>
<td>Deep-fry</td>
<td>Energy consumption for heating of the oil. Water consumption for cleaning the conveyor belt during production. Waste water containing oil and residues from the processed products. Used oil (and sediments from reused oil). Emission of odour.</td>
</tr>
<tr>
<td>Belt frying</td>
<td>Energy consumption for heating. Water consumption for cleaning the conveyor belt during production. Waste water containing residues from the processed products. Emission of odour.</td>
</tr>
<tr>
<td>Hot smoking</td>
<td>Emission of smoke and odour. Waste water from cleaning containing condensed smoke.</td>
</tr>
<tr>
<td>Cold smoking</td>
<td>Emission of smoke and odour.</td>
</tr>
<tr>
<td>Fermentation, maturing</td>
<td>Energy consumption for conditioning of air (temperature and humidity) in fermentation/climate chambers.</td>
</tr>
<tr>
<td>Drying</td>
<td>Energy consumption for conditioning of air (temperature and humidity) in climate chambers.</td>
</tr>
<tr>
<td>Cooling after heat treatment</td>
<td>Depending of the chosen process, consumption of energy. Water consumption if water is used in the cooling process. Waste water containing organic matter from the processed products if water is used.</td>
</tr>
<tr>
<td>Freezing</td>
<td>Depending of the chosen process, consumption of energy or/and cryogenic gasses.</td>
</tr>
<tr>
<td>Shell freezing</td>
<td>Depending of the chosen process, consumption of energy or/and cryogenic gasses.</td>
</tr>
<tr>
<td>Slicing</td>
<td>-</td>
</tr>
<tr>
<td>Packing, consumer</td>
<td>-</td>
</tr>
<tr>
<td>Bulk packing</td>
<td>-</td>
</tr>
</tbody>
</table>

**Source:** [220, Chitravi-Avec 2016]  

10.3.1.1 **Energy consumption**

A considerable amount of thermal energy is used in processes involving heat treatments such as boiling, cooking, pasteurising, sterilising drying and smoking. Other large energy-consuming operations are chilling, freezing, thawing, and cleaning and disinfection.

Figure 10.2 shows data for specific energy consumption (MWh/tonne of raw materials) in various meat processing installations.
10.3.1.2 Water consumption

The main environmental impact of meat and poultry manufacturing is the production of waste water. Significant quantities of water are used for washing and thawing meat. The reported water consumption is about 3–5 m$^3$/t. The water used for thawing can be recirculated in a closed-circuit and used again [94, Germany 2003]. Some other major water-consuming steps are, e.g. pasteurising, sterilising, cooling, cleaning and disinfection. Stringent hygiene measures are applied to the cutting and chilling of carcases which lead to relatively large quantities of waste water arising from equipment and installation cleaning.

Usually, all the water used in the meat product producing sector water must have drinking quality [268, Clitravi-Avec 2015]. Figure 10.3 shows data for specific water consumption (m$^3$/tonne of raw materials) in various meat processing installations.
10.3.1.3 Solid output

Cutting and deboning meat and poultry produces bones, fat and skin. The use of animal by-products is regulated by Regulation 1774/2002/EC [99, EC 2002]. Bones and fat may be used for, e.g. producing pet food, fur animal feed, glue and detergents, or for producing gelatine which can be used, e.g. in some cases in the food or pharmaceutical industries. Some animal by-products are disposed of as waste. Solid output may also be produced in packing operations such as waste packaging [268, Clitravi-Avec 2015].

When mincing meat, mixing, pumping minced meat, filling sausages etc. a loss of product is unavoidable when changing to a new batch or ending the production [268, Clitravi-Avec 2015].

Table shows the proportion of carcases considered to be by-products.

<table>
<thead>
<tr>
<th>By-products in cutting/deboning (%) of carcass weight</th>
<th>Beef</th>
<th>Pig</th>
<th>Poultry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bones</td>
<td>12</td>
<td>5–9.5</td>
<td>1–2</td>
</tr>
<tr>
<td>Fat</td>
<td>3–6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Skin</td>
<td>1–2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: [71, AWARENET 2002]

10.3.1.4 Emissions to water

Figure 10.4 shows reported data on specific waste water discharges (m³/tonne of raw material) from meat processing installations.

Figure 10.4: Specific waste water discharge (m³/tonne of raw material) in meat processing

Source: [193, TWG 2015]
10.3.1.5 Emissions to air

Air pollution is produced mainly due to the operation of boilers and smokers. Odour may be a nuisance. Refrigerants may leak causing air pollution.

10.3.2 Meat and poultry production

10.3.2.1 General information

This category covers a wide range of products and processing techniques, which are not practicable to consider individually.

All lines, equipment and process areas that are not in designated dry areas require wet cleaning, which generates waste water contaminated with the product, raw materials and cleaning chemicals. If scraps are washed down the drain, this will increase the COD, fat and TSS content of the waste water. Cooking methods that involve direct contact between water or steam and product, produce waste water, as do cooling, chilling, freezing and filling operations.

Ingredients added to the meat may enter the waste water stream as a result of equipment washouts and spillage. Those used in large quantities, e.g. batter, bread crumbs and cooking oil, can make a significant contribution to the BOD, TSS and FOG emission levels in the waste water.

It is reported that in the UK, fresh meats, especially poorer quality beef, are often treated with enzymes of plant or fungal origin to improve tenderness. The meat is either dipped in or sprayed with enzymes in solution. Enzymes are complex organic structures and unless operators ensure that the discharge of the enzyme solutions is kept to a minimum, they will carry a BOD contribution and may potentially affect the biology of a WWTP [8, Environment Agency of England and Wales 2000]. Italy reports that the technique is not used there [96, Italy 2003].

Table summarises reported consumption and emission levels expressed per tonne of finished product in the Italian meat industry for cooked ham manufacturing. A flow sheet for cooked ham and shoulder production is given in Figure.

Table: Consumption and emission levels for cooked ham manufacturing in Italy

<table>
<thead>
<tr>
<th>No.</th>
<th>Unit operation</th>
<th>Water consumption (m³/t)</th>
<th>Waste water load (kg COD/t)</th>
<th>Solid output (kg/t)</th>
<th>Electrical energy (kWh/t)</th>
<th>Thermal energy (kg steam/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1</td>
<td>Materials handling and storage <em>(plastic, cardboard)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.2</td>
<td>Sorting/screening, grading, dehulling,destemming/destalking and trimming <em>(meat)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.4</td>
<td>Washing and thawing</td>
<td>0–15 **</td>
<td>**</td>
<td>** <em>(fat)</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.1</td>
<td>Cutting, slicing, chopping, mincing, pulping and pressing <em>(meat)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.2</td>
<td>Mixing/blending, homogenisation and conching <em>(meat)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.3</td>
<td>Forming/moulding and extruding <em>(meat)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.2</td>
<td>Brining/curing and pickling</td>
<td>0.5 ±</td>
<td>±</td>
<td>± <em>(salt)</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.8</td>
<td>Smoking <em>(ash)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.13</td>
<td>Coating/spraying/enrobing/agglomeration/encapsulation <em>(dust)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
10.3.2.2 Salami and sausage production

The main environmental factors relating to sausage manufacture concern the smoking and cooling processes. Wood smoke contains many compounds, which are of concern from a health point of view. They are, e.g. PAH, phenols, nitrite and N-nitroso compounds plus CO. Effective ventilation and exhaust is, therefore, necessary for kilns and rooms.

The smoke can produce odour problems in the surroundings. The odour concentration in the emissions from a smoking kiln depends on the smoking process and the ventilation and drying conditions. Typical odour concentration in untreated air is 5000–20 000 OU\text{E}/m$^3$. A wet scrubber for cleaning the emissions from a smoking kiln will typically have an efficiency of 50–70\%, measured in OU\text{E}/m$^3$.

A carbon content of 1000 ppm has been measured in the exhaust from a modern warm smoking and cooking unit. After thermal oxidation at 815 °C and cooling to 26 °C, 5 ppm carbon was measured.

In a Norwegian investigation, the following emission levels from smoking were given per tonne of product: 0.3 kg CO, 0.15 kg inorganic particles, and 0.2 kg TOC. Furthermore, when examining a cooking/smoking cabinet, the following emissions were found after thermal oxidation of the smoke gases: 7 mg TOC/m$^3$ or 0.2 mg TOC/t of sausages. The gas did not contain CO.

Soot and tar compounds are deposited in the kilns and on smoking sticks and frames. This is removed and often carried out with powerful alkaline detergents. Waste water from the smoking department can, therefore, contain a large number of chemical compounds.

Only very limited information is available about the use of resources and pollution from the manufacturing of salami and Vienna sausages. One reason is that a meat processing installation or a slaughterhouse may have many other activities than those mentioned here and that the companies do not have sufficient separation of the figures for consumption or emission levels for each product line. Table 10.4 shows reported specific consumption of water and energy, and emissions of waste water in salami and sausage production.
Table 10.4: Specific consumption of water and energy and emissions of waste water in salami and sausage production

<table>
<thead>
<tr>
<th>Product</th>
<th>Unit*</th>
<th>Salami</th>
<th>Salami</th>
<th>Various</th>
<th>Various sausages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td></td>
<td>DK</td>
<td>DK</td>
<td>SE</td>
<td>NO</td>
</tr>
<tr>
<td>Water</td>
<td>m³/t</td>
<td>7.5</td>
<td>5.3</td>
<td>7.7</td>
<td>10</td>
</tr>
<tr>
<td>Electricity</td>
<td>kWh/t</td>
<td>unknown</td>
<td>1000</td>
<td>750</td>
<td>1300</td>
</tr>
<tr>
<td>Heat</td>
<td>kWh/t</td>
<td>1240</td>
<td>900</td>
<td>1000</td>
<td>450</td>
</tr>
<tr>
<td>Recuperation</td>
<td>kWh/t</td>
<td>unknown</td>
<td>230</td>
<td>250</td>
<td>unknown</td>
</tr>
<tr>
<td>Total energy</td>
<td>kWh/t</td>
<td>unknown</td>
<td>2130</td>
<td>2000</td>
<td>1750</td>
</tr>
<tr>
<td>BOD</td>
<td>kg/t</td>
<td>4.7</td>
<td>15</td>
<td>8–10</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>g/t</td>
<td>300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>g/t</td>
<td>140</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NB: * t refers to tonnes of finished product

Source: [20, Nordic Council of Ministers 2001]

Table summarises consumption and emission levels expressed per tonne of finished product reported for the Italian meat industry for preserved meat products manufacturing.

Table: Consumption and emission levels for preserved meat products manufacturing in Italy

<table>
<thead>
<tr>
<th>Preserved products, e.g. sausages, dressed pork, ham, bacon, etc</th>
<th>Unit operation</th>
<th>Water consumption</th>
<th>Waste water load</th>
<th>Solid output</th>
<th>Electrical energy</th>
<th>Thermal energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>(m³/t)</td>
<td>(kg COD/t)</td>
<td>(kg/t)</td>
<td>(kWh/t)</td>
<td>(kg steam/t)</td>
</tr>
<tr>
<td>A.1 Materials handling and storage</td>
<td>A.2 Sorting/screening, grading, dehulling, destemming/destalking and trimming</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>A.4 Washing and thawing</td>
<td>A.5 =</td>
<td>=</td>
<td>**(fat)</td>
<td>=</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>B.1 Cutting, slicing, chopping, mincing, pulping and pressing</td>
<td>B.2 Mixing/blending, homogenisation and conching</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>B.4 Forming/moulding and extruding</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>L.1 Brining/curing and pickling</td>
<td>L.2 Dehydration (solid to solid)</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>L.3 Smoking</td>
<td>L.4 Packing and filling</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>L.5 Cleaning and disinfection</td>
<td>L.6 Energy generation and consumption</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>L.7 Water use</td>
<td>L.8 Overall totals of typical installations</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>Overall totals of typical installations</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
<td>=</td>
</tr>
</tbody>
</table>

**The higher value is valid for thawing with water
** low consumption/emission
** medium consumption/emission
*** high consumption/emission

Source: [52, Italy 2001]
10.3.3 Meat and poultry preservation

10.3.3.1 Freezing

The only waste water generated from freezing is the overflow from the cooling system and freezer defrost water.

10.3.3.2 Curing

Salting and curing can introduce NaCl and Na$_2$NO$_3$ into the waste water. Operators need to minimise over production of brine and also production out of specification brine. Not only would this constitute discharge of raw material, but excess/waste brine that would also have a detrimental effect on the WWTP if discharged in large quantities. Chloride brine is not reduced through a biological WWTP, apart from dilution. Traditional dry curing is practised by a number of small highly specialised companies. The process liberates small quantities of cooking waste water only.
Table summarises consumption and emission levels expressed per tonne of finished product reported for the Italian meat industry for cured ham manufacturing. A flow sheet for cured ham production is given in

Source: [54, Italian contribution 2001]

Figure
### Table: Consumption and emission levels for cured ham manufacturing in Italy

<table>
<thead>
<tr>
<th>Unit operation</th>
<th>Water consumption</th>
<th>Waste water load</th>
<th>Solid output</th>
<th>Electrical energy</th>
<th>Thermal energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Description</td>
<td>(m³/t)</td>
<td>(kg COD/t)</td>
<td>(kg/t)</td>
<td>(kWh/t)</td>
</tr>
<tr>
<td>A.1</td>
<td>Materials handling and storage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.2</td>
<td>Sorting/screening, grading, dehulling, destemming and trimming</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.3</td>
<td>Washing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.4</td>
<td>Thawing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.1</td>
<td>Cutting, slicing, chopping, mincing, pulping and pressing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.2</td>
<td>Mixing/blending, homogenisation and conching</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.3</td>
<td>Forming/moulding and extruding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.4</td>
<td>Smearing and pickling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.5</td>
<td>Smoking (Spek and Hungarian salami)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.1</td>
<td>Dehydration (solid to solid)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.2</td>
<td>Packaging and filling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.1</td>
<td>Cleaning and disinfection</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.2</td>
<td>Energy generation and consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.3</td>
<td>Water use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.4</td>
<td>Vacuum generation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.5</td>
<td>Refrigeration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Overall totals of typical installations</th>
<th>2–20</th>
<th>20–25</th>
<th>35–50</th>
<th>2500–4000</th>
</tr>
</thead>
</table>

*Thermic + electric (1300–1400 kWh/t + 150–180 m³ methane/t)

** low consumption/emission
** medium consumption/emission
*** high consumption/emission

Source: [52, Italy 2001]

### 10.3.3.3 Smoking

Smoking is most often carried out on cured meat; however, it can be used on fresh meat products that are cooked before serving. Traditional smoking techniques rely on smouldering wood or sawdust and do not generate waste water. The mass production alternative is to use liquid smoke, prepared by the destructive distillation of wood and applied by spraying, dipping or atomisation. Contaminated waste water is produced when containers or equipment that have been in contact with liquid smoke are cleaned.

During the application of smoke to the meat products, a portion of the smoking ingredients condenses on the walls of the chambers. These tar-like layers are removed with hot water by an alkaline cleaning solution. This water is highly contaminated and should be disposed of separately; it has COD emission levels of 20 000–100 000 mg/l, pH of 12–14, phenol index of 20–480 mg/l, and PAH emission levels of 1–5 mg/l.
10.3.3.1 TVOC emissions to air from smoke kilns

The reported TVOC emission data are presented in Table 10.5.

Table 10.5: Reported TVOC emission data from smoke kilns (spot samples, concentrations)

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>TVOC (1) (mg/Nm³)</th>
<th>Frequency of monitoring</th>
<th>Monitoring standard</th>
<th>Sampling duration (h)</th>
<th>Abatement technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>331-1</td>
<td>0.10</td>
<td>Yearly</td>
<td>EN 12619</td>
<td>1.00</td>
<td>Carbon adsorption</td>
</tr>
<tr>
<td>102-1</td>
<td>&lt;7.70</td>
<td>Monitored between 2 and 4 years</td>
<td>VDI-3481</td>
<td>0.75</td>
<td>Thermal oxidation of waste gases</td>
</tr>
<tr>
<td>102-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>102-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>102-5</td>
<td>8.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>102-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NB: (1) = no info provided about % O₂ levels.
Source: [193, TWG 2015]

10.3.3.4 Drying

Dried meats are produced by curing, followed by drying at low humidity. Unless odour abatement considerations make it necessary to condense water vapour from the dryer flue-gases, no waste water is generated.

10.3.3.5 Canning

The use of hot water or direct steam heating for cooking, prior to canning produces waste water contaminated with fat, protein and fragments of meat. After canning, the meats are heat-processed to achieve pasteurisation and shelf stability. Can cleaning, both before and after filling, and can cooling use considerable quantities of water.

Table summarizes consumption and emission levels expressed per tonne of finished product reported for the Italian meat industry for canned meat manufacturing.

Table: Consumption and emission levels for canned meat in Italy

<table>
<thead>
<tr>
<th>Unit operation</th>
<th>No.</th>
<th>Description</th>
<th>Water consumption (m³/t)</th>
<th>Waste water load (kg COD/t)</th>
<th>Solid output (kg/t)</th>
<th>Electrical energy (kWh/t)</th>
<th>Thermal energy (kg steam/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1</td>
<td></td>
<td>Materials handling and storage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.4</td>
<td></td>
<td>Washing and thawing</td>
<td>6–12</td>
<td>4–3</td>
<td>0.5–1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.5</td>
<td></td>
<td>Cutting, slicing, chopping, mincing, pulping and pressing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.8</td>
<td></td>
<td>Pasteurisation, sterilisation and UHT</td>
<td>1.5–3.5</td>
<td></td>
<td></td>
<td>2–4</td>
<td>800–900</td>
</tr>
<tr>
<td>G.1</td>
<td></td>
<td>Cooling, chilling and cold stabilisation</td>
<td>1.5–3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H.1</td>
<td></td>
<td>Packaging and filling</td>
<td>4–3</td>
<td>0.74</td>
<td>400–120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.1</td>
<td></td>
<td>Cleaning and disinfection</td>
<td>0.5–2.0</td>
<td>20</td>
<td>5–10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.2</td>
<td></td>
<td>Energy generation and consumption</td>
<td>1–2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.3</td>
<td></td>
<td>Water use</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

WORKING DRAFT IN PROGRESS
<table>
<thead>
<tr>
<th>U.4</th>
<th>Vacuum generation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>U.5</td>
<td>Refrigeration</td>
<td></td>
</tr>
</tbody>
</table>

**Overall totals of typical installations**  
(all unit operations are not undertaken at each installation, so the totals are not the sum of the levels for each unit operation)

<table>
<thead>
<tr>
<th></th>
<th>10–18</th>
<th>20–25</th>
<th>20–30</th>
<th>150–400</th>
<th>800–900</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic, cardboard</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cans</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sludge, resins</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: [52, Italy 2001]*
Chapter 10

10.4 Techniques to consider in the determination of BAT

10.4.1 Techniques to increase energy efficiency

10.4.1.1 Friction smoke

See Section 7.4.1.1.

10.4.2 Techniques to reduce water consumption

10.4.2.1 Techniques related to cleaning

10.4.2.1.1 Dry cleaning

This technique is described in Section 2.3.3.2.1.

Technical description

Reported examples of where the technique is applied are the following ones:

- when ground meat residues, particularly meat mix for salami production or from sausage making, from equipment such as bowl choppers, sausage fillers and from floors, is left standing, it sticks to the surfaces and makes subsequent cleaning difficult. Cleaning such equipment immediately after the end of production minimises the cleaning efforts and the need for water and detergents. The ground meat residues are manually removed to the maximum practical extent, prior to cleaning and sending for rendering;
- applying dry cleaning of meat scraps during trimming and cutting operations to reduce the waste water pollution load;
- fit covers for the drains with adequate hole diameters to stop meat scraps entering the WWTP.

Technical considerations relevant to applicability

Applicable to meat manufacturing installations.

Reference literature

[20, Nordic Council of Ministers 2001]

10.4.2.1.2 Minimise the production and use of flake ice

Description

Use of a suitable mixture of chilled and frozen raw materials, to avoid the use, and therefore the production, of flake ice.

Technical description

When processing ground frozen meat, flake ice is often used to cool the meat mixture. By using a suitable mixture of chilled and frozen raw materials, it is possible to avoid the use, and therefore the production, of flake ice. Sometimes flake ice is added when processes such as chopping make the temperature of the meat rise, so causing a risk to the hygiene or the quality of the product or if only a small amount of water needs to be added to the product.

Achieved environmental benefits

Reduced water and energy consumption.

Environmental performance and operational data

TWG, please provide information.
Technical considerations relevant to applicability
Applicable in ground frozen meat processing installations.

Economics
TWG, please provide information.

Example plants
TWG, please provide information.

Reference literature
[20, Nordic Council of Ministers 2001]

10.4.3 Techniques to reduce waste

10.4.3.1 Segregation Separation of residues outputs, to optimise use, reuse, recovery, recycling and disposal (and minimise water use and waste water contamination)

This technique is described in Section 2.3.5.3.

Reported examples of where the technique is applied
There are likely to be many other opportunities to apply this technique within the sector.

- apply dry collection of all solid wastes by means of trays or baskets to prevent them from falling on the floor and entering the WWTP;
- many raw materials are received or transported/stored in open vats or trolleys. A quantity of meat juice collects in the bottom of such containers. Rather than emptying this juice into the WWTP and therefore, increasing the pollution of the waste water, it is used in the manufacturing of processed meat products;
- cutting and deboning operations usually take place after chilling. After chilling, the carcasses are more easily handled, cut and deboned. The bones are separated from the meat and together with meat scraps and fats, not intended for human consumption, are collected in trays fixed to the equipment and sent for treatment or disposal at animal by-products installations.

Technical considerations relevant to applicability
Applicable to meat manufacturing installations.

Reference literature
[20, Nordic Council of Ministers 2001]

10.4.4 Techniques to reduce emissions to air

10.4.4.1 Techniques to reduce TVOC emissions from smoke kilns

10.4.4.1.1 Adsorption

A general description of the technique is given in Section 2.3.7.3.3.

Environmental performance and operational data
Adsorption has been applied for the abatement of TVOC emissions from a smoke kiln in installation #331. A TVOC concentration of 0.1 mg/Nm³ was achieved (one measurement in 2014). The monitoring standard used was EN 12619. The 2013 measurement value was 3.1 mg/Nm³.
10.4.4.1.2 Thermal oxidation of waste gases

A general description of the technique is given in Section 2.3.7.3.6.

Environmental performance and operational data

Table 10.6 shows installation-specific performance data related to the application of thermal oxidation for abating TVOC emissions to air from a smoke kiln.

Table 10.6: Average values of periodic measurements of TVOC emissions to air from a smoke kiln after thermal oxidation

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>TVOC (mg/Nm$^3$)</th>
<th>$O_2$ content (%)</th>
<th>Monitoring standard</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>102-1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>102-2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>102-4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>102-5</td>
<td>&lt;7.70</td>
<td>NI</td>
<td>VDI-3481</td>
<td>Mainly bacon and sausages production. Obtained values are below the detection limit. Smoke from smouldering wood.</td>
</tr>
<tr>
<td>102-3</td>
<td>8.70</td>
<td>NI</td>
<td>VDI-3481</td>
<td>Mainly bacon and sausages production. Smoke from smouldering wood.</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.

Source: [193, TWG 2015]

In a Norwegian investigation of smoking sausages, when examining a cooking/smoking cabinet, the following emissions were found after the thermal oxidation of the smoke gases: 7 mg TOC/Nm$^3$ or 0.2 mg TOC/t sausages. The gas did not contain CO [20, Nordic Council of Ministers 2001].

Reference literature
[20, Nordic Council of Ministers 2001], [193, TWG 2015]

10.4.4.1.3 Liquid smoke

See also Section 7.4.4.1.1.

Environmental performance and operational data

When Vienna sausages are smoked/cooked, emissions of 2–3 million odour units per batch have been measured in Denmark from a kiln using a scrubber, and in the order of 100 000 odour units from a kiln where liquid smoke was used (unpublished results, DMRI). It can, therefore, be suggested that odour can be eliminated by using liquid smoke.

10.4.4.1.4 Smoke from superheated steam

See Section 7.4.4.1.2.
10.4.4.2 Techniques to reduce odour

10.4.4.2.1 Recirculate and burn exhaust gases from frying

Description
Recirculate and burn exhaust gases from frying.

Technical description
Emissions to air are dependent on the operational temperature of frying, e.g. high temperature frying at 180–200 °C will result in more rapid production of oil breakdown products than frying at lower temperatures. The air above a fryer is extracted and vented. This exhaust air contains VOCs, and may lead to odour complaints. Oil and heat recovery and recirculation of exhaust gases to the burner minimises these emissions.

Achieved environmental benefits
Reduced emissions to air, including odour. Recovery of oil. Recovery of energy. Recycling of exhaust gases.

Environmental performance and operational data
For example, when controlling a crisp frying process, ensuring that the frying process ends when the final moisture content is in the critical range of 1–2 % leads to a minimisation of emissions to air. Furthermore, to save energy, the heat exchangers are mounted in the fryer exhaust hood.

Figure 10.5 illustrates a heat and oil recovery system applied to a fryer.

Technical considerations relevant to applicability
Applicable in the fish, meat and poultry and potato frying sectors.

Reference literature
10.5 Emerging techniques

TWG, please provide information.
11 OILSEED PROCESSING AND VEGETABLE OIL REFINING

11.1 General information about the sector

In the EU annually 47 million tonnes of oilseeds are crushed. This results in the production of 17 million tonnes of crude oils and 29.5 million tonnes of meals. The EU annual consumption of oilseed meals is around 52 million tonnes. The EU imports annually 24 million tonnes of meals, meaning almost half of the EU meal consumption is imported [213, FEDIOL 2015].

Key environmental aspects of oilseed crushing and vegetable oil refining are the consumption of water, steam, electricity, hexane, bleaching earth and chemicals (acids, caustic soda) and emissions to air (VOC, H₂S, CO₂) and to water [213, FEDIOL 2015].

11.1.1 Oilseed processing

Oilseed processing (or crushing) is the processing of oleaginous seeds, such as rape, soya or sunflower, for the production of crude vegetable oils and protein-rich meals. Crude oils generally need further processing (refining) to render them suitable for consumption. The protein-rich meals are used for animal feeding.

The EU has around 50 oil mills (oilseed crushing facilities) that fall under the scope of the FDM BREF (reference year 2015). Some 20 of these are stand-alone oil mills of which the crude oil produced is sold and/or processed elsewhere. The other mills are integrated crushing and refining installations where the crude oil resulting from the oilseed crushing is refined at the same installation. Some ten oil mills are processing only soybeans, around 35 only soft seed (rapeseed and/or sunflower seeds) and some five can process both soybeans and soft seeds (so-called switch installations). Increasing imports of South American soybean meal in the last decade triggered some EU soybean crushing sites to modify their installation to be able to process both soybeans and soft seeds [213, FEDIOL 2015].

Crushing installations are often located at waterways or in the proximity of harbours to allow bulk delivery of raw materials, whether imported from outside the EU (e.g. soybeans) or from soft seed growing areas in the EU.

11.1.2 Vegetable oil refining

Crude vegetable oils from rapeseeds, soybeans and sunflower seeds, and tropical oils such as palm, palm kernel and coconut oil are refined before being used in food, feed, biofuels, cosmetics, lubricants and other technical applications.

The EU has around 35 refining installations that fall under the scope of FDM BREF (reference year 2015). Some 20 of these refine the crude oils that they themselves produce from oilseeds in the same installation, the so-called integrated crushing and refining installations. The other 15 are stand-alone refining installations. Three types of stand-alone refineries can be distinguished [213, FEDIOL 2015]

• refineries that are processing tropical oils in bulk. Palm fruits, palm kernels and copra are pressed in tropical countries close to their origin, i.e. the palm and coconut plantations. Crude palm, palm kernel and coconut oil are exported to the EU and refined in bulk-tropical oil refineries located in the import harbours;
• refineries that refine oils and fats of varying botanical origin. These refineries generally can handle crude seed oils as well as tropical oils (multi-oil refining). They are oriented on batch processing rather than on continuous (or bulk) processing;
• specialty oils and fats refineries processing crude and/or refined oils for specific functional or nutritional applications. The processing may include specific refining steps such as hardening, fractionation or interesterification, with the aim of giving the oil physical characteristics needed for the end application.
11.2 Applied processes and techniques

Oils and fats occur naturally in a wide range of sources, although only around 22 vegetable oils are processed on a commercial scale around the world. These are summarised as:

- production of oils from oilseeds, i.e. sunflower seed, soya bean, rapeseed, safflower seed, mustard seed, cotton seed and ground nuts
- production of oils from fruit pulp, e.g. olives
- production of animal fats
- production of fish oils.

Oils produced in the largest quantities come from soya beans, ground nuts, olives, sunflower seeds, safflower seeds, cotton seeds, mustard seeds and rapeseeds; the latter is also known as colza oil. Mediterranean countries produce 95% of the total world olive oil production estimated to be 2.4 million tonnes per year. Animal fats for human consumption are generally produced by a process known as fat melting and by fish-oil production. Animal fat and fish-oil production is within the scope of the “Slaughterhouses and animal by-products BREF” [181, EC, 2003].

The preparation of raw materials includes husking, cleaning, crushing, and conditioning. The extraction processes are generally mechanical, e.g. boiling for fruits and pressing for seeds and nuts, or involve the use of solvents such as hexane. After boiling, the liquid oil is skimmed. After pressing, the oil is filtered. After solvent extraction, the crude oil is separated and the solvent is evaporated and recovered. Residues are conditioned, e.g. dried, and are reprocessed to yield by-products such as animal feed. Crude oil refining includes degumming, neutralisation, bleaching, deodorisation, and further refining. Oils can be processed further to produce margarine.

11.2.1 Oilseed processing

11.2.1.1 Overview of production process

The production of crude vegetable oil from oilseeds is a two-step process. The first step involves cleaning followed by preparation of the oilseeds, i.e. drying, dehulling, flaking, conditioning and pressing. Pressing results in crude pressed oil and a cake with an oil content of 12% to 25%. Deep expelling reduces the oil content to below 10%. With deep expelling no subsequent hexane extraction takes place. Soya beans have an oil content of 20% oil or less. This low oil content makes pressing superfluous. Soybeans are extracted directly after cleaning and preparation [214, FEDIOL, 2015].

The second step entails extraction of the oil from the pressed cake or flaked beans using hexane as a solvent. The extraction takes place in a countercurrent-flow extractor, resulting in two output streams, a mixture of hexane and vegetable oil, called miscella, and a solvent-laden meal. For hexane recovery, the miscella is further processed in a distillation process. For the same reason, the meal is further processed in a counter-current desolventiser/toaster using indirect and direct steam. Besides removing hexane from the meal, desolventising/toasting also reduces the enzyme activity in the meal. The heat contained in the hexane/steam vapours from desolventising/toasting is reused in the miscella distillation. The meal is dried and cooled by air before being stored in silos or before transport.

No subsequent hexane extraction takes place, if the oil content of the cake after pressing is only reduced to between 6 and 12%. Beans with 20% oil or less are not pressed, because of their lower fat content, but are extracted directly after cleaning and preparation.
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The mixture of hexane and oil, called miscella, is further processed in a distillation process to recover the hexane from the vegetable oil. The solvent is passed through a hexane/water separation technique and then reused in the extraction process. The remaining hexane in the cake is recovered by a stripping process, using steam. This desolventising/toasting process also reduces the enzyme and microorganism activity in the meal. The hexane/steam vapours are used in the miscella distillation process for solvent and heat recovery. The meal is dried and cooled by air before being stored in silos or before loading.

There are a variety of manufacturing methods associated with the large range of oil sources which release oil and improve subsequent extraction. A number of key steps are typically always undertaken. Coarse extraneous matter such as wood, stones and metal are first removed with, e.g. sieves or magnets. Fine impurities such as plant residues, dust and sand are then removed, e.g. by vibrating sieves, wind sifters and cyclones. The husks and hulls of seeds, such as soya and sunflowers, are removed, and the seeds are then cracked, followed by air classification, to expose the flesh of the raw material. After this, the flesh is conditioned or dried to a required moisture level, typically 9 to 10 % and rolled into flakes.

11.2.2 Vegetable oil refining of edible oils and fats

11.2.2.1 Refining of vegetable oils

Refining removes undesirable compounds such as gums, free fatty acids (FFA), pigments, undesirable flavours and odour compounds. In general, there are two ways to refine seed oils, i.e. physical refining and the more conventional chemical refining. Conventional chemical refining, as applied to crude oils for instance, includes degumming for the removal of phospholipids, neutralisation for the removal of FFA and bleaching for decolourisation and deodorisation.

11.2.2.1.1 Chemical refining of vegetable oils

Chemical refining of vegetable oil refers to the following process sequence: degumming/neutralisation, bleaching and deodorisation. “Chemical” in chemical refining refers to the neutralisation step, during which FFA are reduced by the chemical reaction of FFA and a diluted alkali solution (generally sodium hydroxide) to form soap. Soap can be separated from the oil by settling or centrifugation [215, FEDIOL 2015].

Chemical neutralisation involves the addition of caustic soda at 75 – 110 ºC to saponify the FFA, precipitation of soaps in the heavy aqueous phase and removal of the heavy phase, called soap-stock, by using sedimentation or centrifugation. Removal of non-hydratable gums and phosphatide acids can be integrated in this process using a preceding acidification step, i.e. using phosphoric acid or citric acid (see description of degumming in Section 11.2.2). The oil is preheated using steam, after which phosphoric acid or citric acid is mixed with it to increase the water solubility of the phosphatides. The aqueous mixture of soap and phosphatides, which is known as soap-stock, is separated from the oil by centrifugation. The oil is mixed with water to wash off the rest of the soaps. Again, the water is removed from the oil by centrifugation. The caustic refined oil may be dried under vacuum conditions and then pumped to a storage tank. The process is typically operated in a continuous way, as shown in Figure 11.1, but it can also be a semi-continuous or batch process, using long period mixing and sedimentation equipment.

Then, the soap-stock can be further processed into acid oils by splitting or can be sold to a third party and for an integrated installation. There is also an option to recycle it back into the process. In soap-stock splitting, the fatty acid soaps are reacted with sulphuric acid to reform fatty acids. The process can either be continuous or discontinuous. The reaction medium is heated up to 70 – 100 ºC to increase the speed of the reaction and to improve the separation of the upper oil phase from the lower aqueous phase. Depending on the amount of phosphatides still
present in the crude oil between the aqueous phase and the fatty acids, an intermediate layer of phosphatides can be formed [35, Germany 2002], [75, FEDIOL 2002]. The chemical refining of vegetable oils is shown in Figure 11.1.

Figure 11.1: Chemical refining of vegetable oils

For example, if a batch deodoriser is used, it would take between 4.5 to 5 hours depending on the oil type and the quantity. However, if the same oils were processed in a semi-continuous deodoriser it would take about 15 minutes.

Figure shows a flow diagram of crude oil chemical refining. Olive oil and husk from pomace oil refining is similar to oilseed oil refining.
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Physical refining is a simpler process in which the crude oil is degummed and bleached, followed by steam stripping which removes ffa, odours and volatiles in one step. The oil is heated to temperatures of up to 270 ºC and then refined by the oil flowing over a series of trays countercurrent to the flow of the stripping steam. The advantages of physical refining are the higher yield, the lower cost and the fewer chemicals used. One of the disadvantages, compared to chemical neutralisation, can be a lower quality of the end-product.

The centrifuge aqueous discharges, i.e. the soap-stocks, are combined and further treated in a soap-stock splitting system. This acidulation process is used to recover the FFA after treatment with concentrated acid, usually sulphuric acid or occasionally hydrochloric acid, and heating with steam. The separated FFA are then removed in a decanter centrifuge. In integrated installations, the soap-stock can be added to the meal toasting process. The phosphatides recovered are used as lecithin in human food or in animal feed.

The neutralisation process requires cooling water. The waste water that results from a combined neutralisation and soap-stock splitting has a temperature of about 100 ºC, high acidity and contains salts of sodium sulphate or sodium chloride and sodium phosphate in high concentrations. If citric acid is used, this increases the BOD load of the waste water. The disposal of process waste water with high concentrations of sulphates (>2000 mg/l) into a MWWTP may cause corrosion of the concrete. Phosphorus emission levels may be high. The waste water may also contain FOG.

Fatty acids are considered a by-product. The treatment of waste water from neutralisation can produce high amounts of sludge, due to the presence of phosphates and/or sulphates. The waste water may have high salt concentrations.

11.2.2.1.2 Physical refining of vegetable oils

Physical refining refers to the following process sequence: bleaching (optionally with acid and/or water pretreatment before addition of the bleaching earth) and deodorisation at high temperature. “Physical” in physical refining refers to the deodorisation step during which the FFA are reduced by physical distillation at high temperature under deep vacuum [215, FEDIOL 2015].

The oil is mixed under vacuum conditions with 0.1 to 3 % of bleaching earth. This is a clay mineral, such as bentonite or montmorillonite, that has been activated by thermal and/or acidic or other treatments. These earths, sometimes mixed with small amounts of activated carbon, have a very high adsorbing capacity. After bleaching for 30 or 90 minutes, the oil is separated from the bleaching earth, using filters. The spent earth contains high amounts of oil, up to 30 %. A steam stripping process can recover a part of the oil or fat. Used bleaching earth can be added to the meal in integrated installations. The bleached oil is further treated in other refinery processes. The equipment used for bleaching consists of mixing vessels, vacuum generators and filters.

The solid output from bleaching is known as spent earth. Due to its high oil content, there is a risk of self-ignition. The spent earth of an oil refinery can be added to the meal formed by crushing to make a by-product. The spent earth used for bleaching hardened oils can also be added to the meal, as long as it does not contain nickel and/or activated carbon. Otherwise, as it has a high calorific value, it is used as an energy source, e.g. in the production of concrete or to produce biogas.

It is possible to remove all the FFA present in the oil in a deodoriser by distillation. A physical pretreatment can be made to achieve low phospholipid content by degumming and using bleaching earth. FFA can then be stripped from the physically pretreated oil, by using steam under vacuum at temperatures of around 250 ºC. Previous neutralisation processes can be skipped as neutralisation and deodorisation are combined and are performed in continuously operating single or multistage equipment with integrated heat exchangers and injected stripping
steam. This is directly followed by using a scrubber to condense the greater part of the fat from
the vapours as a water-free product. This is generally carried out, but depends on the raw
material and products and on the incoming oil being rich in FFA and low in phospholipids. The
scrubber system located after the deodoriser has to remove a much higher amount of FFA than

The bleached oil is steam distilled at low pressure to remove volatile impurities including
undesirable odours and flavours. This process, known as deodorisation, takes place in the
temperature range of 180 °C to 270 °C and may last from 15 minutes to 5 hours depending upon
the nature and the quantity of the oil, and the type of equipment used (e.g. batch deodoriser or
semi-continuous deodoriser).

There are three other processes which may be carried out during oil refining, depending upon
the oil source. These are winterisation, which essentially is the removal of wax which would
otherwise cause cloudiness. This is carried out on, e.g. sunflower oil. The process involves
cooling the oil followed by filtration, using a filter aid to remove wax. The second process is
fractionation. Typically this may be carried out on crude or refined oil. This involves
completely melting the solid oil, followed by cooling to yield solid and liquid fractions which
have different functional properties. The third process is interesterification. This involves
the separation of triglycerides into fatty acids and glycerol followed by recombination. The reaction
is carried out using citric or phosphoric acid plus a catalyst, typically sodium methoxide.
Interesterification modifies the functional properties of the treated oil and may be carried out
after neutralisation or deodorisation.

11.2.2.1.3 Differences between chemical and physical refining of vegetable oils

The main process differences between chemical and physical refining are [ 215, FEDIOL
2015 ] :

- chemical refining may have the additional combined degumming/neutralisation process.
  For low volumes, the reaction and settling can be done in a batch vessel. However, most
  high volume refineries use a continuous reactor and one to three centrifuges for reaction
  and separation. The soap separated from the oil can be sold as such (low value) but is in
  most refineries split by a strong acid (sulphuric acid) in a soap-splitting installation. The
  products of the soap-splitting installation are a high quality acid oil (FFA and some
  entrained oil) and acid water. The acid water normally requires further treatment before
  discharge to a municipal waste water treatment plant;
- the phospholipids level of oils for physical refining needs to be relatively low to avoid
  uneco nomically high bleaching earth levels in the bleaching step. A diluted acid
  pretreatment (phosphoric or citric acid) before bleaching earth dosing enhances the
  phospholipids and metals reducing capacity of bleaching earth. Most extracted seed oils
  are high in phospholipids and require acid degumming before physical refining. Water
degumming alone will likely not sufficiently reduce the level of non-hydratable
  phospholipids and, if so, may need to be followed by chemical refining. Tropical oils
  like palm oil, palm kernel oil and coconut oil are sufficiently low in phospholipids level
  to apply physical refining without pre-degumming;
- the stripping of FFA by distillation requires deodorisation temperatures in the range
  170–270 °C. The FFA reduction at lower temperatures is generally insufficient to meet
customer specifications. This high temperature may lead to formation of undesirable
  components like trans fatty acids (especially in highly unsaturated oils like linseed oil
  and fish oil) and glycidyl ester. It may also reduce the levels of thermo-sensitive minor
  components like sterols, tocopherols, carotenes, co-enzymes etc. The deodorisation
temperature in chemical refining can be lower than in physical refining since stripping
of FFA is not required. The applied temperature in deodorisation follows from practical
considerations like deodoriser efficiency, heat recovery, product mix, etc.
Comparison of the chemical with physical refining sequences leads to the following disadvantages of chemical refining:

- higher production costs (depreciation, labour, maintenance) due to the additional neutralisation and soap-splitting lines;
- higher oil loss due to entrainment of neutral oil in the soap stock;
- higher liquid effluent discharge, this effluent is rich in COD, BOD, phosphates and sulphates.

Physical refining is not possible at all refineries because of type of oil processed, quality requirements and food safety limitations. The main advantages of chemical refining over physical refining are:

- the flexibility to obtain a high quality product more or less independent of feedstock pretreatment and quality;
- the possibility to use lower deodorisation temperatures to restrict undesirable by-product formation and to retain desired minor components.

The choice of the best available refining process route depends also on many operational criteria like: processed volume, flexibility to oil type and quality, environmental restrictions, stand-alone refinery or in combination with an oil mill on the same site, etc.

Chemical refining may be preferred for oils high in phospholipids like non-degummed seed oils, water degummed oils and highly unsaturated oils also high in FFA (low quality linseed oil, fish oil, etc.). Chemical refining is the most flexible choice for a stand-alone refinery processing seed oils with different pretreatments and qualities. Physical refining may be preferred for oils low in phospholipids and high in FFA like tropical oils. It is also an important refining route for partly processed oils. However, physical refining needs a higher temperature for deodorisation. This may be a barrier in view of food safety.

The next step is neutralisation in which an aqueous alkali, typically caustic soda or sodium carbonate, is splashed into the oil which has been preheated to around 75 to 95 ºC. The alkali reacts with the ffa in the oil to form soaps, which are separated by sedimentation or centrifugation. A drying step may be incorporated after neutralisation to ensure the complete removal of the added water.

The neutralised oil is bleached to remove colouring matter, such as carotenoids and other minor constituents, such as oxidative degradation products or traces of transition metals. Bleaching uses activated Fuller’s earth with treatments typically in the 90 to 130 ºC range for 10 to 60 minutes. The earth is sucked into the oil under vacuum and is removed by filtration.

### 11.2.2.2 Degumming

Degumming involves the addition of water to hydrate any gums present, followed by centrifugal separation. Non-hydratable gums are removed by converting them first to a hydratable form using phosphoric or citric acid, followed by the addition of water and centrifugation.

Degumming consists of two parts: water degumming and acid degumming. Water degumming is carried out at the oil mill and thus belongs to the oilseed processing. Acid degumming is the first step in refining. Degumming reduces the level of phospholipids in vegetable oils. Phospholipids in vegetable oils originate from the plant tissue (cell membranes). They concentrate in the oil during the oil extraction process. Extracted seed oils like soybean oil, sunflower oil and rapeseed oil are high in phospholipids (generally measured as ppm phosphorus). Palm oil, palm kernel oil and coconut oil are low in phospholipids. Phospholipids need to be reduced in the first step of the refining sequence since they will lead to high bleaching earth consumption, fouling of heating coils and brown colouring of the oil at high temperature. A part of the phospholipids is hydratable. This means that they adhere to water and that they can be removed by water washing (water degumming). The remaining phospholipids
are non-hydratable. They need to be treated with acid (citric or phosphoric acid) to make them hydratable. After water or acid dosing and a reaction time, a centrifuge separates the phospholipids from the oil. The separated phospholipids will entrain some oil and impurities; this mixture is called gums or lecithin. Good quality lecithin from water degumming can be used as emulsifier in food applications.

The industrial degumming processes are [215, FEDIOL 2015]:

- **water degumming**, which only removes the hydratable phospholipids. The level of non-hydratable phospholipids in water degummed oils is relatively high (above 100 ppm P) and difficult to remove by subsequent acid degumming. Water degumming is generally carried out at the oil mill, the removed lecithin can be purified for use as emulsifier (high value by-product) or added to the meal and valued as feed;
- **acid degumming** (see Figure 11.2), which also removes a part of the non-hydratable phospholipids. The phospholipids level in acid degummed oils (10–30 ppm) is much lower than that in water degummed oils. However, the removed phospholipids are of insufficient quality for lecithin production. They can be valorized by adding them to the meal as feed. Acid degumming can be carried out with citric acid or phosphoric acid (sometimes diluted alkali is added after the reaction time to neutralise the remaining acid). Citric acid is often preferred because of its efficiency and because it chelates metal traces. However, it is not effective for all oils. Phosphoric acid is a stronger acid which is a benefit for oils that are high in non-hydratable phospholipids. However it increases the phosphorus emission in waste water;
- **water or acid degumming** followed by treatment with enzymes. This process is recently introduced after efficiency improvement and cost reduction of the enzymes. The enzyme phospholipase-A2 catalyses the splitting of the fatty acid ester under mild conditions. The liquid enzyme is dispersed into the oil at 60 °C and at pH 5, with citric acid and caustic soda as a sodium citrate buffer. To increase the low reaction rate of the enzymatic reaction, a battery of continuous stirred reactors is applied. The resulting lysolecithin molecule is water soluble and can be separated by centrifugation. The main advantage is the lower oil loss of the degumming process. Implementation depends on the additional costs of the enzymatic process, the oil loss of the current process and the value of the by-product. The crude oil quality is more constant when applying enzymatic degumming, compared with acid degumming;
- **degumming combined with chemical neutralisation** of the oil. Phosphoric or citric acid is dosed to the oil before addition of a diluted alkali solution. The alkali reacts with free fatty acid (FFA) to form soap. The phospholipids are removed together with the soap and further treated in the soap splitting installation. This process is robust and flexible and is the only process that can remove non-hydratable phospholipids from water degummed oils.

**Figure 11.2**: Basic flow diagram for the acid degumming of vegetable oil
11.2.2.3 Deodorisation

Deodorisation is the use of steam distillation to strip FFA and other highly volatile components, under vacuum conditions, from oils and fats. The equipment used for deodorisation consists of a steam distillation column, barometric condenser, demisters and scrubbers. Steam is injected into the oil heated to over 200 °C at the bottom of the distillation column, which is under vacuum conditions. The steam strips the FFA and other impurities from the oils and fats but gums are not removed by this process. The steam is condensed afterwards, using a barometric condenser of either once-through or closed-circuit design. The separation of the volatile components from this steam can be enhanced by a one-stage or a two-stage scrubbing/condensation system and by demisters. Deodorisation can be operated in batch or continuous deodorising vessels.

Deodorisation is the final treatment step in the refining process that converts crude oil to finished oil. The pretreated oil is heated up to the deodorising temperature, i.e. 180–270 °C, using a heat exchanger and indirect steam. To prevent oxidation of the oil, the atmosphere in the deodorising equipment is at almost absolute vacuum, i.e. 0.5–8 mbar. At the given vacuum and temperature conditions, stripping steam provides the driving force and the carrier for removing volatile components from the feedstock.

The vapours from the deodoriser vessel contain air, water vapour, fatty acids and other volatiles. Prior to entering the vacuum equipment, the vapours pass a scrubber. A scrubbing liquid is sprayed in the vapour stream. Fatty acids and volatiles partly condense on the scrubbing droplets or alternatively on the packing material. Since the scrubber is at the same vacuum as the deodoriser, water vapour will not condense.

The pre-cleaned vapour stream now enters the booster steam ejector of the multistage vacuum system. The steam jet is a thermo compressor and hence the vapour pressure increases up to 30–50 mbar. In a classical designed vacuum system, the vapours are then condensed in an open barometric condenser. The water vapour coming from stripping steam and pressurised steam are condensed and a tremendous reduction in volume is achieved. This contributes to maintaining the vacuum at the specified levels. Non-condensable components from the barometric main condenser are removed by a de-aerating system comprising one or more small intermediate condensers and one or more small steam ejectors. The condensers also use cooling water, i.e. 10–15 % of the cooling water flows through the main condenser. The water from the barometric condensers may be polluted. The function of 1 or 2 steam jets may be replaced by the application of a water ring vacuum pump (see Section 11.4.1.1).

Section 11.4.2.3 describes some techniques used for deodorisation.

Table 11.1 shows a comparison of the cooling systems used for vacuum generation in vegetable oil deodorisation based on generating a moderate vacuum of approximately 4 mbar.

Table 11.1: Comparison of cooling systems for vacuum generation in vegetable oil deodorisation

<table>
<thead>
<tr>
<th>Cooling systems for vacuum generation</th>
<th>Steam</th>
<th>Electricity</th>
<th>Total primary energy input</th>
<th>Waste water</th>
<th>Investment costs</th>
<th>System complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once-through system</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Alkaline loop</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>−</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Alkaline loop with chiller</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>−</td>
<td>−</td>
</tr>
</tbody>
</table>

+ (+, +) = (most) favourable
− (−, −) = (most) unfavourable

NB: The total primary energy input for the specified vacuum system is the sum of the amount of energy needed in the installation for generating steam and the energy input in the external power plant to produce the electricity needed.

Source: [75, FEDIOL 2002]
11.2.2.4 Crystallisation of edible oils and fats

Crystallisation of edible oils and fats, also called fractionation, is based on the principle that the solubility of the higher melting components in the liquid phase change at different temperatures. This difference can be extended by using an organic solvent which has the effect of decreasing the viscosity and leading to better washing of the crystals.

The equipment includes tanks for preheating; stirred and cooled tanks for crystallisation; band or membrane filters for the separation of the crystals from the liquor and distillation vessels for solvent recovery. The oil is heated to 10 ºC above the melting point of the highest tracylglycerol present, to give a fully liquid starting material, e.g. the heating point is typically 75 ºC for palm oil. The molten oil is then cooled and stirred to form crystal nuclei, and the temperature is maintained at a lower temperature to induce crystal growth, typically for 12 hours at 28–30 ºC for palm oil. If a solvent is used, it is added to the molten oil prior to cooling. The mixtures containing the crystallised solids and the dissolved liquids are separated by filters. If a solvent is used, it is removed from the fractions by distillation.

11.2.2.5 Further processing of edible oils and fats—margarine

The main products manufactured from edible oils and fats are margarine, edible fats, edible oils and mayonnaise. In view of its major outstanding importance, only margarine production is described here.

Most installations carry out hydrogenation to produce fats with superior retention qualities and higher melting points. Hydrogenation is usually carried out by dispersing hydrogen gas in the oil, in the presence of a finely divided nickel catalyst supported on diatomaceous earth. The resultant hydrogenated fats are filtered to remove the hydrogenation catalyst, subjected to a light earth bleach and deodorised before they can be used for edible purposes. After hardening, the oil is mixed with an aqueous solution to produce an emulsion. The emulsified mixture is then pasteurised, cooled and crystallised to obtain the final product.

Hardening, or hydrogenation of oils, is the process of saturating mono or poly-unsaturated fatty acids by adding hydrogen gas (H₂) for the hydrogenation and nickel as a catalyst. Hydrogen molecules, in the presence of nickel and under special process conditions, saturate the unsaturated bonds of the fatty acids of edible oils. Neutral or bleached oil is heated to a temperature of 150 to 205 ºC in the presence of a nickel catalyst, maximum 10 kg catalyst/tonne product. H₂ is then added to the mixing reactor to achieve the hardening, i.e. the transformation from oil to fat. Hydrogenation is an exothermic process. After the reaction, the fats are separated from the nickel, using filter presses or other filter systems. In a minority of cases, the nickel catalyst can be reused several times until it is deactivated. Specialised companies recycle the spent nickel. The residual nickel concentration in the fats is removed by bleaching, which produces bleaching earth contaminated with nickel. The equipment used for hardening consists of mixing vessels, reaction tanks, autoclaves and filters.

Emissions to air

Hydrogen emissions, e.g. in the case of installation breakdown, have an associated explosion/fire risk.

Solid output

The solid output contains the spent nickel and specialised companies can recycle this.

Noise

Noise issues may arise from cooling towers, compressors or vacuum systems.
11.3 Current consumption and emission levels

11.3.1 Energy consumption

The energy consumption during the production of crude vegetable oil depends on the type of raw material, the equipment and the manufacturing processes. Heating, cooling, drying, milling, pressing, evaporation and distillation are the major energy-consuming steps. Cold pressing, without heat conditioning of the raw material, which is especially used for olive oil production, needs twice as much energy as the pressing of heat conditioned oilseeds.

Figure 11.3 shows data for specific energy consumption (MWh/tonne of product) from oilseed processing and vegetable oil refining installations.

![Figure 11.3: Specific energy consumption (MWh/tonne of product) in oilseed processing and vegetable oil refining](image)

Energy consumption of extraction is of 170–390 kWh steam (600 to 1400 MJ) and 30–60 kWh/t oilseed (100 to 200 MJ). The energy consumption depends mainly on the kind of oilseed and of the type of cooling water circuit.

For deodorisation, energy is needed in the form of steam and electricity. The electrical energy consumption ranges from 17–42 kWh/t product (60–150 MJ/t), and steam consumption from 115–310 kWh/t product (420–1120 MJ/t).

For hardening, energy is supplied as steam and electricity. Total energy consumption is between 110 to 280 kWh/t product (400 and 1000 MJ/t).

Steam consumption is in the range 200–500 kg steam/t processed seed (155–390 kWh/t) and the electricity need is in the range 25–50 kWh/t processed seed (90–180 MJ/t) [109, CIAA-FEDIOL, 2003, 182, Germany, 2003, 185, CIAA-FEDIOL, 2004]. Table shows energy and steam consumption for some processes in crude vegetable oil refining in German installations. Further energy consumption figures for some processes are given in techniques described in Sections.


### Table: Energy consumption in crude vegetable oil refining

[65, Germany, 2002, 109, CIAA-FEDIOL, 2002]

<table>
<thead>
<tr>
<th>Processing step</th>
<th>Total energy consumption</th>
<th>Steam consumption</th>
<th>Electricity Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(MJ/t final product)</td>
<td>(MJ/t final product)</td>
<td>(MJ/t final product)</td>
</tr>
<tr>
<td>Neutralisation</td>
<td>145–330</td>
<td>112–280</td>
<td>22–44</td>
</tr>
<tr>
<td>Soap splitting</td>
<td>620–2850</td>
<td>560–2800</td>
<td>11–36</td>
</tr>
<tr>
<td>Deodorisation</td>
<td>510–1350</td>
<td>420–1120</td>
<td>60–150</td>
</tr>
<tr>
<td>Hardening</td>
<td>400–1000</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>Bleaching</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>Neutralisation</td>
<td>40–92</td>
<td>34–78</td>
<td>6–12</td>
</tr>
<tr>
<td>Soap splitting</td>
<td>172–792</td>
<td>156–778</td>
<td>3–10</td>
</tr>
<tr>
<td>Deodorisation</td>
<td>142–375</td>
<td>117–311</td>
<td>17–42</td>
</tr>
<tr>
<td>Hardening</td>
<td>441–278</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>Bleaching</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
</tbody>
</table>

*Calculated using 2.8 × kg steam/t = MJ/t

**MJ/t soap or kWh/t soap

n.d. (no data available)

Final product = refined vegetable oil

### 11.3.2 Water consumption

Figure 11.4 shows data for specific water consumption (m³/tonne of product) from oilseed processing and vegetable oil refining installations.

![Figure 11.4: Specific water consumption (m³/tonne of product) in oilseed processing and vegetable oil refining](source)

In the extraction process of oil from oilseeds with hexane, cooling water is needed in an amount of 0.2 to 14 m³/t oilseed. Furthermore, a certain amount of waste water is generated, mainly from the hexane/water separation, which amounts to 0.2 to 0.5 m³/t oilseed; the load being of 0.1 to 1 kg COD/t oilseed. The amounts of water consumption and of pollution depend on the cooling water system, e.g. once-through or with recycling, and on the kind of oilseeds. The
throughput rate of the toaster also has a major influence on these parameters. Water consumption for the pressing of oil seeds and beans is minimal.

For hardening, water is used for cooling purposes because the end-product should not be warmer than 100 °C. Steam, from demineralised water, is necessary to heat the autoclaves and/or reactors. Water is also used for cleaning the installation. The water consumption is between 0.8 and 2 m³ of drinking water and/or demineralised water per tonne of product. This depends on the type of cooling system. Cooling water consumption is between 2 and 5 m³ of product [62, CIAA-FEDIOL 2002].

11.3.3 Waste Solid output

Depending on the type of vegetable, i.e. oilseed or oilfruit, the raw materials for vegetable oil production can almost completely be converted into products, e.g. vegetable oil, protein-rich meal, fatty acids and lecithin, or by-products, e.g. for human food, animal feed and pharmaceutical products.

Solid waste, e.g. leaves, wood, pieces of metal and stones, is generated in the raw material’s primary treatment step (cleaning and hulling). This is separated during the cleaning of the raw material by wind sifters, magnet separators and sieves. In oilseed production, this fraction is less than 1 % of the processed seed. Metals are sent for recycling or disposal and the remainder, such as stones and sand, is disposed of. Dust may be incinerated. In the pressing/centrifuging step, used filter clothes from seed pressing are produced and are also disposed of [90, Verband Deutscher Oelmühlen 2003].

In the case of chemical refining, soap stock is produced during the neutralisation of crude oil. This consists mainly of NaOH saponified FFA, but also contains phosphatides, proteins and other compounds. Normally, it is further processed in the refinery by splitting the soaps and regaining the fatty acids (acid oil). In some countries, it is possible to mix the soap stock from the chemical refining of vegetable oil with other ingredients for the production of low quality soaps or for use in meal for animal feed.

The production of solid wastes from vegetable oil refining and processing is dependent on the specific site. In bleaching operations, spent bleaching earth containing 20–40 % fat is produced. This makes the waste prone to spontaneous combustion. In production installations, which exclusively refine and modify edible oil, the spent bleaching earth is utilised by third parties for energy production by co-fermentation to produce biogas or to make bricks [94, Germany 2003]. The spent catalyst is recycled to third parties for regeneration.

In mixed production installations, which produce crude oil and meal, and refine/modify the edible oil, there are further opportunities for utilisation of components of the raw material and of wastes. For example, utilisation of phospholipids in meal and utilisation of spent bleaching earth in meal, both as animal feed. The precondition for the latter example is the absence of nickel catalyst residues [90, Verband Deutscher Oelmühlen 2003].

Deodoriser distillate, collected from the steam distillation of refined edible oils, has a variable composition depending on the raw material and the refining process. When arising from physical refining, if the pesticide content is low, it can be used in the feed industry. Otherwise, it can be sold as a source of technical fatty acids. Those from chemical refining have higher values due to their higher tocopherol content. They are an attractive feedstock for the production of vitamin E. Due to the increasing interest in natural antioxidants, such as tocopherol, and the use of phytosterols in the food and pharmaceutical industry, the importance of this distillate will probably increase.

The types of solid/liquid output from different vegetable oil processing unit operations, are shown in Table 11.2.
Table 11.2: Summary of key solid/liquid emissions and by-products in the manufacturing of crude vegetable oils

<table>
<thead>
<tr>
<th>Solid/liquid output</th>
<th>Degumming</th>
<th>Neutralisation</th>
<th>Bleaching</th>
<th>Deodorisation</th>
<th>Hardening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mucilage</td>
<td>Soapstock and spent acids/alkalis</td>
<td>Spent earth containing gums, metals and pigments</td>
<td>None</td>
<td>Spent catalysts and spent filtering aid</td>
<td></td>
</tr>
</tbody>
</table>


A comparison between the solid output from olive oil production and seed oil production is given in Table.

Table: Summary of solid output from manufacturing crude vegetable oils

Types and quantities of wastes and by-products are summarised in Figure.

Figure: Types and quantities of wastes and by-products generated in vegetable oil processing
11.3.4 Chemicals used

Ideally, the extraction solvent should only dissolve glycerides and leave undesirable components such as colouring matter, gums, and phospholipids. The solvents must not contain toxic components, and should be recoverable with minimum loss, be safe in handling, and be readily removable from the extracted material. For these reasons, aliphatic hydrocarbons, especially hexane, are used almost exclusively. Technical hexane with a boiling point range of 55–70 °C has proved to be the optimum solvent. Hexane can be readily removed from the oil at temperatures below 100 °C under vacuum and can be stripped from the meal with steam. The solubility of hexane in the condensed water is only 0.1 %.

Alcohols like ethanol, isopropanol, methanol, butanol, and furfural are especially suited to the extraction of relatively wet materials. The extraction of oilseed with alcohols leads to relatively high concentrations of phosphatides, glycolipids, carbohydrates, and similar constituents in the crude oil, although the glycerides can, in principle, be concentrated by cooling or extraction of the alcoholic solutions. Alcohols are generally not used as primary extraction solvents. However, they are occasionally used as secondary extraction solvents to remove gossypol from cottonseed meal, thioglycosides from rapeseed meal, sugars from soybean meal (to produce protein concentrates), and alkaloids from bitter lupine meal. A new technology is oil supercritical propane or carbon dioxide extraction, where extraction takes place under high pressure. This process is reserved for special products of high intrinsic value because of the high equipment costs involved [51, Ullmann 2001].

Chemicals are used in the chemical neutralisation of crude oil. 1–6 kg/t oil NaOH and 0.1–2 kg/t oil is used depending on the function of the type of oil and the ffa content of the pre-degummed or not, crude oil. If phosphoric acid is used, 0.1–2.0 kg/t oil is consumed. Alternatively, citric acid may also be used; its consumption is 0.1–1.0 kg/t oil. Sulphuric acid used in soap-stock splitting amounts to 100–250 kg H₂SO₄/t soap [62, CIAA-FEDIOL 2002].

11.3.5 Emissions to water

During production of refined oil from rapeseed, about 10–12 m³ waste water can be generated per metric tonne of raw material. The waste water contains emission levels up to 5 000 mg/l COD, 4 500 mg/l TSS and 1 200 mg/l FOG [71, AWARENET 2002].

Figure 11.5 shows reported data on specific waste water discharges (m³/tonne of product) from oilseed processing and vegetable oil refining installations.
11.3.6 Emissions to air

11.3.6.1 Dust emissions from seed processing

Dry dust is generated during seed delivery, silo storage, seed cleaning, seed preparation, meal shipment and indoor transportation/conveying. Wet dust can arise during seed preparation, meal drying and cooling, and indoor transportation/conveying.

Bag filters and cyclones or a combination of them (cyclones as a first step) are mainly used as final abatement techniques for the dust emissions from seed processing. Most common related emissions sources are raw materials unloading/uploading, raw materials storage and transport, raw materials cleaning and seed drying. A general overview of the data received for dust emission from seed processing is shown in Figure 11.6 (lower values) and Figure 11.7 (higher values).

![Figure 11.6: Total dust emissions to air from seed processing (1 of 2)](source: [193, TWG 2015])

![Figure 11.7: Total dust emissions to air from seed processing (2 of 2)](source: [193, TWG 2015])
The meaning of the symbols used in Figure 11.6 and Figure 11.7 is indicated in Table 3.5.

11.3.6.2 Dust emissions from drying and cooling of meal

Table 11.3 shows data on average dust emissions to air from drying and cooling of meal. Basically bag filters (sometimes in combination with a previous cyclone step) are used as final abatement technique.

Table 11.3: Average dust emissions to air from drying and cooling of meal

<table>
<thead>
<tr>
<th>Number of release points involved</th>
<th>Range of average dust emissions (mg/Nm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>$&lt;1$–39.63</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

11.3.6.3 TVOC emissions

Data from monitoring of channelled TVOC emissions are shown in Figure 11.8. The data refer to 24 points of release. In 16 cases TVOC measurements are below 200 mg/Nm$^3$. Channelled emissions include the desolventising process and the drying and cooling of meal. Wet scrubbers and biofilters are applied as final abatement techniques.

Figure 11.8: TVOC emissions to air from oilseed processing and vegetable oil refining

The meaning of the symbols used in Figure 11.8 is indicated in Table 3.5.

11.3.6.4 Hexane loses

The hexane recovery cycle is quite effective but some losses of hexane occur during oilseed processing. In a typical extraction installation, the following sources and causes of hexane loss can be distinguished [214, FEDIOL 2015]:

- residual hexane in meal (after desolventising/toasting and drying/cooling);
- residual hexane in crude oil (after miscella distillation and oil stripping);
• exhaust from the mineral oil absorption system;
• exhaust from the meal dryer and meal cooler vents;
• process waste water (after hexane-water separator and reboiler);
• fugitive losses from equipment leaks via e.g. seals, gaskets and flanges, sight glass mountings.

The following factors determine hexane loss during oilseed processing [214, FEDIOL 2015]:

• the hexane retention characteristics of the meal as affected by the oilseed type, its geographical origin and the climatic conditions during its cultivation;
• the local ambient temperatures, affecting the effectiveness of condensing/cooling systems involved in the hexane recovery processes;
• the complex interrelationship of consecutive processing steps. Operators aim to strike a balance between installation capacity utilisation, throughput, oil yields, product quality considerations, energy efficiency, process safety, hexane loss and processing cost and margins.

More in detail, hexane losses can be generally attributed as follows [223, FEDIOL 2014]:

• hexane losses via meal are generally dominant in the total losses and are typically in the range of 30-60 %;
• hexane losses via oil are typically in the range of 2-6 % of total hexane losses;
• the combined hexane loss via the exhaust from the mineral oil absorber and meal drying/cooling vents typically represents 5-20 % of total hexane losses;
• the process water is virtually hexane-free and hexane losses via water fed to the waste water system are negligible;
• the combined losses associated with evaporative losses from equipment leaks and start-up and shut-down operations may explain the balance of the hexane losses.

Indicative contribution of sources of hexane loss during oilseed processing is shown in Table 11.4.

Table 11.4: Indicative contribution of sources of hexane loss during oilseed processing

<table>
<thead>
<tr>
<th>Sources of hexane loss</th>
<th>Kg hexane per tonne of seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meal</td>
<td>0.05–0.3</td>
</tr>
<tr>
<td>Crude oil</td>
<td>0.02–0.05</td>
</tr>
<tr>
<td>Exhaust from Mineral Oil System and Drying/Cooling vents</td>
<td>0.05–0.15</td>
</tr>
<tr>
<td>Waste water</td>
<td>Negligible</td>
</tr>
<tr>
<td>Fugitive losses and losses from start-ups and shutdowns</td>
<td>0.1–0.5</td>
</tr>
</tbody>
</table>

Source: [223, FEDIOL 2014]

A general overview of the data received for specific hexane loses (which are equivalent to specific hexane consumption) is shown (in an anonymised form) in Figure 11.9.
Chapter 11

If solvent extraction is applied, leakages and transportation can cause losses to the air. Following the extraction step, emissions of solvent (hexane) may occur during drying, cooling, storage and the transportation of meal and crude oil. Air emission levels for hexane, associated with various seed feedstocks, are shown in Table.

![Figure 11.9: Specific hexane consumption](image)

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Hexane Output (kg hexane/t raw seed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soy beans</td>
<td>0.5 – 1.0</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>0.5 – 1.2</td>
</tr>
<tr>
<td>Sunflowerseed</td>
<td>0.5 – 1.2</td>
</tr>
<tr>
<td>Linseed</td>
<td>about 2.0</td>
</tr>
<tr>
<td>Castor</td>
<td>&gt;3.0</td>
</tr>
</tbody>
</table>

Table: Hexane emission to air
[65, Germany, 2002]

11.3.6.5 Odour emissions

Odour is produced in all steps where heating is involved. It results from the volatile fatty acids, organic nitrogen compounds and, in the case of rapeseed, hydrogen sulphide and organic sulphur compounds.

The exhausts from aspiration systems in seed preparation and seed pressing, exhausts from meal drying and cooling and the exhaust from the mineral oil system are sources of odour emissions. Odour emissions generally are higher for rapeseed than for soybean due to the presence of sulphur-containing substances (H\textsubscript{2}S) in the rapeseed. The sulphur content of the rapeseed may depend on the crop variety and applied agricultural practices. Sulphur-containing organic substances may decompose under influence of seed/meal being exposed to relative high temperatures in seed heating, seed pressing, seed extraction and meal desolventising/toasting and meal drying/cooling. Hydrogen sulphide can be a key odour component in the exhaust of the mineral oil system of a rapeseed crushing installation. Odour can be an issue when the emitting installation is relatively close to residential areas.

In some seeds, e.g. rapeseed, the sulphur content may be high. Enzymatic and biological processes may convert sulphur compounds into hydrogen sulphide. No emission data have been
reported yet during storage but significant hydrogen sulphide concentrations have been detected in the exhaust air of extractors [65, Germany, 2002]. Air emission types during the manufacture of crude vegetable oils are shown in Table.

<table>
<thead>
<tr>
<th>Degumming</th>
<th>Neutralisation</th>
<th>Bleaching</th>
<th>Deodorisation</th>
<th>Hardening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatile compounds</td>
<td>Odour</td>
<td>Eta</td>
<td>Volatile compounds</td>
<td>Odours</td>
</tr>
</tbody>
</table>

Table: Summary of air emissions in the manufacturing of crude vegetable oils [10, Environment Agency of England and Wales, 2000, 74, Greek Ministry for the Environment, 2001]
11.4 Techniques to consider in the determination of BAT

11.4.1 Techniques to increase energy efficiency

11.4.1.1 Water ring pumps for generating an auxiliary vacuum

Description
The auxiliary vacuum used for oil drying, oil degassing or minimisation of oil oxidation is generated by pumps (e.g. water ring pumps). The vacuum reduces the amount of thermal energy needed for these process steps.

Technical description
Water ring pumps generate a low stable vacuum which can be used for degassing and drying of oils and fats of animal and vegetable origin. When degassing the oil, the vacuum is used during hydrogenation, where H₂ is used, and after interesterification, where water is used to inactivate the catalyst. When drying the oil, vacuum is used after degumming, after neutralisation, before and after interesterification and before hydrogenation. Vacuum is also used to ensure an oxygen free atmosphere in the reactor/evacuating reactor during hydrogenation and interesterification.

Achieved environmental benefits
Reduced energy requirements. Low pollution of the waste water. Reduced emissions from energy generation.

Cross-media effects
Generation of waste water.

Environmental performance and operational data
Waste water results from the water used to drive the pumps. This is generally characterised by a low specific volume per unit. Owing to the applications, such water is only slightly polluted at the point of origin, even if it contains condensates from the drying processes. The load can be described in terms of its COD emission level, because nitrogen or phosphorus compounds cannot be carried into such water in significant quantities under the prevailing process conditions, e.g. temperatures \( \leq 100 \) °C. The reported volume of waste water is of up to 1.7 m³/t unrefined oil and the COD emission level is of up to 75 mg/l.

Technical considerations relevant to applicability
Applicable when a vacuum range of 40 to 120 mbar is required. It is readily available and its operating reliability is very good, allowing series production. The technique results in a low throughput. Diversity of systems concerned. Completely different vacuum conditions for distillative neutralisation/deodorisation.

Economics
TWG, please provide information.

Driving force for implementation
Reduced costs due to appropriate vacuum conditions.

Reference literature
[ 35, Germany 2002 ], [ 100, Bockisch M. 1993 ]

Reuse of heat in the hardening of vegetable oils

Technical description
The hydrogenation reaction that occurs during the hardening of oils to produce fats for cooking, eating and soap making, is an exothermic process. The reaction produces heat of 41.67 – 152.78 kWh/t (150 – 550 MJ/t) of feedstock. The heat generated depends on the
feedstock and product specification and range, e.g. if fewer hydrogenated products are made, then less steam is generated. This heat is used to heat the product to the desired reaction temperature and to generate steam later in the reaction.

**Achieved environmental benefits**
Reduced energy consumption, e.g. improvement in the process efficiency through heat recovery. Reduction in emissions due to energy generation.

**Environmental performance and operational data**
In an example edible oil refinery, the steam generated is fed into the existing 300 000 Pa (3.5 bar) steam main pipe of the installation, thereby reducing the primary steam consumption of the installation as a whole. The reported energy (steam) generation amounts to 25–425 kWh/t (90–450 MJ/t) (40–200 kg/t) unrefined oil. In addition, by using the exothermic energy from hydrogenation, a 5 to 10% reduction in consumption of primary energy at the selected site is achievable.

**Technical considerations relevant to applicability**
Widely applicable and good operating reliability. The following issues can restrict its applicability:

- proportion of the entire product specification and range which involves hydrogenation
- the existing energy supply strategy of the installation as a whole, e.g. external supply
- the existing energy mix of the installation as a whole, e.g. ratio of electricity to steam
- type of energy agreements with external suppliers/consumers.

**Economics**
Additional investment costs are needed. Lower operational costs due to the reduced input of steam generation.

**Driving force for implementation**
Precautionary energy management.

**Reference literature**
[35, Germany 2002], [97, CIAA/FEDIOL 2004]

### 11.4.2 Techniques to reduce emissions to air

#### 11.4.2.1 Reduction of dust emissions from seed handling and preparation

**11.4.2.1.1 Bag filter**

The technique is generally described in Section 2.3.7.2.2.

**Environmental performance and operational data**
Table 11.5 shows installation-specific performance data related to the application of bag filters for dust abatement.
Table 11.5: Total dust emissions to air from seed handling, preparation and drying after treatment in a bag filter

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm$^3$)</th>
<th>O$_2$ content (%) dry basis</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>094-5</td>
<td>0.20</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Rapeseed receipt of raw material (rape receipt, washing)</td>
</tr>
<tr>
<td>092-5</td>
<td>0.50</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Rapeseed Dust extraction ship unloading</td>
</tr>
<tr>
<td>304-3</td>
<td>0.60</td>
<td>21.00</td>
<td>EN 13284-1</td>
<td>Twice a year</td>
<td>Sunflower seed, grapeseeds Seed cleaning</td>
</tr>
<tr>
<td>466-2</td>
<td>0.70</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Soybean, rapeseed Soy beans sieving</td>
</tr>
<tr>
<td>304-4</td>
<td>0.75</td>
<td>21.00</td>
<td>EN 13284-1</td>
<td>Twice a year</td>
<td>Sunflower, grapeseeds Corn germ dryer Tubular filter</td>
</tr>
<tr>
<td>225-4</td>
<td>0.93</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Biennial</td>
<td>Soybean Preparation</td>
</tr>
<tr>
<td>086-2</td>
<td>1.00</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Soybean, rapeseed Crushing soybeans (flakers)</td>
</tr>
<tr>
<td>225-2</td>
<td>1.10</td>
<td>20.00</td>
<td>EN 13284-1</td>
<td>Biennial</td>
<td>Soybean Seed drying</td>
</tr>
<tr>
<td>469-8</td>
<td>1.15</td>
<td>21.00</td>
<td>PN-Z-0403-7</td>
<td>Yearly</td>
<td>Rapeseed Rapeseed unloading Cyclone step before</td>
</tr>
<tr>
<td>223-2</td>
<td>1.70</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Soybean Silos</td>
</tr>
<tr>
<td>224-8</td>
<td>1.80</td>
<td>NI</td>
<td>NI</td>
<td>Biennial</td>
<td>Sunflower seed Cyclone step before Seed drying</td>
</tr>
<tr>
<td>304-7</td>
<td>1.90</td>
<td>21.00</td>
<td>EN 13284-1</td>
<td>Twice a year</td>
<td>Sunflower seed, grapeseeds Hexpeller</td>
</tr>
<tr>
<td>305-4</td>
<td>2.20</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Soybean Flaking mills</td>
</tr>
<tr>
<td>375-8</td>
<td>3.00</td>
<td>20.90</td>
<td>NI</td>
<td>Once every three years</td>
<td>Soybean, rapeseed, sunflower seed Seeds pre-cleaning, cleaning, grinding, dehulling and hulls grinding dedusting Cyclone step before</td>
</tr>
<tr>
<td>471-4</td>
<td>5.00</td>
<td>NI</td>
<td>NI</td>
<td>Yearly</td>
<td>Sunflower seed Seed cleaning</td>
</tr>
<tr>
<td>090-3</td>
<td>6.13</td>
<td>20.90</td>
<td>VDI 2066</td>
<td>Once every three years</td>
<td>Rapeseed Nacelle (seed)</td>
</tr>
<tr>
<td>094-1</td>
<td>9.19</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Rapeseed Seed drying and bulk container Cyclone step before</td>
</tr>
</tbody>
</table>

NB: NI = No information provided
Source: [193, TWG 2015]

Reference literature
[193, TWG 2015]
11.4.2.1.2 Cyclone

The technique is generally described in Section 2.3.7.2.3.

Environmental performance and operational data

Table 11.6 shows installation-specific performance data related to the application of cyclones as dust abatement technique.

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>O₂ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>089-2</td>
<td>0.50</td>
<td>21.00</td>
<td>VDI 2066</td>
<td>Once every three years</td>
<td>Rapeseed, sunflower seed Pelletisation bruised grain</td>
</tr>
<tr>
<td>272-2</td>
<td>1.29</td>
<td>NA</td>
<td>NA</td>
<td>Yearly</td>
<td>Sunflower seed Expeller aeration system (seed side)</td>
</tr>
<tr>
<td>224-1</td>
<td>1.40</td>
<td>NA</td>
<td>NA</td>
<td>Biennial</td>
<td>Sunflower seed Preparation of seed</td>
</tr>
<tr>
<td>375-4</td>
<td>3.00</td>
<td>20.90</td>
<td>NA</td>
<td>Once every three years</td>
<td>Soybean, rapeseed Seeds pre-cleaning, cleaning, grinding, dehulling and hulls grinding</td>
</tr>
<tr>
<td>466-1</td>
<td>3.30</td>
<td>NA</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Soybean, rapeseed Soy flakers (white flakes line)</td>
</tr>
<tr>
<td>466-10</td>
<td>4.00</td>
<td>NA</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Soybean, rapeseed Flakes transport</td>
</tr>
<tr>
<td>304-8</td>
<td>5.25</td>
<td>21.00</td>
<td>EN 13284-1</td>
<td>Twice a year</td>
<td>Sunflower seed, grapeseeds Flaking</td>
</tr>
<tr>
<td>226-1</td>
<td>7.00</td>
<td>20.30</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Soybean Seed preparation</td>
</tr>
<tr>
<td>086-4</td>
<td>7.00</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>NA</td>
<td>Soybean, rapeseed Grist preparation</td>
</tr>
</tbody>
</table>

NB: NI = no information provided

Source: 193, TWG 2015

Reference literature

[193, TWG 2015]

11.4.2.1.3 Wet scrubber

The technique is generally described in Section 2.3.7.3.1.

Environmental performance and operational data

One installation (#468) reported the use of wet scrubbers as abatement technique for dust emissions from seed handling and preparation (see Table 11.7).
### Table 11.7: Dust emission levels to air from seed handling preparation and drying after treatment in a wet scrubber

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm$^3$)</th>
<th>$O_2$ content (%)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>304-10</td>
<td>3.50</td>
<td>21.00</td>
<td>EN 13284-1</td>
<td>Twice a year</td>
<td>Sunflower seed, grapeseeds Welding</td>
</tr>
<tr>
<td>468-7</td>
<td>4.80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>468-1</td>
<td>5.80</td>
<td></td>
<td>PN-Z-04030-7</td>
<td>Yearly</td>
<td>Rapseseed Cyclone and bag filter step before</td>
</tr>
<tr>
<td>468-3</td>
<td>6.80</td>
<td>20.90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>468-4</td>
<td>8.80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>468-6</td>
<td>10.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>468-8</td>
<td>11.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>468-9</td>
<td>13.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>468-5</td>
<td>15.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Source:** [193, TWG 2015]

### Reference literature

[193, TWG 2015]

---

**11.4.2.2 Reduction of dust emissions from the drying and cooling of meal**

#### 11.4.2.2.1 Cyclones

For general information about cyclones see Section 2.3.7.2.3.

**Technical description**

Following the extraction of oil from crushed oilseeds, the desolventised and toasted meal is dried and cooled with ambient air. The exhaust air from the drying and cooling contains dust. Due to the relatively high humidity of the exhaust air from the drying stage, the dust is wet and sticky. This sticky dust is difficult to separate from the airstream. A proper technology to do this is by using cyclones. The use of these enables a relatively smooth and uninterrupted dust removal from the dryer and cooler exhaust air. Dust collected by the cyclones can be returned to the dried meal. Therefore, cyclones are used for practical and safety reasons.

The use of fabric filter systems would lead to the condensation of the moisture, causing a deposition of dust and blockage of ducts. The combination of hot drying air and deposited meal dust can eventually result in the self-ignition of the dust, which could start a fire. Such fires present an especially hazardous situation because of the proximity of the hexane-wet flakes in the preceding desolventising-toasting section.

Electrostatic precipitators also create a fire and explosion risk due to sparking in combination with incidental high hexane concentrations in the exhaust air. The fine moist and sticky meal particles tend to agglomerate, causing the fraction of fine particles in the exhaust gases to be relatively low. In this sense, these separators, normally designed for removal of fine particles, are not suitable. Furthermore, the dried meal particles would become wet in the scrubber and the collected meal would then have to be dried again.

Figure 11.10 shows a basic flow diagram of a wet dust emission separation by cyclones.
Achieved environmental benefits
Reduced dust emissions, recovered product and reduced fire risk.

Environmental performance and operational data
The use of cyclones is reported to have good operating reliability and availability. Wet dust emission concentrations of <50 mg/Nm$^3$ are achieved.

Table 11.8 shows installation-specific performance data related to the application of cyclones as dust abatement technique.

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm$^3$)</th>
<th>O$_2$ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>225-6</td>
<td>0.90</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Biennial</td>
<td>Soybean Meal cooler</td>
</tr>
<tr>
<td>305-6</td>
<td>1.00</td>
<td>21.00</td>
<td>EN 13284</td>
<td>Yearly</td>
<td>Soybean Meal dryer</td>
</tr>
<tr>
<td>225-6</td>
<td>1.00</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Biennial</td>
<td>Soybean Meal cooler</td>
</tr>
<tr>
<td>223-8</td>
<td>&lt;1.30</td>
<td>NI</td>
<td>EN 13284</td>
<td>Biennial</td>
<td>Soybean Meal cooler</td>
</tr>
<tr>
<td>044-3</td>
<td>1.72</td>
<td>NI</td>
<td>NI</td>
<td>Biennial</td>
<td>Rapeseed Meal cooler</td>
</tr>
<tr>
<td>225-5</td>
<td>2.20</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Biennial</td>
<td>Soybean Meal dryer</td>
</tr>
<tr>
<td>226-3</td>
<td>5.60</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Soybean Meal dryer</td>
</tr>
<tr>
<td>466-9</td>
<td>11.00</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Soybean, rapeseed Exhaust from meal drying and cooling</td>
</tr>
<tr>
<td>088-1</td>
<td>11.60</td>
<td>NI</td>
<td>VDI 2066</td>
<td>Yearly</td>
<td>Soybean Exhaust from meal drying and cooling</td>
</tr>
</tbody>
</table>

NB: NI = no information provided  
Source: [193, TWG 2015]

Economics
There is an investment cost for the cyclones and transport systems for the recovered meal. Operating costs are high, e.g. due to extra energy consumption.
Driving force for implementation
Reduced product losses and prevention of fires. Also, the technique is reported to be technically and operationally good.

Reference literature
[75, FEDIOL 2002], [193, TWG 2015]

11.4.2.3 Reduction of TVOC and odour emissions

11.4.2.3.1 Thermal oxidation of waste gases

A general description of the technique is given in Section 2.3.7.3.6.

Environmental performance and operational data
Data have been reported by one oilseed installation (#303: soybean, rapeseed, sunflower seed, grapeseed as raw materials). Thermal oxidation is the final abatement technique for combustion of waste gases from a steam generator and direct contact dryer (only with pomace). A cyclone and an ESP step are applied before the thermal oxidation. A spot measurement in 2014 gave as a result 18.70 mg/Nm$^3$ of TVOC (16.70 % O$_2$ content, dry basis). The measurement was performed according to the EN 12619 monitoring standard. The sampling duration was 1 h. [193, TWG 2015]

11.4.2.3.2 Double wet scrubber in combination with a once-through cooling system in vegetable oil deodorisation

Description
Vapours are treated in a wet scrubber. The pre-cleaned vapour stream is mixed with the driving steam from the booster steam jet. Installing a second wet scrubber between a booster steam jet and the main condenser allows a further condensation of the volatiles.

Technical description
Vapours are treated in a wet scrubber. The pre-cleaned vapour stream is mixed with the driving steam from the booster steam jet. Installing a second wet scrubber between a booster steam jet and the main condenser allows a further condensation of the volatiles, replacing the stripping and driving steam prior to the mixing with cooling water in a once-through cooling system. The second scrubber may have fixed packing material or may be equipped with a dedicated scrubbing loop, a heat exchanger to remove the heat of condensation and a demister pad. The second scrubber operates at a higher pressure and due to the addition of steam, via the booster steam jet, the partial pressure of the volatiles is reduced. These two factors provide the basis for further condensation.

The double scrubber arrangement results in an improved scrubbing efficiency of the vapours. The additional condensation of volatile components in the second scrubber reduces the mass flow through the system. At the same time, the second scrubber contributes to an additional heat loss, however, the total energy requirements for the system are low. Figure 11.11 shows a basic flow diagram of the process.

The combined stripping steam and motive steam of the booster(s) is cooled in a condenser by surface water (river or lake) or in a closed loop through a cooling tower. Pollution of surface water or the cooling tower by residual fat is kept low by using an efficient fatty acid scrubber between deodoriser and vacuum system and a fat trap to capture fatty matter from the condenser outlet water. The cooling water is surface water that is returned into the environment after passing a fat trap. The presence of fatty material in the cooling water is very limited. In addition, the use of the second scrubber reduces the pollution load of the cooling water and improves the environmental profile of the cooling system.
The operational availability of the once through vacuum system is in general not limiting the operational availability of the deodoriser system. Maintenance of the equipment is done during the planned maintenance of the deodoriser (on average 1 week every two years).

Figure 11.11: Basic flow diagram of the double scrubber arrangement in deodorisation

Achieved environmental benefits
Reduction of odour emissions. Low energy requirements for the vacuum system. Reduction of the COD pollution. Higher by-product recovery compared to the single scrubber once-through cooling system.

Cross-media effects
Electricity consumption for the second scrubber loop.

Environmental performance and operational data
The scrubbing efficiency of the first scrubber is well above 90% when the feedstock is chemically refined. This treatment step achieves the initial removal of the bulk of the fatty acids. The second scrubber adds another 2–5% to the overall scrubbing efficiency [75, FEDIOL 2002]. The scrubber efficiency is related to the input of fatty acids with the deodoriser feedstock. The double scrubber arrangement combined with a once-through cooling system has no heat exchangers. Hence there are no problems with either heat exchanger fouling, or related to poor heat transfer issues. Process stability is high due to the simplicity of the system layout.

As the cooling system design is based on steam ejectors and open condensers with direct cooling water, it has the lowest energy requirement for generating the desired vacuum based on the consumption of electricity and steam. However, this system produces a cooling water flow with increased COD emission levels. The increase in COD emission levels may vary from 50–150 mg/l depending on the cooling water flow and the quality of the deodoriser feedstock. The double scrubber arrangement results in a lower increase of COD emission levels, i.e. 40–100 mg/l. The reported waste water volume is 1–10 m³/t unrefined oil [75, FEDIOL 2002].

Table 11.9 shows energy data of a double scrubber combined with a once-through cooling system.
Table 11.9: Energy data of a double scrubber combined with a once-through cooling system

<table>
<thead>
<tr>
<th>Energy consumption</th>
<th>Specific values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (depends on the content of FFA in the unrefined oil)</td>
<td>2–5 kWh/t unrefined oil</td>
</tr>
<tr>
<td>Steam</td>
<td>39–50 kWh/t (50–100 kg/t unrefined oil)</td>
</tr>
</tbody>
</table>

Source: [75, FEDIOL 2002]

In general, the steam consumption and electrical energy use depends on operating vacuum pressure, the temperature of cooling water or ambient air and the use of ejectors or vacuum pumps to extract the non-condensables. A once-through system running at a suction pressure of 2 mbar (deodoriser pressure = 3 mbar due to pressure drop over scrubber) with two boosters uses around 105 kg steam (excluding stripping steam) and 20 kWh electricity per ton deodorised oil. The total energy use for vacuum generation of a once-through vacuum system is around 15% lower than that of a cooled alkaline closed-circuit system. The system uses no chemicals [193, TWG 2015].

Technical considerations relevant to applicability
Suitable for existing and new installations, good operating reliability and readily available. The deodoriser feedstock quality should not contain high concentrations of short-chain fatty acids, e.g. coconut oil. Space availability is needed for the second scrubber.

The system can operate with only one booster if the maximum surface water or ambient air temperature is very low (around 10°C). However, for most EU countries the maximum surface water or ambient temperature is around 30°C, in that case two boosters in series are needed to obtain the low vacuum pressure of 2 mbar.

Economics
In general, rather low investment and maintenance costs [193, TWG 2015]. Investment costs are needed for the second scrubber.

Driving force for implementation
- Ensures operating stability of the deodoriser vacuum system.
- Compliance with water pollution legislation and government energy saving schemes. Reduced installation operational costs.
- The low investment and maintenance cost together with the simple operation makes it attractive to relative low capacity refineries.

Example plants
TWG, please provide information.

Reference literature
[75, FEDIOL 2002], [193, TWG 2015]

11.4.2.3.3 Single wet scrubber in combination with an alkaline closed-circuit system in vegetable oil deodorisation

Description
Vapours are treated in a wet scrubber. Afterwards, cooling water is circulated in a closed-circuit and the volatile components of the vapour stream are mostly trapped in the main condenser.

Technical description
Vapours (containing fatty acids) coming from the deodoriser are treated in a fatty acid wet scrubber. The pre-cleaned vapour stream is mixed with the driving steam from a booster steam jet. When the deodoriser feedstock contains higher concentrations of short-chain fatty acids, e.g. coconut oil, the installation of a second scrubber between the booster steam ejector and the main
barometric condenser will not reduce the COD pollution load from the once-through system to an acceptable emission level. In such cases, the overall assessment of the technique may conclude that the pollution load of the cooling water return is not acceptable despite the low energy requirements of the once-through cooling system. In this case or in similar situations, alkaline closed-circuit systems can be applied. The installation of a closed-circuit system makes the investment in a second scrubber obsolete.

In this cooling system, the cooling water is circulated in a closed-circuit and the volatile components of the vapour stream are mostly trapped in the main condenser. The main and intermediate condensers of the vacuum system may be part of the internal cooling water circuit, with a bleed to the waste water treatment system of the installation via the soap splitting installation. Two heat exchangers need to be installed to allow for cleaning. Caustic needs to be added to avoid rapid fouling by fatty material. The pH is raised to approximately 9 in the primary barometric condenser circuit. The condensate from the oil stripping steam and the ejector steam provides the water needed in the alkaline circuit. Excess water is withdrawn from the alkaline circuit as a soap solution. Soap splitting is carried out in a separate department. The aqueous phase is part of the acid waste water. The introduction of a closed-circuit system increases the steam consumption needed for generating the same vacuum.

The inlet temperature to the main condenser is 5 °C higher than with the open condenser system, which incurs on higher steam consumption on the steam ejectors and hence higher cooling water demands. This can make this process impossible under the given physical conditions necessary for product quality. Also, the internal closed-circuit may be chilled resulting in increased consumption of electricity and lower driving steam consumption. In this case, the cooling water circuit operates at a lower temperature emission level because it is cooled by a chiller. This system is generally used during higher ambient temperatures, e.g. in summer. Figure 11.12 shows a basic flow diagram of an alkaline closed-circuit cooling water system as part of a deodoriser vacuum system.

![Figure 11.12: Basic flow diagram of an alkaline closed-circuit cooling water system as a part of a deodoriser vacuum system](image)

In the chilled alkaline closed-circuit systems, the stripping steam leaving the deodoriser is compressed by one booster. The combined stripping steam and motive steam of the booster is cooled in a condenser by water circulating in a closed loop through a heat exchanger (primary
loop). The secondary loop through the heat exchanger is chilled by a refrigeration system to a few degrees Celsius. Alkaline is dosed in the primary loop to saponify residual fatty acids, the bleed of the primary loop (volume equal to volume of condensed steam) needs treatment with acid to split the soap before treatment in an effluent plant. The coolant compressor can use ammonia as refrigerant. Freon type of refrigerants can be used if local legislation does not allow the use of ammonia. [193, TWG 2015].

**Achieved environmental benefits**
Reduction of odour emissions. Chilled alkaline closed-circuit systems eliminate the COD pollution load of the waste water and reduce the waste water load. The closed-circuit reduces the fresh water requirements.

**Environmental performance and operational data**
A 99 % waste water volume reduction has been reported in comparison to once-through cooling (see Section 11.4.2.3.2). The volume of waste water generated is 0.06–0.15 m$^3$/t unrefined oil. It is reported that when using a closed-circuit system, the complexity increases and the reliability decreases. Closed-circuit systems involve internal heat exchangers, extra pump capacity and chiller installation. The energy requirements for the deodorising step in a refinery involve more than 50 % of the refinery’s total energy consumption. Closed-circuit alternatives, therefore, result in 10–20 % higher specific energy consumption values [192, COM 2006]. Table 11.10 shows energy data of an alkaline closed-circuit system.

<table>
<thead>
<tr>
<th>Energy consumption</th>
<th>Specific values</th>
<th>German example installation data</th>
<th>Reported data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (depends on content of FFA in the unrefined oil)</td>
<td>8–10 kWh/t unrefined oil</td>
<td>8–20 kWh/t unrefined oil</td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td>47–117 kWh/t unrefined oil (60–150 kg/t)</td>
<td>39–117 kWh/t unrefined oil (50–150 kg/t)</td>
<td></td>
</tr>
</tbody>
</table>

*Source: [192, COM 2006]*

In general, the steam consumption and electrical energy use depends on operating vacuum pressure, the temperature of cooling water or ambient air and the use of ejectors or vacuum pumps to extract the non-condensables. Typically, an alkaline recirculation system running at a suction pressure of 2 mbar (the deodoriser pressure is 3 mbar due to pressure drop over scrubber) with two boosters uses around 125 kg steam (excluding stripping steam) and 20 kWh electricity per tonne of deodorised oil [193, TWG 2015].

In the chilled alkaline closed-circuit systems, the steam consumption and electrical energy use depends on operating vacuum pressure and the use of ejectors or vacuum pumps to extract the non-condensables. In an example installation (#274), a chilled alkaline recirculation system running at a suction pressure of 2 mbar (deodoriser pressure = 3 mbar due to pressure drop over scrubber) uses around 35 kg steam (excluding stripping steam) and 20 kWh electricity per ton deodorised oil.

**Cross-media effects**
Increased input of caustic soda for the alkali circuit. Increased use of sulphuric acid for soap splitting. Increased volume of acid water. Increased organic load to the WWTP. Increased consumption of electricity and steam. Increased safety and environmental risks related to the use of refrigerants, e.g. ammonia.
Technical considerations relevant to applicability
Applicable when the deodoriser feedstock contains higher concentrations of short-chain fatty acids, e.g. coconut oil. Suitable for new and existing installations, and readily available. The space availability may restrict its application.

Under hot climate conditions, where there is a higher risk of process instability, e.g. vacuum fluctuations, the operating reliability is acceptable, in combination with adequate process controls. Under moderate climate conditions and after treatment for the removal of fats from the deodoriser vapours, if the technique is correctly operated its reliability can be very good, mainly due to the robust steam-jet vacuum pumps.

Economics
Closed-circuit systems have higher investment costs, operational costs and energy consumption compared to once-through systems. In addition, higher investment costs are reported for chilled closed-circuit systems. Maintenance costs are rather low. Maintenance of the equipment is done during the planned maintenance of the deodoriser (on average 1 week every two years).

Example plants
Various installations in Europe (e.g. Belgium, France, Germany) [193, TWG 2015].

Reference literature
[35, Germany 2002], [75, FEDIOL 2002], [100, Bockisch M. 1993], [193, TWG 2015]

11.4.2.3.4 Single wet scrubber in combination with a dry/ice condensing system in vegetable oil deodorisation

Description
Dry/ice condensing systems are placed between the scrubber and the de-aerating system, the latest removing non-condensable compounds.

Technical description
Dry condensing (DC) systems, also called ice condensing systems, are placed between the wet scrubber and the de-aerating system. The wet scrubber removes the major part of the FFA. The DC system takes out the remaining part of the FFA and the stripping steam that was used to drive out the FFA. The steam and FFA are condensed on the coils (heat exchanger) of the DC system at temperatures as low as -30 °C. The low temperature is generated by the mechanical compression of ammonia and evaporates it in the coils afterwards. The chiller unit requires extra electricity and cooling water. Only the non-condensable vapours will pass the scrubber and the DC system to the vacuum system. Figure 11.13 shows a basic flow diagram of a single scrubber in combination with a DC system.
Achieved environmental benefits
Reduction of odour emissions. Recovery of highly concentrated fatty acids. Reduced water consumption. Reduced waste water volume and load. Reduced steam consumption.
The main environmental benefits to be gained by using dry condensing for vacuum generation in deodorisation are: lower steam consumption leading to reduced energy consumption, a reduced water consumption and reduction of water pollution.

Cross-media effects
Increased input of electricity due to the refrigeration system. The use of ammonia for refrigeration results in an occupational health hazard and safety issue due to potential ammonia releases. Ammonia sensors and personal protection (gas masks) are required to minimise the risk of ammonia inhalation.

Environmental performance and operational data
It is reported that more than 95 % of all the condensable vapours are removed by the DC system, so the vacuum system can be much smaller [192, COM 2006]. Table 11.11 shows performance data from a case study of a DC system.

Table 11.11: Performance data of an example DC system

<table>
<thead>
<tr>
<th>Consumption level</th>
<th>Specific values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water for water ring pumps and for cooling the</td>
<td>300 kg/t unrefined oil</td>
</tr>
<tr>
<td>refrigeration plant for ice condensation</td>
<td></td>
</tr>
<tr>
<td>Electricity (depends on the content of FFA in the</td>
<td>10.5–21.5 kWh/t unrefined oil</td>
</tr>
<tr>
<td>unrefined oil)</td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td>5.5–15.5 kWh/t (20–150 kg/t)</td>
</tr>
<tr>
<td>Waste water</td>
<td>Up to 0.350 m³/t unrefined oil.</td>
</tr>
<tr>
<td></td>
<td>No phosphate or sulphate</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]
The polluted water production is generally equal to the steam consumption, approximately 15 kg per ton processed oil reported in one installation (#45). There is no solid waste for disposal.

**Technical considerations relevant to applicability**

Applicable when applying distillative neutralisation/deodorisation (physical refining). Suitable for new and existing installations. The space, low vapour fat contents, installation capacity and external safety requirements, e.g. due to the application of ammonia in the refrigeration system, can restrict its applicability. The operating reliability is good, thanks to control technology. The vacuum system is better as it is independent of weather conditions. Each deodoriser unit needs a separate dry condensing system.

The operational availability of the dry condensing system is in general not limiting the operational availability of the deodoriser system. Maintenance of the equipment is done during the planned maintenance of the deodoriser (on average 1 week every two years).

**Economics**

High investment costs. Increased electricity costs. High maintenance costs. Reduced need for steam. Increased costs for electrical energy. Reduced costs due to lower steam and cooling water consumption.

An investment cost of EUR 750 000 has been reported for a dry condensing system. Annual operating cost (costs of electricity, steam, cooling water and effluent treatment) of EUR 100 000 have also been reported [193, TWG 2015].

**Driving force for implementation**

- Possibility to create deeper vacuums to meet stricter product requirements.
- Water savings.
- Compliance with water pollution legislation.

**Example plants**

Various installations in Europe (e.g. Belgium, France, Germany) [193, TWG 2015].

**Reference literature**

[35, Germany 2002] [75, FEDIOL 2002] [100, Bockisch M. 1993], [193, TWG 2015]

11.4.2.3.5 Bioscrubber

For general information see Section 2.3.7.3.5.

**Environmental performance and operational data**

Off gases of the mineral oil system of a rapeseed extraction contain a lot of sulphur compounds generating odour, especially H$_2$S. A Belgian rapeseed installation (#044) with the application of a bioscrubber achieved a reduction of around 97% of the sulphur compounds (removal of 2-3 kg H$_2$S per hour), with a minor consumption of chemicals and with no generation of waste. Similar results were reported in another installation (#92).

**Reference literature**

[193, TWG 2015]

11.4.2.3.6 Biofilter

For general information see Section 2.3.7.3.4.
Environmental performance and operational data

In one oilseed installation (#090) a biofilter is used for exhaust air purification. TVOC emission of 2 mg/Nm$^3$ has been reported (monitoring standard, EN 13649). In another oilseed installation (#090) the process exhaust air from the pressing plant and extraction is passed through a biofilter. An average TVOC emission level of 87.9 mg/Nm$^3$ has been reported (based on three spot measurements). The monitoring standard used for both cases is EN 13649. Electricity is needed to operate the fan to push the exhaust air through the biofilter (fans together have a power of 120 kW at full load). Approximately 4.5 m$^3$ water/d are consumed for humidification of the filter material. The filter material has to be changed depending on the load every 3–5 years.

In another oilseed installation (#466) a biofilter was used to treat a total of 85,000 m$^3$ emissions in 2014. A reduction of around 50% in odour emissions was achieved resulting in odour emissions of 77,046 OU/m$^3$.

Reference literature

[193, TWG 2015]

11.4.2.3.7 Wet scrubber in combination with a biofilter

Description

Reduction of odour emissions with the combined application of a wet scrubber and a biofilter.

Technical description

The exhaust air scrubber removes dirt and oil particle out of the exhaust of vapours, drying, cooling decks of the DC and other aspiration exhaust from conveyers. With a pump and nozzles, washing water is nebulised into the exhaust volume flow to disperse the particle. The water is recirculated for cleaning the exhaust. By cooling the air and because of the high moisture, the exhaust air condensates. The condensate is pumped into the water treatment plant. After pre-cleaning the exhaust, a cooling tower decreases its temperature to approximately 40 °C, which is needed as the inlet temperature for the biofilter. The biofilter is made of concrete. The air is led into two chambers that are filled with biofilter material. This material is spread with a bacterial fluid for removing the odour. In the end, the cleaned air is blown into atmosphere.

Achieved environmental benefits

Reduction of odour emissions.

Environmental performance and operational data

A Germany installation (#086) reported odour abatement efficiencies higher than 99%. Electricity consumption for the scrubber was around 616 MWh and for the biofilter around 680 MWh. The biofilter needs an inlet temperature of maximum 40 °C and 100% relative humidity. 20 m$^3$/d of water and aqueous nutrition are supplied periodically at two layers across the entire biobed area; a corrosion inhibitor, a biocide and a disperser for cooling tower are also supplied.

Cross-media effects

Water consumption is needed for moisturising the biobed and filling up the cooling tower or scrubbers when necessary.

Technical considerations relevant to applicability

Space for installing the abatement techniques is needed.

Economics

Investment cost of around EUR 1,700,000 and yearly operating cost of around EUR 165,000 have been reported.
Driving force for implementation
Reduction of odour emissions.

Example plants
At least one rapeseed installation in Germany (#86).

Reference literature
[193, TWG 2015]

11.4.2.4 Recovery of hexane

11.4.2.4.1 Monitoring hexane losses using a mass balance (bookkeeping process)

Description
It includes using installation purchase records, weighing records and inventories with regard to hexane and oilseeds. Residual hexane in oil and meal is periodically measured. Monitoring devices are installed that will trigger an alarm in case of incidental releases of hexane caused by e.g. leakages or spills. Monitoring of critical temperatures, pressures and flows in the process equipment involved in hexane recovery can also be carried out.

Technical Description
Monitoring of specific hexane losses (e.g. kg hexane per tonne of oilseed processed as a yearly average) on the basis of a mass balance constitutes a cost-efficient method for assessing the overall performance of the combined process-integrated hexane recovery systems. Operators usually focus on total installation hexane loss and more specifically on kg of hexane loss per tonne of oilseed processed over a longer period of time, typically one year. The specific hexane consumption as a yearly average includes losses from all sources and conditions throughout the year. The monitoring includes using installation purchase records, weighing records and inventories with regard to hexane and oilseeds, and is also known as bookkeeping process.

Operators monitor hexane purchases and on-site hexane inventories much more often so as to be able to control unusual deviations in hexane loss. The monitoring of specific hexane consumption (loss per tonne of oilseed processed) is based on existing installation purchase records and inventories of hexane and oilseeds. Moreover, in the framework of product quality control, residual hexane in oil and meal is routinely measured.

The monitoring of specific hexane consumption as a yearly average is complemented and aligned with product quality control practices that ensure routine measuring of residual hexane in oil and meal. Next to that, for process safety reasons, monitoring devices are installed that will trigger an alarm in case of incidental releases of hexane caused by e.g. leakages or spills. Indirectly, hexane losses are also monitored through the monitoring of critical temperatures, pressures and flows in the process equipment involved in hexane recovery. Effectively, the explosion risk prevention measures ensure prevention of prolonged releases or elevated emissions of hexane.

Detailed information about the methodology of the mass balance evaluation can be found in the Part 7 of the Annex VII to the IED [265, COM 2010].

Achieved environmental benefits
Optimized environmental performance as a whole, taking into account hexane losses and energy used. Heat needed for recovery of hexane from the meal is efficiently reused for hexane recovery from miscella.
Environmental performance and operational data
Monitoring of hexane losses with the bookkeeping process is implemented in a lot of oilseed installations, even on daily basis. Values (as annual averages) from 0.19 to 0.78 kg of hexane / ton of crashed seed of bean have been reported.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
Quantifying total losses on the basis of bookkeeping principles is preferred over quantifying hexane losses from sampling and testing of individual emission points in terms of cost-efficiency.

Driving force for implementation
Compliance with environmental legislation.

Example plants
Various installations across Europe.

Reference literature
[193, TWG 2015]

11.4.2.4.2 Countercurrent flow of meal and steam in the desolventiser-toaster (DT) in vegetable oil extraction

Description
Hexane is removed from the hexane-laden meal in a meal desolventiser-toaster (DT) involving a countercurrent flow of steam and meal.

Technical description
After oil extraction, the meal contains 25–40% solvent. The solvent is removed by evaporation in the desolventiser-toaster (DT) by means of direct and indirect steam. The DT vessel has several predesolventising and desolventising/striping decks. The meal from the extractor enters the DT via the top and arrives at the first predesolventising deck. The predesolventising decks have only indirect steam heating to flash off the surface solvent. This configuration reduces the amount of water condensed on the meal at the stripping sections thereby reducing the energy input needed for the meal drying step following afterwards.

Direct steam is introduced in the system via a sparge steam deck at the bottom of the DT. The steam migrates through the layers of meal on each deck. Herewith a large proportion of the hexane is removed from the meal due to condensation of steam on the meal. The DT demonstrates a true countercurrent flow of live sparge steam and meal. The steam consumption is minimised by the countercurrent flow and the application of predesolventising decks. Vapours from the stripping decks and predesolventising decks are combined inside the boundaries of the DT vessel and reused elsewhere in the extraction process as a heating medium in the miscella distillation after scrubbing (see Section 11.4.2.3.3). Due to the contact of steam with the meal, toasting takes place as well. The toasting process inactivates the enzymes, so ensuring optimum protein quality of the meal for use as animal feed and improving its digestibility [75, FEDIOL 2002]. Figure 11.14 depicts a basic flow diagram of a countercurrent flow in a meal DT.
Achieved environmental benefits
Reduction of solvent loss into the meal and the environment. Reduction in steam consumption for the desolventising and meal drying process. Reduced volumes of waste water. More balanced heat integration with miscella distillation system, so reducing the need for hot and cold utilities.

Environmental performance and operational data
Energy consumption is normally given for the DT and downstream drying operation as a whole. For example, by predesolventising via indirect steam in the top decks the amount of water condensed on the meal at the stripping sections is reduced in comparison with the case when direct steam is applied. Subsequently, the energy input needed for the meal drying step following afterwards is reduced. Table 11.12 shows energy consumption data for the DT and downstream drying operation in oilseed extraction.

Table 11.12: Energy consumption data for the DT and downstream drying operation in oilseed extraction

<table>
<thead>
<tr>
<th></th>
<th>Heating steam</th>
<th>Stripping steam</th>
<th>Electricity for DT drive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kWh/t</td>
<td>MJ/t</td>
<td>kWh/t</td>
</tr>
<tr>
<td>Heating steam</td>
<td>15.55–31.11</td>
<td>56–112</td>
<td>2–5</td>
</tr>
<tr>
<td></td>
<td>56–112</td>
<td>196–420</td>
<td>7–18</td>
</tr>
<tr>
<td></td>
<td>20–40</td>
<td>70–150</td>
<td></td>
</tr>
</tbody>
</table>

It is reported that the countercurrent flow enables the operator to maintain acceptable residual solvent levels in the meal exiting the DT to minimise the hexane loss of the extraction process and also to minimise the temperature of the vapour mixture leaving the DT at the same time. At higher vapour temperatures, the consumption of indirect steam increases.

The DT vapours are reused in the first evaporator of the miscella distillation system (see Section 11.4.2.4.3). The final evaporation and stripping is completed with steam. The condensate mixture of water and hexane is separated in a solvent water separator. Hexane is reused and the
waste water is discharged to the WWTP. The waste water contains only COD and Kjeldahl nitrogen.

**Technical considerations relevant to applicability**
Suitable for new and existing installations. The technique is easily available and has a good operating reliability.

**Economics**
High initial investment costs. Reduction in energy costs for the extraction installation.

**Driving force for implementation**
- Potential lower residual solvent levels in the meal.
- Reduction of installation operational costs.
- Increased installation safety.
- Ensured operational safety of the downstream process.
- Compliance with legislation controlling VOCs.

**Reference literature**
[75, FEDIOL 2002]

11.4.2.4.3 Evaporation of oil/hexane: Reuse of the vapours from the DT in the miscella distillation in vegetable oil extraction

**Description**
Hexane is removed from the oil/hexane mixture using evaporators. The vapours from the desolventiser-toaster (steam/hexane mixture) are used to provide thermal energy in the first stage of the evaporation.

**Technical description**
The DT removes the hexane from the meal (see Section 11.4.2.4.2). The vapours from the DT stage (steam/hexane mixture) are fed to the first stage of the miscella distillation pre-evaporator to provide a heating source, so recovering energy. Additional removal of hexane from the concentrated miscella (oil/hexane mixture) takes place in second-stage evaporator and in third-stage oil-stripper.

Figure 11.15 shows a flow diagram of the vapour-heat integration in the DT.

![Vapour-heat integration in the desolventiser-toaster](image)

**Achieved environmental benefits**
Reduced energy and solvent consumption.

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Environmental performance and operational data
The reported energy savings in the extraction process amount to approximately 37.5 kWh/t (135 MJ/t) (60 kg steam/t) seed. Energy is also saved by reducing the heat load to the cooling water system of the installation.
In the pre-evaporator, the miscella concentration (% oil in hexane/oil mixture) increases from approximately 20–30 % to 60–75 %. For example, when processing soya, the pre-evaporator arrangement results in an evaporation of about 0.4 tonnes of hexane per tonne of seed based on the DT vapour waste heat availability. This represents a significant amount of the fresh solvent input to the extraction. The reuse of the energy value reduces the heat load to the DT condenser. Also the steam demand for the downstream miscella distillation is minimised.

Technical considerations relevant to applicability
Widely applicable in oilseed extraction. The technique is easily available and has a good operating reliability.

Economics
High initial investment. Reduction of installation operational costs due to energy recovery.

Driving force for implementation
- Optimisation of the miscella distillation energy balance.
- Improved installation safety.
- Compliance with governmental energy saving schemes.

Reference literature
[ 75, FEDIOL 2002 ], [ 214, FEDIOL 2015 ]

11.4.2.4.4 Condensation in combination with mineral oil wet scrubber

Mineral oil scrubber to recover hexane

Description
Hexane vapours are cooled to below their dew point so that they condense. Non-condensed hexane is absorbed in a scrubber using mineral oil as a scrubbing liquid for subsequent recovery.

Technical description
Hexane and steam vapours coming from meal desolventising-toasting, miscella distillation, reboiler and from the stripping column of the mineral oil system, all pass through a condenser. The components that cannot be condensed by the condenser, e.g. very low volume exhaust air with traces of hexane, are absorbed by a mineral oil scrubber.

The mineral oil scrubber consists of an absorption column, where the hexane is absorbed by cold, food grade mineral oil. The hexane-laden mineral oil is then passed through a steam stripping column to recover the hexane. The mineral oil is cooled and reused in the absorption column.

The hexane and steam vapour from the steam stripping column are condensed in the condenser. The hexane-water condensate then goes to the hexane-water separator. The waste water is decanted in the hexane-water separator and the hexane is recirculated to the extraction process. The process is shown in Figure 11.16.
Achieved environmental benefits
Recovery of hexane for reuse and consequently lower VOC emission levels.

Cross-media effects
Extra energy consumption, mainly due to heating the mineral oil, using stripping steam and from using electrical power for pumping the oil.

Environmental performance and operational data
Hexane emission concentrations below the lower explosive limit, e.g. approximately 40 g/m$^3$, can be achieved. The energy consumption is approximately 25 kg steam/tonne seed and 0.5 kWh/tonne seed.

Technical considerations relevant to applicability
Suitable for existing and new installations, good operating reliability and readily available.

Economics
Investment costs are high and there are extra operating costs due to extra energy consumption. Costs are saved due to hexane recovery.

Driving force for implementation
Higher installation safety, recovery and reuse of hexane, legislation controlling VOC emissions and lack of a better alternative for food grade mineral oil as an absorption liquid.

Example plants
Widely applied in the oilseed processing and vegetable oil refining sector.

Reference literature
[75, FEDIOL 2002]
11.4.2.4.5 Gravitational phase separation in combination with distillation Hexane recovery using a reboiler and gravity separator

Description
Undissolved hexane is separated from the aqueous phase water by means of a gravitational phase separator. Any residual hexane is distilled off by heating the aqueous phase to approximately 80–95 °C.

Technical description
The oil extraction process uses hexane as a solvent. As a consequence, hexane-rich vapour condenses to form process water containing hexane at temperatures of around 50 °C. The undissolved hexane is largely separated by means of a gravitational phase separator, i.e. hexane-water separator.

Any residual solvent content in the aqueous phase of the hexane-water separator is distilled off by heating the aqueous phase to approximately 80–95 °C in the reboiler. The resulting hexane-water vapours from the reboiler are condensed together with the vapours from the miscella distillation stage. The non-condensable gaseous matter of the vapours is treated in the mineral oil scrubber after the condenser where residual hexane is absorbed (see Section 11.4.2.4.4).

All recovered hexane is reused in the extraction process. After boiling, the almost hexane-free water is fed to the waste water system. This technique also eliminates possible risks of explosion from solvent-rich wastes in the downstream waste water treatment system. The process is shown in Figure 11.17. The safety of a waste water system is ensured by preventing explosive hexane-air mixtures.

![Diagram](image)

Source: [214, FEDIOL 2015]

Figure 11.17: Process flow diagram for hexane recovery from process water in the extraction of unrefined vegetable oils

Achieved environmental benefits
Reduced consumption and emission of hexane. Minimisation of solvent losses and TOC or COD, and BOD load in the waste water.

Cross-media effects
Increased input of heat energy. Increased waste water temperature.
Environmental performance and operational data
Steam is consumed at a rate of 0.778 kWh/m$^3$ water (1 kg/m$^3$). The hexane content in the waste water is less than 3 mg/l. The recovery of hexane is approximately 5 kg/t seed [192, COM 2006].

Technical considerations relevant to applicability
Universally applicable and readily available, without any restrictions. The operating reliability is very good, due to the multistage design, temperature control and monitoring.

Economics
TWG, please provide information.
Increased costs due to increased energy input.

Driving force for implementation
- Reduced costs due to smaller hexane losses.
- Ensure installation safety.
- Meet local waste water limit values for hydrocarbons.
- Comply with statutory solvent retention requirements, including legislation controlling VOCs, i.e. EC/99/13 and related national legislation.

Example plants
Installation #223 [193, TWG 2015].

Reference literature
[35, Germany 2002], [75, FEDIOL 2002], [100, Bockisch M. 1993], [192, COM 2006], [193, TWG 2015]

Refining of vegetable oils
Crude edible oils contain different types of undesirable substances, e.g. 0.5 to 7.0 % FFA, gums (also named phosphatides or phospholipids or lecithin), traces of metals, colouring components and volatile components. The removal of FFA (< 0.1 % FFA in refined oil) can be achieved either by chemical or physical refining.

Chemical refining

Figure : Basic flow diagram for the chemical refining of vegetable oils

Source: [215, FEDIOL 2015]
Achieved environmental benefits
Removal and recovery of FFA. High potential for recovery and upgrade of by-products for animal feed or technical applications in other industries. Reduced input of bleaching earth.

Cross-media effects
The complexity of waste water treatment is increased due to the increased P-load for soapstock splitting if phosphoric acid is used for degumming; the increased COD/BOD load for soapstock splitting; the use of citric acid for degumming and the increased sulphate load.

Environmental performance and operational data
It is reported that the consumption of chemicals depends on the composition of the raw material and that its dosing can be reduced by mechanical mixing of chemicals and oils/fats. For example, most of the crude oils have an FFA content of 0.5 to 3.0%, but others, e.g. crude palm and palm kernel oil, olive oil and coconut oil, have an FFA content of up to 7% and their consumption data are higher.

Table shows consumption and emission levels for the chemical refining of vegetable oils.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>General data</th>
<th>German example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caustic soda (100%) for neutralisation. Amount dependent on the FFA content (maximum 3%)</td>
<td>1.6 kg/t oil</td>
<td>–</td>
</tr>
<tr>
<td>Steam for neutralisation and soap splitting. Amount dependent on the phosphatide and water content</td>
<td>117 kWh/t soap (150 kg/t)</td>
<td>117 kWh/t unrefined oil (150 kg/t)</td>
</tr>
<tr>
<td>Phosphoric acid (75%) for degumming². Amount dependent on the phosphatide content</td>
<td>0.8–5 kg H₃PO₄/t oil</td>
<td>–</td>
</tr>
<tr>
<td>Sulphuric acid (96%) for soapstock splitting². Amount dependent on the caustic soda content</td>
<td>400–250 kg/t soap</td>
<td>50–250 kg/t soap</td>
</tr>
<tr>
<td>Water for washing of oil</td>
<td>50–300 l/t soap</td>
<td>200 kg/t unrefined oil</td>
</tr>
<tr>
<td>Electricity</td>
<td>5–15 kWh/t of oil (18–54 MJ/t)</td>
<td>–</td>
</tr>
<tr>
<td>Waste water</td>
<td>up to 0.3 m³/t unrefined oil</td>
<td>–</td>
</tr>
<tr>
<td>COD</td>
<td>up to 15000 mg/l</td>
<td>–</td>
</tr>
<tr>
<td>Sulphate</td>
<td>up to 15000 mg/l</td>
<td>–</td>
</tr>
<tr>
<td>Organic phosphorus</td>
<td>up to 2000 mg/l</td>
<td>–</td>
</tr>
</tbody>
</table>

¹If instead of phosphoric acid, citric acid is used, there is a potential risk of hydrogenation catalyst (Ni) poisoning by traces of citric acid, thus decreasing the throughput rate of the downstream processes.
²To reduce the sulphate content in the waste water, optimal dosing of sulphuric acid during the soapstock splitting process is needed.

Technical considerations relevant to applicability
Suitable for new and existing installations. This technique is suitable for crude oils with low FFA contents, i.e. < 3 %. The technique is easily available and has a good operating reliability for an extensive spectrum of raw materials and products.
Economics
The high potential of by-product recovery saves money and there are costs associated with the provision of equipment for acid water handling, treatment and operation.

Driving force for implementation
Better product quality, i.e. lower FFA, a longer shelf life and a more reliable process. The technique is suitable for an extensive spectrum of raw material and products.

Reference literature

Physical refining

Achieved environmental benefits
Recovery of highly concentrated FFA. Reduced chemicals consumption due to the absence of the chemical neutralisation step, i.e. no caustic soda or sulphuric acid is needed. No soap splitting is needed (for a standalone refinery). Physical refining gives a higher oil yield, uses less water and has a reduced production of waste water. Reduced fat, sulphate and phosphate loads in the waste water.

Cross-media effects
The consumption of bleaching earth is up to 4 times higher compared with that for oil that is chemically refined. Increased stripping steam consumption compared to chemical refining.

Environmental performance and operational data
Highly concentrated FFA (up to 85 %) can be recovered. The reported steam consumption is 116.7–311 kWh/t of oil (150–400 kg/t) and the electricity consumption 15–40 kWh/t of oil (54–144MJ/t).

Technical considerations relevant to applicability
Suitable for new installations. This technique is suitable for crude oils with high FFA contents, i.e. >2 %, and low phospholipid contents before deodorisation, i.e. approximately 10 ppm or less. The technique is easily available and has a good operating reliability.

Economics
Compared to chemical refining, as there is no chemical neutralisation step, the associated costs are avoided; there are reduced labour costs due to the lack of soap splitting; lower costs for waste water treatment as there is less water pollution and increased costs due to higher bleaching earth consumption. Higher refinery yield compared to chemical refining.

Driving force for implementation
Higher yields, lower environmental load and no acid water.

Reference literature

Enzymatic degumming

Technical description
Physical refining (see Section) offers lower costs, higher yields and less chemical use for refining crude vegetable oils. A prerequisite for physical refining is a low phosphatide content in the oil entering the final deodorisation stage. The content of phosphatides is reduced in the degumming step. Degumming can be made by enzymatic hydrolysis of phosphatides.

Achieved environmental benefits
Reduced consumption of caustic soda, phosphoric and sulphuric acids, water and energy.
Environmental performance and operational data
In an example installation, operational problems were observed after the start of production. Emission limit values were achieved within 3 months and costs were reduced significantly by improving the characteristics of the phospholipase.

In the example installation, the conventional method produces a waste water stream of about 3,200 kg/h, which also contains sulphate and phosphate, compared to about 400 kg/h for the enzymatic process. In addition, the amount of sludge is reduced by a factor of about 8. Consumption figures for conventional and enzymatic degumming are compared in Table.

Table: Consumption figures for conventional and enzymatic degumming of vegetable oil

<table>
<thead>
<tr>
<th>Resource</th>
<th>Unit</th>
<th>Conventional method</th>
<th>Enzymatic degumming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caustic soda (100%)</td>
<td>kg</td>
<td>5.3</td>
<td>0.43</td>
</tr>
<tr>
<td>Phosphoric acid (75%)</td>
<td>kg</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Sulphuric acid (96%)</td>
<td>kg</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Citric acid</td>
<td>kg</td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Soft water</td>
<td>kg</td>
<td>127.8</td>
<td>107.6</td>
</tr>
<tr>
<td>Cooling water</td>
<td>m³</td>
<td>4.5</td>
<td>NA</td>
</tr>
<tr>
<td>Electric power</td>
<td>kWh</td>
<td>2.7</td>
<td>2</td>
</tr>
<tr>
<td>Steam</td>
<td>kWh</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>Steam</td>
<td>MJ</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>Steam</td>
<td>kg</td>
<td>95.5</td>
<td>28</td>
</tr>
<tr>
<td>Enzyme solution</td>
<td>kg</td>
<td></td>
<td>0.014</td>
</tr>
</tbody>
</table>

Source: [17, OECD 2001] [94, Germany 2003]

Technical considerations relevant to applicability
Can be applied to all types of rape and soya bean oil.

Economics
Costs for conventional and enzymatic degumming are compared in Table.

Table: Costs of conventional and enzymatic degumming of vegetable oil

<table>
<thead>
<tr>
<th>Resource</th>
<th>Specific cost (USD/unit)</th>
<th>Total cost (USD/t oil)</th>
<th>Conventional</th>
<th>Enzymatic degumming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caustic soda (100%)</td>
<td>0.6/kg</td>
<td>2.18</td>
<td>2.18</td>
<td>0.26</td>
</tr>
<tr>
<td>Phosphoric acid (75%)</td>
<td>0.672/kg</td>
<td>1.34</td>
<td>1.34</td>
<td></td>
</tr>
<tr>
<td>Sulphuric acid (96%)</td>
<td>0.075/kg</td>
<td>0.39</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>Soft water</td>
<td>0.013/kg</td>
<td>1.66</td>
<td>1.66</td>
<td>0.14</td>
</tr>
<tr>
<td>Steam</td>
<td>0.01-0.09/kg*</td>
<td>1.24</td>
<td>1.24</td>
<td>0.36</td>
</tr>
<tr>
<td>Cooling water</td>
<td>0.006/m³</td>
<td>0.69</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>Electric power</td>
<td>0.003/kWh</td>
<td>0.69</td>
<td>0.69</td>
<td>0.63</td>
</tr>
<tr>
<td>Citric acid</td>
<td>1.87/kg</td>
<td>1.87</td>
<td>1.87</td>
<td></td>
</tr>
<tr>
<td>Enzyme solution</td>
<td>144.75/kg</td>
<td>2.04</td>
<td>2.04</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>147.173</td>
<td>9.19</td>
<td>9.19</td>
<td>5.27</td>
</tr>
</tbody>
</table>

*Difference due to different steam pressure
Source: [17, OECD 2001]

Driving force for implementation
Reduced costs.
Example plants
The technique is used in at least one oilseed crushing, oil refining, oil bottling and packaging
installation in Germany.

Reference literature
[17, OECD 2001]

Using citric acid instead of phosphoric acid for acid degumming

Technical description
Citric acid may be used instead of phosphoric acid for degumming, i.e. the removal of
phosphatides/phospholipids/lecithins.

Degumming can be carried out separately or integrated with chemical refining, i.e. during
neutralisation (see Section). Degummed oil, i.e. <30 ppm P in the oil, can also be used for
further processing in physical refining processes (see Section).

There are two types of ffa gums: hydratable and non-hydratable. The hydratable gums can be
separated from the oil after mixing with water with a centrifuge and added to the meal of an
integrated oilseed extraction installation, and then further processed to obtain food grade
lecithin or sold as a feedstock raw material.

If the non-hydratable gums and phosphatide acids are first acidified they can then be separated
from the crude oil by adding water followed by centrifugation. This process is also called acid
degumming. The market demands a phosphorus content lower than 5 ppm in the refined oil.
Phosphorus will unavoidably be present in the waste water due to the residues of phosphoric
acid and due to the occurrence of organically bound phosphorus in the form of phosphatides.
The phosphatides are reportedly not removable by pretreatment. If the acidification is done using
citric acid instead of phosphoric acid, the P-load of the waste water can be reduced. The P-load
produced by the phosphatide content in the crude oil will not be reduced by the use of citric
acid. Citric acid will, however, increase the COD and BOD loads of the waste-water

Achieved environmental benefits
Phosphatides can be further refined to give food grade lecithin as a co-product or added to the
meal of an integrated installation, i.e. by-product reuse. Reduced phosphorus load in the waste
water. Slight reduction in the amount of sludge.

Cross-media effects
Increased COD and BOD loads of the waste-water.

Environmental performance and operational data
A reduction of more than 50% in the phosphorus load of the waste water is reported, depending
on product portfolio. It is also reported that using 1 kg citric acid results in a COD output of
0.75 kg into the waste water. The consumption of citric acid is significantly higher than the
consumption of phosphoric acid. The use of citric acid might give problems for the degumming
of some types of crude oils with high phosphatide contents.

It is reported that the removal of hydratable phospholipids is done at a temperature of
60-70°C. Whereas the removal of non-hydratable phospholipids requires higher temperatures,
e.g. 75-110°C.

Technical considerations relevant to applicability
The technique is universally applicable and suitable for new and existing installations. The use
of citric acid instead of phosphoric acid might reduce the throughput rate of the downstream
processes. Furthermore, residual citric acid can poison the Ni-catalyst during the hardening
process, if the oil is used for margarine production, so this may influence the choice of acid used
for degumming. The technique is easily available and has a good operating reliability.
Economics
Reduction in waste water treatment costs. Increase in costs of chemicals. To obtain a good degumming of the crude oil, up to five times more citric acid than phosphoric acid is required. Citric acid has a higher molecular weight and is a weaker acid. The by-products have a saleable value.

Driving force for implementation
Stricter regulation of waste water quality. The value of the by-products, e.g. phospholipids, can influence the choice between separate degumming or integrated degumming FFA removal.

Reference literature
[35, Germany 2002] [75, FEDIOL 2002] [100, Bockisch M. 1993]
11.5 Emerging techniques

TWG, please provide information.
12 OLIVE OIL PROCESSING AND REFINING

12.1 General information about the sector

In 2014, the EU was the largest producer of olive oil in the world, accounting for almost three quarters of global production. Olive trees are grown in Spain, Italy, Greece, Portugal, France, Croatia, Cyprus, Slovenia and Malta — although 99.5 % of the olive production in the EU-28 in 2014 was concentrated in the first four of these nine EU Member States (see Figure 12.1).

![Pie chart showing olive oil production by EU Member States in 2014](image)

**Figure 12.1: Production of olives for olive oil by main producing EU Member States in 2014 (% EU-28)**

In 2007 there were 1.9 million farms with olive groves in the EU. The olive sector is characterised by a large number of small operations. Olive oil production in Spain (413 000 holdings with an average size of 5.3 ha) seems to be relatively less fragmented than in Greece (531 000 holdings with an average size of 1.6 ha) or in Italy, which has the highest number of holdings (776 000, with an average size of 1.3 ha).
12.2 Applied processes and techniques

Olive oil refers to the product obtained from *Olea europea*. It is composed of about 98% glycerides with the remaining 2% being various components naturally present in olives, some of which play a fundamental role in the olfactory and taste characteristics and which are also important for the stability and quality of the product. Olive oils and husk oils are classified on the basis of denominations and definitions from Regulation 136/66/EEC of 22 September 1966 on the establishment of a common organisation of the market in oils and fats [121, COM 1966].

Extra virgin oils, virgin oils and ordinary virgin oils are edible; yet only extra virgin oils and virgin oils can be commercialised as they are for direct consumption. Ordinary virgin oils are commonly used mixed with refined olive oils and refined husk oils. Acid oils with an acidity higher than 3.3 degrees are usually refined.

The quality of the olive oil depends on the ripeness of the olives, the type of harvesting, e.g. picking or shaking, the type of intermediate storage, and the type of processing carried out. Olives contain 38% to 58% oil and up to 60% water. Ripe olives should be processed as quickly as possible since lipases in the pulp cause rapid hydrolysis of the oil, impairing its quality for edible purposes. Top-grade oils are made from freshly handpicked olives by size reduction, pasting, and cold pressing. In the production of olive oil, there are three systems currently in use for the extraction of the oil: traditional, by pressing; three-phase separation; and two-phase separation.

In traditional production of olive oil, olives are ground into a paste with stone mills, however these days modern milling equipment is also used. Milling is followed by mashing, possibly with the addition of salt. The pulp is then pressed and the press oil is clarified by sedimentation or centrifugation. Traditional open-cage presses are now being replaced by continuous screw expellers. The mashed pulp can also be separated in a horizontal decanter, in which case the crude oil is re-centrifuged after the addition of wash-water. Alternatively, machines can be used to remove the kernels from the pulp and the residue is then separated using self-discharging centrifuges. Cold pressing, which yields virgin grades, is generally followed by a warm pressing at approximately 40°C. Cold-pressed olive oil is a valuable edible oil.

In Spain, most installations use the two-phase type centrifuges, while in most other Mediterranean countries larger installations use the three-phase technique, and smaller installations typically still use traditional pressing. While the two-phases generate a paste-like waste, both the traditional and the three-phase systems produce a liquid phase, i.e. olive mill waste water, or alpechin and a press cake known as pomace, husk, or orujo. This latter product may be further treated as husk or pomace oil. The remaining solid husk is dried to 3–6% of humidity and used as fuel. Olive kernel oil is obtained by pressing and solvent extraction of cleaned kernels. It is similar to olive oil but lacks its typical flavour.

Trade specifications are based primarily on the content of FFA and flavour assessment. In some countries, warm-pressed olive oil with a high acidity is refined by neutralisation, bleaching, and deodorisation (see Section 11.2.2), and flavoured by blending with cold-pressed oil. The press cake contains 8% to 13% of a relatively dark oil, called sanza or orujo, which can be extracted with hexane and is used for technical purposes. After refining, it is also fit for edible consumption.

Olive oil production has traditionally been one of the major sources of industrial pollution in the regions where it is carried out, e.g. in Andalusia, Spain. In traditional olive processing, i.e. the three-phase production, the extraction of the olive seeds has resulted in three streams, i.e. oily, aqueous, and solid.

The oily stream is the virgin oil. It is produced at a rate of about 200 kg/t of olives if obtained using continuous separation by decanter centrifuges, or 150 kg/t using olive presses.
The aqueous waste, i.e. waste water, is sometimes called vegetable water and is highly polluted. Its volume depends on the technique applied but, in general, 1 m$^3$ of waste water is produced per tonne of olives processed. The specific pollution is estimated to be about 65 kg BOD$_5$/t olives processed. In the beginning of the 1990s, the resultant waste water during a 100 days campaign represented about the same amount of water as Andalusia’s total population for the whole year. At that time, only the classical presses and the three-phase continuous separation by decanter centrifuges were used.

The solid waste consists of two major parts, i.e. the stones or kernels and the crude oil cake/pomace. The stones accumulate in installations where destoned or stuffed table olives are produced. They can be used as fuel for heating, building materials or, for activated charcoal. There is still a small amount of oil in the olive cake from the first pressing of the olives and this can be extracted. Its water content and composition depend on the extraction technique applied. If not going on for further processing, i.e. extraction, this cake is often used as fuel for heating, for animal feed supplement or returned to the olive grove as a mulch to condition the soil.

In a technique implemented first in 1991–1992, the decanter centrifuges were modified so that the crushed (mixed) olives were separated into two-phases, i.e. the oil phase and a solid phase. This technique does not require the addition of water to the olive mixture. By 2000, virtually all of the Andalusian olive oil mills had converted to the two-phase process.

The degree of application of the two-phase and three-phase olive oil processes, in Andalusia, are compared in:

![Figure: The two-phase and three-phase olive oil extraction processes](image)

Source: [50, Junta de Andalucia and Agencia de Medio Ambiente 1994]

Water is saved in the extraction part of the two-phase process. The amount of waste water and its contaminant load are also reduced. The water savings are particularly significant because olives are grown and processed in areas of very low rainfall. The rural settings of a significant proportion of the industry also means that there is little access to MWWTPs. However, the wetter solid output is also considered a problem comparable to the waste water produced from the three-phase process.
The solid output, i.e. spent olives or pomace (in Spanish “alperujo”) is produced in greater amounts than from the three-phase process and contains 7–21 % more water. After further hexane extraction, the so-called spent olive cake is generated. This is often used as fuel for heating, for animal feed supplement or returned to the olive grove as a mulch. The spent olive cake is normally dried before disposal. The energy requirement and the cost of the drying is higher and the drying is more difficult due to the higher water, polysaccharides, and polyphenols content of the “alperujo”. The continuous three-phase generates spent olives with humidities of 35–45 %. With the continuous two-phase system, the spent olives present humidities of between 60 % and 70 % [277, RC/SPC 2000].

No water is used in the extraction part of the two-phase process and, in consequence, there is no need to treat it. The energy savings are about 20 %. The amount and the pollution load of the waste water is less. In the traditional process, the processing of 1 tonne of olives resulted in the production of about 0.6 m³ of waste water with a BOD₅ emission level of 150 000–130 000 mg/l. The amount of waste water produced using the two-phase technique is about 0.15 m³/tonne olives, with an average BOD₅ of 45 000–60 000 mg/l. As no water is used in the extraction, there are also savings in water consumption [277, RC/SPC 2000].

There are difficulties associated with the handling of the spent olive cake, which has a higher moisture content than the traditional cake and is not accepted by traditional extraction installations. It is also reportedly less profitable to extract the oil from it, due to its lower oil content, compared to the traditional or three-phase systems. Composting is reported to be an option in all cases. Use as biomass fuel is reported to be an option if a critical mass of spent olive cake is available, so not in cases of individual dispersed and isolated installations.

The throughputs of the two-phase and three-phase olive oil processes are compared in Table 12.1.

### Table 12.1: Comparison of throughputs for the three-phase and two-phase olive oil processes

<table>
<thead>
<tr>
<th></th>
<th>Two-phase process</th>
<th>Three-phase process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olives (t)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Water (m³)</td>
<td>0.1–0.12 (rinsing water)</td>
<td>0.1–0.12 (rinsing water)</td>
</tr>
<tr>
<td>Output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil (t)</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Waste water (t or m³)</td>
<td>0.1–0.15</td>
<td>1–1.2</td>
</tr>
<tr>
<td>Spent olives (t)</td>
<td>0.8</td>
<td>0.5–0.6</td>
</tr>
<tr>
<td>Organic pollutants (per tonne of olive oil produced)</td>
<td>1.5 (as pomace)</td>
<td>27 (as pomace)</td>
</tr>
</tbody>
</table>

Source: [277, RC/SPC 2000]

In two-phase extraction of olive oil it is not necessary to add hot water. The energy consumption for both systems is reported to be <90–117 kWh/t. Also, both systems use the same volume of washing water, i.e. 0.1–0.12 m³/t olives. This water consumption is independent of the extraction process, although, in some cases, it gets mixed with the waste water or wet pomace from the extraction process. Some mills do not use washing water as they collect the olives directly from the trees.

In Spain, the overall reported yields for two-phase and three-phase extraction of olive oil, for the 2004–2005 campaign, are 20.68 and 20.29 % respectively.

Existing three-phase decanter centrifuges can be modified to two-phase operation. Pomace dryers originally used after three-phase extraction are unsuitable for drying the pomace produced using the two-phase technique. Compare to the pomace produced by the three-phase
extraction technique, the pomace produced using the two-phase technique contains both much more moisture and organic pollutants. If the two-phase pomace is not dried under suitable conditions, the oil produced from it can contain PAH emission levels which could exceed those allowed under food safety legislation (COMMISSION REGULATION (EC) No 208/2005 of 4 February 2005 amending Regulation (EC) No 466/2001 as regards polycyclic aromatic hydrocarbons (text with EEA relevance)).

The decanter centrifuges for the two-phase separation are about the same price as the decanter centrifuges for three-phase separation. The cake/pomace drier can cost more than the decanter centrifuge, but the cost can be shared between neighboring small mills. The cost of replacing three-phase driers with two-phase driers may be prohibitive for small isolated installations, due to the economy of scale and/or the lack of opportunity to share the cost between a number of neighboring installations.

Operational costs at an example extraction installation were reduced by EUR 12–24/t olive oil produced. In Andalusia, 30 % of the olives were processed using the new technique within the first two years. It was estimated that during the 1992/93 and the 1993/94 campaigns, ESP 1 150 million (about EUR 6.9 million), and ESP 7 200 million (about EUR 43.3 million) were invested respectively.

Complying with the requirements for waste water discharges for a growing sector. State support for the management of the solid waste produced.

The advantages and disadvantages of the two-phase system compared to the traditional systems are summarised in Table.

<table>
<thead>
<tr>
<th>Table: Advantages and disadvantages of two-phase separation compared to the three-phase system in olive oil production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantages</td>
</tr>
<tr>
<td>Less liquid waste is produced</td>
</tr>
<tr>
<td>Water savings</td>
</tr>
<tr>
<td>Production costs reduced</td>
</tr>
<tr>
<td>More olive oil is produced</td>
</tr>
<tr>
<td>More by-products</td>
</tr>
<tr>
<td>Costs of retrofitting the existing system are low and it is easy</td>
</tr>
</tbody>
</table>

Source: [192, COM 2006]

12.2.1 Olive-pomace oil refining

Olive-pomace installations process the olive-pomace remaining after the extraction of oil from the olives. Oil is extracted with solvents resulting in crude pomace oil and exhausted husks. Oil is sent to refineries and later used in the food industry, while exhausted pomace is mainly used as fuel. Refined olive-pomace oils are mixed with virgin oils different from the lampante oils. It is also classified on the basis of denominations and definitions from Regulation 136/66/EEC [121, COM 1966].

12.2.2 Waste water treatment

In recent years, there have been extensive investigations into biological treatment of waste water from edible oil production and refining, with the aim of eliminating the previously unavoidable waste water loads. Phosphorus is present in inorganic and organic form. Tests have been performed at laboratory and pilot plant scale. Treatment strategies developed and as a result
have been implemented in two prototype production scale systems. Both examples are tailored to the special operating conditions of the installations and their local situation. Optimisation of the prototypes is still in progress.

Primary treatment used in the vegetable oil sector generally includes:

- flow and load equalisation (see Section 2.3.6.1.3)
- sedimentation (see Section 2.3.6.1.5)
- fat trap (see Section 2.3.6.1.2)
- DAF (see Section 2.3.6.1.6)
- precipitation (see Section 2.3.6.1.8), to reduce phosphorus emission levels.

Further, secondary treatment is applied and aerobic processes are used (see Section 2.3.6.2.1). In general, the waste water is well suited to biological treatment. Activated sludge (see Section 2.3.6.2.1.1), trickling filters (see Section 2.3.6.2.1.5) and rotating biological contactors (see Section 2.3.6.2.1.7) can be used. Industry specific factors that can influence biological waste water treatment are the presence of low volatile lipophilic substances, sulphate, elevated phosphatide levels and a low pH.

### 12.2.2.1 Olive oil waste water

See also Section, for information about process-integrated reduction of the amount of waste water and its pollutant load.

The olive mill waste water is considered as one of the most polluting waste water from the FDM sector and causes great problems in the olive tree cultivation areas in Europe. It has a very high COD, i.e. 200 000 mg/l, a low pH, i.e. 3–5.9, and a high content of solid matter, i.e. TSS 20 000 mg/l. In addition, the high polyphenol content of olive oil waste water, up to 80 000 mg/l, make bacterial degradation very difficult and give them phytotoxic characteristics.

Usually, small olive mills, very many of which are below the IPPC Directive threshold, use evaporation lagoons (see Section 2.3.6.2.1.4). Allowing their waste water to evaporate in open lagoons for months leads to stale odours and, in many cases, leakage causes groundwater contamination. The solid residue is then sent for landspreading. Direct deposition in olive groves can result in groundwater contamination. Connection to a MWWTP is not usually possible, as olive mills are normally in rural areas where MWWTPs either do not exist or are not designed to treat such waste water. Thermal concentration (not described in this document) can also be used to treat olive oil waste water.

Olive oil waste water can also be treated using an anaerobic WWTP, which can reduce COD emission levels by 65–95%. This has a high investment cost, particularly because olive oil mills have seasonal harvesting, the campaigns are carried out between October and March and only last three months at each location. The seasonal characteristic of these mills does not affect the treatment as an anaerobic digester can be easily restarted after a dormant state, although it takes some time to re-establish treatment conditions.

The high polyphenol content of the waste water inhibits the growth of aerobic bacteria. In addition, the autoxidation of phenolic compounds during contact of olive oil waste water with air leads to the formation of macromolecular polyphenols which are even more difficult to degrade.

A further alternative treatment of waste water from olive mills can involve an effective primary treatment (see Section 2.3.6.1) to remove solids. Using precipitation (see Section 2.3.6.1.8), with the selection of an optimal flocculation agent, eliminates a very high percentage of the dissolved and particulate organic matter which will then be removed by filtration (see Section 2.3.6.3.6). The final step consists of applying membrane separation (see Section 2.3.6.3.7) to
ensure 95% reduction of the organic load. This is still under investigation but could be a solution for the future.

Table 12.2 shows a comparison of treatment alternatives for olive oil waste water.

Table 12.2: Comparison of treatment alternatives for olive oil waste water

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landspreading</td>
<td>Improved fertility because of K, Mg and organic matter content</td>
<td>Groundwater contamination, High salinity, Legal limitations, Negative effects on vegetation if certain levels are surpassed due to polyphenol content</td>
</tr>
<tr>
<td>Evaporation lagoon</td>
<td>Low cost, No specialised workers required</td>
<td>Large land surfaces needed, Putrid odours and insects, Groundwater contamination if the insulation of the basin is not correct</td>
</tr>
<tr>
<td>Thermal concentration</td>
<td>Faster system</td>
<td>High power consumption and cost, Crust formation in the evaporators</td>
</tr>
<tr>
<td>Anaerobic processes</td>
<td>Low energy consumption, Methane production, Stabilised sludge</td>
<td>Expensive installation</td>
</tr>
</tbody>
</table>

Source: [71, AWARENET 2002]
Chapter 12

12.3 Current consumption and emission levels

12.3.1 Energy consumption

Specific energy consumption values of 0.29, 0.72 and 1.18 MWh/tonne of product have been reported [193, TWG 2015].

12.3.2 Water consumption

Specific water consumption values of 2.16, 8.27 and 10.29 m³/tonne of product have been reported [193, TWG 2015].

Olive oil producers use about 12 million tonnes of water per year [142, IMPEL, 2002], corresponding to about 5 m³ water/t olive oil produced.

12.3.3 Waste Solid output

In crude olive oil production, the traditional system, i.e. pressing, and the three-phase system produce a press cake and a considerable amount of waste water while the two-phase system, which is mainly used in Spain, produces a paste-like waste called “alperujo” that has a higher water content and is more difficult to treat than traditional solid waste. The water content of the press cake, composed of crude olive cake, pomace and husks, is about 30% if it is produced by traditional pressing technology and about 45–50% using decanter centrifuges. The press cake still has some oil that is normally recovered in a separate installation. The exhausted olive cake is incinerated or used as a soil conditioner on olive groves.

12.3.4 Emissions to water

Traditional olive oil production, also called pressing, generates about 2 to 5 litres of waste water per litre of oil produced, the three-phase continuous olive oil extraction generates about 6 to 8 litres of waste water per litre of oil produced, whereas the two-phase continuous olive oil extraction generates only about 0.33–0.35 litres of waste water per litre of oil produced. Table 12.3 shows the characteristics of olive oil waste water using different extraction techniques.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Waste water volume (m³/t olive oil)</th>
<th>BOD₅ (mg/l)</th>
<th>COD (mg/l)</th>
<th>TSS (mg/l)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional extraction (pressing)</td>
<td>2–5</td>
<td>22000–62000</td>
<td>59000–162000</td>
<td>65000</td>
<td>4.6–4.9</td>
</tr>
<tr>
<td>Three-phase extraction</td>
<td>6–8</td>
<td>13000–14000</td>
<td>39000–78000</td>
<td>65000</td>
<td>5.2</td>
</tr>
<tr>
<td>Two-phase extraction</td>
<td>0.33–0.35</td>
<td>90000–100000</td>
<td>120000–130000</td>
<td>120000</td>
<td>4.5–5.0</td>
</tr>
</tbody>
</table>

Source: [42, Greek Ministry for the Environment 1997], [50, Junta de Andalucia and Agencia de Medio Ambiente 1994]
12.4 Techniques to consider in the determination of BAT

12.4.1 Techniques to reduce emissions to air

12.4.1.1 Production of olive-pomace oil

12.4.1.1.1 Mineral oil scrubber to recover hexane

See Section 11.4.2.4.4.

TWG, please provide information.

12.4.1.1.2 Hexane recovery using a reboiler and gravity separator

See Section 11.4.2.4.5.

TWG, please provide information.

Multistage waste water treatment for vegetable oil refining—a case study

Description
This treatment is a combination of treatment techniques implemented in an example edible oil refinery with special conditions. Its application at other installations may be tested first by, e.g., pilot trials.

The technology is used for on-site treatment of the waste water from the refining of crude oils and fats. Waste water from the segregated streams of soap splitting (acid water), storage and cleaning were combined.

The system comprises the following stages:
- segregation (see Section 2.3.3.1.4)
- fat trap (see Section 2.3.6.1.2) in segregated streams
- flow and load equalisation (see Section 2.3.6.1.3)
- DAF (see Sections 2.3.6.1.6), at low pH and without precipitation for FOG removal
- neutralisation (see Section 2.3.6.1.4) and coagulation for the removal of emulsified oils/fats
- DAF (see Sections 2.3.6.1.6), with precipitation for coagulated oils/fats
- activated sludge (see Section 2.3.6.2.1.1), in cascaded stages to treat plug-flow conditions
- DAF (see Section 2.3.6.1.6) to remove sludge
- sedimentation (see Section 2.3.6.1.5) of TSS and flow and load equalisation (see Section 2.3.6.1.3) of the clear water tank.

Achieved environmental benefits
Reduction in waste water COD by more than 95 %. Some phosphorus reduction.

Cross-media effects
Increased use of chemicals such as caustic soda and coagulants for fat elimination. Increased use of energy for physical and biological process steps. Sludge is produced.

Environmental performance and operational data
Table shows the waste water characteristics before and after treatment. Phosphorus is reduced by approximately 50 % and only through biological absorption by assimilation in the sludge
biomass. Precipitation cannot be applied in the waste waters containing the phosphatides, i.e. those which are organic.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Inlet</th>
<th>Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste-water volume</td>
<td>m³/h</td>
<td>&lt;25</td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>mg/l</td>
<td>2500</td>
<td>&lt;150</td>
</tr>
<tr>
<td>BOD₃</td>
<td>mg/l</td>
<td></td>
<td>&lt;5</td>
</tr>
<tr>
<td>Lipophilic substances</td>
<td>mg/l</td>
<td>≈100</td>
<td>–</td>
</tr>
<tr>
<td>Phosphorus* (P_{total})</td>
<td>mg/l</td>
<td>&lt;140</td>
<td>&lt;70</td>
</tr>
<tr>
<td>Sulphate up to</td>
<td>mg/l</td>
<td>12000</td>
<td>–</td>
</tr>
</tbody>
</table>

*Source of phosphorus: phospholipids as phosphatides and lecithins
**Measured using the now-cancelled method (DIN 38509, H 17)

Table: Waste water characteristics before and after treatment

Table shows energy consumption data.

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam</td>
<td>12.5 kWh/t unrefined oil</td>
</tr>
<tr>
<td></td>
<td>45 MJ/t unrefined oil</td>
</tr>
<tr>
<td></td>
<td>16 kg/t unrefined oil</td>
</tr>
<tr>
<td>Electricity</td>
<td>11.5 MJ/t unrefined oil</td>
</tr>
<tr>
<td></td>
<td>3.2 kWh/t unrefined oil</td>
</tr>
</tbody>
</table>

Table: Energy consumption data

Table shows the operating data of a waste water treatment system at an oil and fat processing facility:

**Stage 1: Cooling, neutralisation (NaOH), coagulant and urea addition**
- DAF at low pH: Area = 25 m²
- DAF at neutral pH: Area = 25 m²

**Stages 2–3: Cascaded activated sludge system (aeration + DAF basins)**
- Reactor 1 volume 630 m³
- Reactor 2 volume 1270 m³
- Residence time approximately 35 h
- DAF surface area: Area = 45 m²

**Stage 4: Clear water tank, clarified waste water storage tank for sedimentation of residual suspended matter, buffer for rinsing purposes, out feed pump station**
- Clear water tank volume 279 m³

**Stage 5: Sludge treatment**
- Sludge storage tank with fine bubble aeration for aerobic stabilisation of the surplus sludge
- Sludge storage tank for fatty sludge from chemical/physical primary treatment, with coarse bubble aeration for aerobic stabilisation of sludge

Table: Description of waste water treatment system at an oil and fat processing facility

Technical considerations relevant to applicability

Oil refineries without any requirement for enhanced phosphorus removal. Table shows a summary of applicability data.
Restrictions

<table>
<thead>
<tr>
<th>Low organic loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good primary fat separation</td>
</tr>
<tr>
<td>No preceding precipitation of phospholipids possible</td>
</tr>
<tr>
<td>Simultaneous precipitation with high P concentrations harmful to biocenosis</td>
</tr>
<tr>
<td>Subsequent precipitation to ensure reliable compliance with P emission levels only possible with substantial overdosing</td>
</tr>
</tbody>
</table>

Operating reliability

| Limited owing to substantial unavoidable fluctuations in quality of untreated waste water |
| System requires very high operator input |

Table: Summary of applicability data

**Economics**

There is substantial investment required for the development and construction of the system. There are costs due to increased input of energy, maintenance and repair, operating personnel and increased waste production. In an example installation, the technique was implemented using external financial assistance.

**Driving forces for implementation**

More stringent official requirements regarding waste water volume and quality. Local receiving water conditions. Timing of decision on availability of other alternatives. Demonstration system assisted by public funds.

**Example plants**

One vegetable oil refinery in Germany.

**Reference literature**

[35, Germany 2002], [182, Germany, 2003, 185, CIAA FEDIOL, 2004]
12.5 Emerging techniques

TWG, please provide information.
13 SOFT DRINKS AND NECTAR/JUICE

13.1 General information about the sector

TWG, please provide information.
13.2 Applied processes and techniques

Soft drinks can be categorised into two main types, i.e. carbonated and still. Soft drinks include spring waters, fruit, vegetable and juice based drinks such as cordials, squashes and barley water; flavoured drinks such as ginger beer; tonic water and lemonades, as well as infusions such as tea and coffee.

Ingredients typically found in most soft drinks include water, sweetener, acid and flavourings. Optional ingredients include fruit, vegetables, carbon dioxide, preservatives and colour. Water is the main ingredient of all soft drinks and, as such, the quality of the water, in terms of its microbiological loading and other parameters which affect the final sensory qualities of the drink, are of paramount importance. Most soft drinks are sweetened with natural sweeteners such as sugar and sugar syrups, and/or intense sweeteners such as saccharin and aspartame. Flavourings used in manufacture are often derived from highly concentrated liquid mixtures of plant extracts such as fruit, flowers, seeds, leaves, bark and root. Alternatively, they may be synthetic.

All sparkling soft drinks require the addition of carbon dioxide. This may be sourced as a co-product from the petroleum, beer and whisky industries, or produced on site. The preservation of soft drinks can be achieved by a number of techniques including heating, chemical preservation and filtration. These methods, in combination with low pH, prevent microbiological spoilage.

The aim of carbonation is to dissolve a quantity of carbonic gas into different products to obtain a gasified or carbonated final product. When dissolved in water, carbon dioxide \((\text{CO}_2)\) is sparingly soluble and thus, slowly released, forming bubbles that provide a characteristic mouthfeel and a unique taste when consumed. In addition to an organoleptic property, under suitable conditions, \(\text{CO}_2\) has a preserving property by the inhibition of the development of harmful aerobic microorganisms.

A carbonator combines \(\text{CO}_2\) gas with the liquid to be carbonated. Current carbonators can be classified into two main categories; those that carbonate water only and those that carbonate the finished product mixture of syrup and water. These are sometimes coupled with coolers, often referred to as carbo-coolers. The principal designs available are carbonators with integral coolers, draining wall heat exchangers and carbon dioxide injectors.

In combination with this process, de-aeration, i.e. the removal of air, is vital and is usually applied to the water component in a first stage. The presence of air can create spoilage problems. \(\text{CO}_2\) is sometimes used to flush out air, however, the use of mechanically de-aerated water has become more popular in recent years.

The degree of carbonation varies for each soft drink formulation, from 4 g/l in fruit drinks to 9 g/l in mixer drinks and 12 g/l in soda water. The \(\text{CO}_2\) gas content is one of the smallest constituents by weight, but possibly the most important, in regard to palatability of the product. \(\text{CO}_2\) is one of the very few gases suitable for providing the effervescence in soft drinks; it is non-toxic, inert, and virtually tasteless and allows for convenient bulk transportation and storage.

The basic processes for the manufacture of soft drinks also involves the mixing of ingredients in the syrup room, followed by the addition of water that has been subjected to various water treatments. The mixture may be heat processed or chemically preserved at this stage. The product is carbonated if required. Alternatively, after the syrup and water are combined, the product may be filled into packaging and in-pack heat processed. Syrups may require filtration or homogenisation and may be pasteurised. Most packaging is cleaned prior to filling, either by rinsing with water, possibly containing rinsing aids, or by air blasting.
Waste water treatment

Waste water segregation can be used prior to treatment (see Section 2.3.3.1.4). There may be potential for high volume/low pollutant loaded streams to be either recycled (following suitable treatment), discharged directly to WWTP without treatment, or mixed with treated final waste water prior to discharge. The options available will depend on the receiving water and the consent to discharge [8, Environment Agency of England and Wales 2000].

In general, when applying techniques for the treatment of waste waters from the soft and alcoholic drinks sector, the following primary processes can be used [8, Environment Agency of England and Wales 2000]:

- screening (see Section 2.3.6.1.1)
- flow and load equalisation (see Section 2.3.6.1.3)
- DAF (see Section 2.3.6.1.6)
- diversion tank (see Section 2.3.6.1.7).

Biological treatment systems are used successfully in the soft drinks industry.

Depending on the product range and packaging system, e.g. returnable or non-returnable, constant or intermittent addition of nutrient salts may be necessary. Cleaning and disinfection may lead to temporary peaks in phosphorus concentrations, which may then cause problems for direct dischargers even after equalisation, which is reported to be advisable before biological treatment [35, Germany 2002].

For waste water streams with a BOD concentration greater than 1000 – 1500 mg/l, anaerobic treatment processes can be used (see Section 2.3.6.2.2), followed by surface aeration. For lower polluted waste water streams, aerobic treatment is used (see Section 2.3.6.2.1). A two-stage biological system (see Section 2.3.6.2.3), anaerobic followed by aerobic, may be used.

For discharges to watercourses, or to treat waste water to a quality suitable for reuse, further treatment stages are required.

If suspended solids discharge levels are low, or if the waste water is to be recycled, tertiary treatment (see Section 2.3.6.3) is required. Disinfection and sterilisation (see Section 0) is essential if the waste water is to be used in processing areas as drinking water.

Some installations operate all year round, but process seasonal produce. Such installations have general waste water generated all year round from the continuous production on-site and during the season or campaign, further waste water is generated from intensive processes. The nature of the general waste water and the campaign waste water, therefore, influence the waste water treatment techniques selected for the installation.

Typically, the campaign waste water is higher in pollutant load than the general waste water and a number of factors will affect an operator’s choice of techniques under these conditions, e.g. the proximity of the discharge points for the waste water streams and whether there is process benefit in combining the streams, or keeping them apart. The economics of constructing a waste water treatment plant capable of receiving significantly higher loads during a campaign may be considered.

Some waste water may require primary treatment only if treated separately, prior to discharge to a WWTP. The campaign/seasonal waste water is typically high in pollutant load and comparatively low in volume and is treated using anaerobic processes. Final waste water from the anaerobic process may typically be discharged to a MWWTP, following surface aeration.

For treating the streams together, a WWTP is generally made of modular construction with two or more reactors working in parallel to allow for one reactor to be used out of season with the
plant brought up to full capacity during the seasonal production. A technique considered for this is a conventional activated sludge process (see Section 2.3.6.2.1.1) with pure oxygen (see Section 2.3.6.2.1.2) supplementation during the high loads associated with the seasonal production. The plant may require artificial feeding in preparation for the increased flow and load.
13.3 Current consumption and emission levels

13.3.1 Energy consumption

Figure 13.1 shows data on specific energy consumption (MWh/ hl of product) in various soft drinks and nectar/juice installations. Normally, specific energy consumption values less than 0.035 MWh/ hl of product have been reported.

![Figure 13.1: Specific energy consumption (MWh/ hl of product) in soft drinks and nectar/juice](image)

Source: [193, TWG 2015]

13.3.2 Water consumption

Figure 13.2 shows data on specific water consumption (m³/ hl of product) in the various soft drinks and nectar/juice installations. Normally, specific water consumption values less than 0.3 m³/ hl of product have been reported.

![Figure 13.2: Specific water consumption (m³/ hl of product) in soft drinks and nectar/juice](image)

Source: [193, TWG 2015]
13.3.3 Emissions to water

Figure 13.3 shows reported data on specific waste water discharges \( (\text{m}^3/\text{hl of product}) \) from soft drinks and nectar/juice installations.

Source: [193, TWG 2015]

Figure 13.3: Specific waste water discharge \( (\text{m}^3/\text{hl of product}) \) in soft drinks and nectar/juice
13.4 Techniques to consider in the determination of BAT

13.4.1 Techniques to increase energy efficiency

13.4.1.1 Applying a negative pressure for mixing purposes

Description
A negative pressure is created which is the driving force to empty fluids from containers or to add powder into mixer.

Technical description
A negative pressure is created which is the driving force to empty fluids from containers or to add powder into mixer. Beverage powders are often powders easily dissolved and do not require the same amount of energy as powders like gums, which need a high shear mixer in order to be mixed.

Achieved environmental benefits
Reduced energy consumption compared to high shear mixers.

Environmental performance and operational data
For example, with a 7.5 kW mixer for a 3 000 l mixing tank, fluids of less than 200 cP can be emptied from a barrel. 7.5 kW of electric power would be needed with a radial jet mixer, compared to 18 kW in the case of a high shear mixer. Powder mixing does not work well with too viscous powders like stabilisers.

With this technology, powder can be transported from long distances, keeping powder outside a building and no Atex is required on the machine. This results in a safer production facility for an installation handling powder.

Technical considerations relevant to applicability
The technique is applicable in beverage installations, in the mixing area. For viscous powders like stabilisers, there is a need to add another technique, such as high shear mixing.

Driving force for implementation
- Less risk for explosion when this technology is used for hydraulic transportation.
- Ergonomic solution for operator since operation on floor level is possible.

Example plants
This technique is generally used worldwide.

References
[ 189, Tetra Pak 2015 ]

13.4.1.2 Single pasteuriser for beverages with pulp

Description
Use of one pasteuriser for both the juice and the pulp instead of using two separate pasteurisers.

Technical description
Normally two pasteurisers are used, one for liquid and one for the slurry containing particles or fibres (dual-line solution). The single line solution saves one pasteuriser (the slurry pasteuriser). In the single-line solution, the particles are dosed in-line in the middle of the main pasteuriser and the whole volume is pasteurised once (see Figure 13.4).
Achieved environmental benefits
Reduced energy consumption (heating and cooling).

Environmental performance and operational data
The slurry contains 35–40 % particles and the final beverage around 5 % particles, which means that the slurry represents approximately 1/7 of the total volume. The regenerative in the slurry pasteuriser in the dual-line solution is not more than 50 % (sometimes even zero) due to high pressure drops. For the final beverage pasteuriser, the regenerative is about 85 %. In a dual-line solution \((85-50)/7 = 5\) \% regenerative is lost. This means that the energy loss in the single-line is 15 \% compared to 20 \% for the dual-line solution. The result is that the single-line solution consumes 25 \% less heating and cooling energy.

Technical considerations relevant to applicability
The technique is applicable in lines for production of beverages with inclusions of pulp and particles, in particular where some ingredient might not withstand deaeration or homogenisation. The applicability may be restricted by the particle size.

Driving force for implementation
- Less risk for explosion when coaxial injector technology is used for hydraulic transportation.
- Ergonomic solution for operator since operation on floor level is possible.

Example plants
This technique has been implemented in some installations in Turkey and Nigeria.

References
[ 190, Tetra Pak 2015 ]
13.4.1.3 Hydraulic sugar transportation

Description
Sugar is transported to the production process with water. As some of the sugar is already dissolved during the transportation, less energy is needed in the process for dissolving sugar.

Technical Description
With a hydraulic injector the sugar dissolver is starting to dissolve the sugar already in the sugar store. Since this can be far away, this technique allows a lower sugar dissolving temperature due to the fact that the sugar get a longer dissolving time than in other conventional systems. The energy required is not just used for conveying but also initiates a pre-dissolving process, which means that this energy is not lost. This reduces the amount of energy required, compared to mechanical and pneumatic conveying systems, in order to dissolve sugar continuously. If a pasteuriser is added to the sugar dissolver a better regenerative (energy recovery) is created by having a lower sugar dissolving temperature. This produces a reduction of cooling water consumption.

Achieved environmental benefits
Reduction of dissolving temperature which leads to a lower energy consumption.

Environmental performance and operational data
For example, for a capacity of 10 000 l/h, a conventional system of continuous dissolving requires 31 °C for 62 Brix, which means 168 kW. A continuous dissolving system with hydraulic injector requires 22 °C for 62 Brix, which means 89 kW.

Cross-media effects
There are no cross-media effects associated with this technique.

Technical considerations relevant to applicability
The technique can be applied in sugar treatment, producers of sugar solution and beverage producers who want to produce sugar solution for their beverages (soft drinks, juice, etc.).

Driving force for implementation
- Reduced energy costs.
- Safe working environment by placing the powder outside the factory.

Example plants
This technique has been implemented worldwide.

References
[191, Tetra Pak 2015]

13.4.1.4 Energy-efficient homogeniser

Information on this technique is available in Section 5.4.2.2.

13.4.2 Techniques to reduce water consumption
13.4.2.1 Water recycling

See also Section 2.3.3.1.1.
Chapter 13

Technical Description
Water from the rinsing process goes directly to a store tank and after possible treatment can be used at auxiliary services. Moreover, waste water from the fillers can be used for cooling purposes.

Achieved environmental benefits
Reduction of water consumption.

Environmental performance and operational data
In an example installation (#183) rinsing water goes directly to store tank and after being filtrated it goes through a descalcification resin equipment and is reused for auxiliary services. A 25% reduction of water consumption in auxiliary services is achieved.

In another installation (#279) waste water from the fillers (which is close to clean water, COD around 100 mg/l) is reused in the cooling towers. This cooling system needs around 150 m$^3$ of water per day to be efficient. The waste water has to be treated correctly with biocides in order to be reused in the cooling towers.

Cross-media effects
Increased energy consumption due to pumping system.

Economics
An investment cost of EUR 140 000 and an annual operating cost of EUR 9 300 have been reported (for a storage tank of 10 m$^3$).

Example plants
Installations #183, #279.

Reference literature
[ 193, TWG 2015 ]

Filtration of the product using membrane separation

Technical description
Filtration of the product is carried out in several processes during drinks manufacturing, e.g. during fining and before bottling to remove the remaining solid, insoluble turbid compounds and microorganisms. Membrane separation can be used instead of natural mineral adsorbents such as diatomaceous earth, to reduce water consumption and waste water production. This removes the risk of the filter cake and separated solids being washed away with washing waters and adding to the waste water load. The spent filter material can be dewatered. It is reported that it can be composted or possibly brought out to the vineyard or distilled, depending on the composition. The treatment and recovery of diatomaceous earth are reported to be a problem. This technique enables a strong filtration of the product and removes the remaining microorganisms and other suspended matter. It is also used for sterilisation.

Achieved environmental benefits
Reduced water consumption, waste water pollution and problems disposing of diatomaceous earth.

Technical considerations relevant to applicability
Applicable in drinks manufacturing installations where the strong filtration of the product will not adversely affect its quality. This technique is not used for fining in brewing, but it is under development. There are problems associated with achieving the desired foaming of the final product.
13.4.3 Techniques to reduce waste

13.4.3.1 Segregation Separation of residues outputs, to optimise use, reuse, recovery, recycling and disposal (and minimise water use and waste water contamination)

This technique is described in Section 2.3.5.3.

Reported examples of where the technique is applied

There are likely to be many other opportunities to apply this technique within the sector.

Some other examples from the drink manufacturing sector are the following:

- clarification involves the addition of fining agents. It is reported that sediments from clarification are segregated by centrifugation or filtration
- during alcoholic fermentation, lees are separated from wine (racking) every three to four months and collected instead of flushing them into the WWTP
- before bottling, wine is passed through a filtration system to remove remaining solids and insoluble turbid compounds
- waste water with a high sugar/fermentable content can be reused in other industries, e.g. for yeast production
- returning strong liquors to the process, or recovering them for animal feed (see Section 2.3.1.7.7) or other reuse
- collecting the contents from returned containers rather than washing them to drain.

Technical considerations relevant to applicability

Applicable to all drinks manufacturing installations.

Reference literature

[71, AWARENET 2002]
13.5 Emerging techniques

13.5.1 Optimised juice pasteurisation

Description
Juice pasteurisation is conducted in two steps. The first pasteurisation, commonly conducted immediately after the juice is squeezed, deactivates enzymes and kills microorganisms. Prior to the packaging, another pasteurisation is conducted to destroy microorganisms developed during bulk storage. This second process is usually conducted at a temperature of 95 °C for 15 seconds. With new technologies introduced, the temperature of this process is brought down to 80 °C for juices with a pH level at or below 4.2.

Achieved environmental benefits
Up to 20% reduction of energy consumption.

Environmental performance and operational data
An example of energy savings is shown in Table 13.1.

Table 13.1: Comparison of heat treatment process for pasteurisation

<table>
<thead>
<tr>
<th></th>
<th>95 °C (15 s)</th>
<th>80 °C (15 s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating load (kW)</td>
<td>430</td>
<td>354</td>
</tr>
<tr>
<td>Cooling load (kW)</td>
<td>183</td>
<td>107</td>
</tr>
<tr>
<td>Energy cost (EUR)</td>
<td>99 000</td>
<td>80 000</td>
</tr>
<tr>
<td>CO₂ emissions (kg CO₂/1000 litres)</td>
<td>6.7</td>
<td>5.4</td>
</tr>
</tbody>
</table>

(*) Capacity of 22 000 l/h. Operation 6 000 h/year. Steam cost: 0.035 EUR/kg. Cooling cost: 0.025 EUR/kWh.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique in installations producing juice, nectar and still drinks.

Driving force for implementation
Reduced operational cost.

Example plants
Several installations worldwide are looking at this solution and making their own tests. A Danish producer is close to start using it.

References
[ 187, Tetra Pak 2015 ] [ 188, Tetra Pak 2015 ]
14 STARCH PRODUCTION

14.1 General information about the sector

Starch is a high molecular mass carbohydrate produced naturally by plants as an energy reserve. Starch and its derivatives are used in several sectors including food, feed, paper and board, textiles, pharmaceuticals and cosmetics. Purified starch is usually a white powder. Starch and its derivatives can be used for thickening, binding, gelatinising, colouring, anti-crystallising and for sweetening in the food industry. Physically or chemically treated or modified starches are produced to specifically enhance some functional properties. Hydrolysis of starch by acid or enzymes yields a variety of sugar syrups called liquid sweeteners (e.g. liquid glucose, glucose-fructose syrups), which can also be dried, and be used in confectionery, drinks, baby food, dairy, baked products or other foods. Incomplete hydrolysis yields a mixture of glucose, maltose and non-hydrolysed fractions. Germ is a co-product of the manufacture of starch, and can be used to produce oils. Other co-products are fibre, gluten and de-fatted meal which are all used or sold on for other uses, including animal feed. Other products can also be produced on starch installations, such as polyols and ethanol.

The main raw materials used in Europe for the production of starch and its derivatives are cereals, i.e. maize, wheat, barley and rice, and potatoes of dedicated varieties. Each installation is usually technically dedicated to one raw material [6, Environment Agency of England and Wales 2000], [48, European Starch Association 2001].

The European starch industry produces over six hundred products, from native starches to physically or chemically modified starches, through to liquid and solid sweeteners. The versatility of starch products is such that they are used as ingredients and functional supplements in a vast array of food, non-food, and feed applications. From around 77 starch production facilities in 21 of the 28 EU Member States, the European starch industry produces 10.5 million tonnes of starch each year from EU wheat, maize and potatoes (see Figure 14.1). EU starch production has increased from 8.7 million tonnes 2004 to 10.5 million tonnes in 2014 (see Figure 14.2).

![Diagram showing starch production in the EU-28 (2014)](image)

Figure 14.1: Starch production in the EU-28 (2014)
Figure 14.2: Starch production in the EU-28

The EU-28 consumes 9 million tonnes of starch (excluding starch by-products totalling around 5 million tonnes), of which 61% in food, 1% in feed and 38% in non-food applications, primarily paper making (see Figure 14.3). Of the 9 million tonnes of starch and starch derivatives consumed in the EU, 25% are native starches, 20% modified starches and 55% starch sweeteners.

Figure 14.3: Main starch applications in the EU-28 (2014)

Only starch production (and derivatives) from maize, wheat and potatoes is described in this document.
14.2 Applied processes and techniques

The starch industry separates the components of the plant: starch, protein, cellulose envelope, soluble fractions and in the case of maize, the germ from which oil will be extracted. This first phase utilises a series of simple stages of physical separation of the components: crushing, sifting, centrifuging, etc. However the methods of manufacture are specific to each installation and the industrial tools are normally dedicated to a raw material (maize, wheat, potato in Europe). In the second stage, the starch which has been extracted in its purest form, will be used as it is after drying (this is called native starch) or it will be further processed, undergoing various transformations aiming either at modifying its performance (modified starch) or to obtain sweeteners through the process of hydrolysis. At the end of the process the starch and derived products are delivered to customer industries in the form of powder (with an appearance similar to that of flour) or of syrups. A general overview of the starch production process is shown in Figure 14.4.

![Starch production process in Europe](source: 217, Starch Europe 2014)

Figure 14.4: Starch production process

14.2.1 Maize starch

The commercial separation of pure starch from maize is achieved by a wet milling process which is generally considered to be efficient. The process is operated as an enclosed system in which process water is reused in a closed circuit. The addition of fresh water is limited to one point in the production process.

The raw material is washed using aspiration and screening to remove dust, chaff, broken grain, cobs and other extraneous material. The maize is soaked in water with sulphur dioxide (SO$_2$) or sodium bisulphite (NaHSO$_3$), for around 36 hours, in a process known as steeping, possibly using sulphurous compounds. This removes solubles in the maize, softens the kernel to improve separation of the various components and reduces microbial activity. After steeping, the maize is passed through several grinding and separation operations until only starch and gluten remain. The grain is first ground coarsely and the germs are removed from the coarse grist. After
removing the germ, the grist is finely ground and fibre is removed through a screening operation. Starch and gluten are separated, typically using centrifugal methods. This raw starch is washed with drinking water, using a countercurrent flow, in a series of four to six centrifuges. At one end, raw starch is the input and process water is the output and at the other end, refined starch is the output and fresh drinking water is the input. The starch, which at this stage is called refined starch, is then dewatered and dried. Refined starch is typically 99% pure and 85–88% dry solids. Native starch is refined starch, before physico-chemical modification. The gluten and fibre are collected separately as co-products. An example of a general overview a of the maize starch extraction process is shown in Figure 14.5.

Figure: An example maize starch production process
[84, European Starch Association, 2001]
14.2.2 Wheat starch

The commercial separation of pure starch from wheat is achieved by a two-phase process. In the first phase, the wheat kernel is ground or converted into wheat flour by a dry milling process. The second phase then separates the ground wheat or the wheat flour into its separate components, i.e. starch, gluten, solubles and eventually fibre, by a wet separation process. The process is operated as an enclosed system in which process water is recycled in a closed circuit. Fresh water is used at some stages of the process. An example of a general overview of the wheat starch extraction process is summarised shown in Figure 14.6. The process of washing raw wheat starch to produce refined starch is the same as that for maize starch (see Section 14.2.1).
Figure: An example wheat starch production process
[84, European Starch Association, 2001]
14.2.3 Potato starch

Starch is extracted from potatoes by a wet process. This involves the disintegration of the tuber into a pulp, which is then dewatered and dried to produce the final product. Fibre and fruit juice are also generated from the tuber. An example of a general overview of the potato starch extraction process is summarised shown in Figure 14.7. The process of washing raw potato starch to produce refined starch is the same as that for maize starch (see Section 14.2.1).
Figure: An example potato starch production process
[Source: European Starch Association, 2001]
14.2.4 Sweeteners

Starch slurry is the starting raw material for the manufacture of starch based sweeteners or sugar syrups. These are produced by the action of acids, enzymes or a combination of both, however enzymes are more commonly used. In a typical process, the starch slurry is heated to gelatinise the starch and then mixed with acids and/or enzymes and reacted in different liquefaction reactors. Conversion of the starch only takes a few minutes. The mass is neutralised and after additional enzymatic reactions such as saccharification and/or isomerization, several stages of purification takes place, i.e. separation of insolubles, demineralisation and decolourisation, before the product obtained is evaporated. The temperature is then raised to around 140 °C. The liquor is usually filtered and treated with activated carbon or ion exchange resins to remove colour, ash and other minor impurities, e.g. minerals. The liquid sweetener resulting can be sold as such, or dried, or crystallised to produce dry sweeteners.

14.2.5 Modified (physical/chemical) starches

The properties of native starch can be changed to produce modified starch. Modification can be carried out with chemicals, enzymes or physically. The chemicals added can either be dry or wet, so final drying may be necessary. In the dry chemical modification process, dewatered and dried native starch is used. The products are chemically modified starches. In the wet process, the starch slurry, or the re-slurried native starch, is fed directly into the reactor with chemicals and the reaction takes place in liquid state. The resulting slurry can be washed and/or dewatered prior to drying. The products are physico-chemically treated or modified starches.

14.2.6 Waste water treatment

Starch processing waste water primary treatment applies the following techniques:

- flow and load equalisation (see Section 2.3.6.1.3)
- sedimentation (see Section 2.3.6.1.5)
- DAF (see Section 2.3.6.1.6).
If further treatment is needed, secondary treatment techniques are applied. Anaerobic processes (see Section 2.3.6.2.2) are used when the load of organic matter is high and when the TSS load is low, although reportedly long anaerobic treatments are sometimes used to treat waste water with high TSS emission levels. A reaction of methanisation occurs and produces biogas which contains 50–70 % methane by volume and which is generally recovered in a boiler. The advantage of this treatment is to remove a proportion of the COD load without producing sludge and to save energy. Nevertheless, the optimisation of such a reaction is difficult to obtain and its efficiency can be comprised of between 50–80 % in COD load. The choice of having an anaerobic treatment depends also in the loading ratios, e.g. COD:N, BOD:N and N:P. The COD:N ratio should be high enough to allow bacteria to grow both in anaerobic and aerobic reactors. However, as COD and BOD removal rates are low, further treatment is needed.

The next step is generally an aerobic treatment (see Section 2.3.6.2.1). An oxygen supply is made by either surface aerators or blowing air in at the bottom of the tank. When the waste water has a COD higher than 10000 mg/l, it is best not subjected to aerobic treatment alone. However, aerobic techniques are suitable for less polluted waste water, e.g. condensed vapours from concentration systems or washing and flume water from potato starch production. In particular, when treating condensed vapours, it is important to ensure a balanced nutrient ratio (N:P). In addition, waste water from starch modification can be expected to have extremely imbalanced, carbohydrate-based organic loads with possible problems due to rising and bulking sludge [35, Germany 2002].

Finally, tertiary treatment includes biological nitrification and denitrification (see Section 2.3.6.3.1). It is reported that tertiary treatment is not always required.

The reported composition of waste water after treatment is given in Table 14.1.

### Table 14.1: Characteristics of starch sector waste water after treatment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration (mg/l)</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td></td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>COD</td>
<td></td>
<td>50</td>
<td>300</td>
</tr>
<tr>
<td>Suspended solids</td>
<td></td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td></td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td></td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Source: [63, CIAA-IAAC-UFE 2002]

It is reported that waste water from starch installations is sometimes only subject to preliminary waste water treatment, such as sedimentation (see Section 2.3.6.1.5) and then it sent off-site for landspreading.
14.3 Current consumption and emission levels

Starch is manufactured from basically three major raw materials in Europe: maize, wheat and potatoes. The specific average consumptions are as follows: 1.85 tonnes of maize, 2.85 tonnes of wheat or 6.6 tonnes potatoes are used to produce 1 tonne starch [63, CIAA-AAC-UFE 2002], [84, Austria 2002].

14.3.1 Energy consumption

The energy consumption depends on the starch and starch derived products produced on the site, i.e. on the techniques and processes involved in the starch production and co-products management. However, the main use of energy in starch production is thermal energy for the evaporation and drying processes. The energy used to produce starch slurry is low in comparison to the final production of dry products. More energy is consumed at sites where evaporation and/or drying processes are used for co-products such as fibre, solubles and proteins than at sites where solubles are landspread and fibre is sold as wet cattle feed.

Figure 14.8 shows data for specific energy consumption (MWh/tonne of raw materials) in various starch production installations. Lower specific energy consumption values have been reported in the case of potato processing.

![Energy consumption graph](image)

**Figure 14.8:** Specific energy consumption (MWh/tonne of raw materials) in starch production

The general consumption of energy in the starch sector is given in the Table.

<table>
<thead>
<tr>
<th>Energy</th>
<th>Raw-material</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical energy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>100</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>200</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Potato</td>
<td>40</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td><strong>Thermal energy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>200</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>800</td>
<td>1300</td>
<td></td>
</tr>
<tr>
<td>Potato</td>
<td>50</td>
<td>250</td>
<td></td>
</tr>
</tbody>
</table>

**Table:** Energy consumption in the starch industry

*Source: [63, CIAA-AAC-UFE 2002]*
14.3.2 Water consumption

Water consumption also depends on the starch and starch derived products produced on a particular site. The water consumption also differs according to the raw material used. Due to the higher water content of potatoes, the potato starch process requires less water than the cereal starch process. During the last 20 years, the starch industry has realised substantial savings, up to 20%, in fresh water consumption through process integrating measures, internal recycling of process water and optimisation of the cooling water system. Nevertheless, due to product applications, e.g. food and pharmacy, and to quality requirements, process water recycling is not always possible.

Figure 14.9 shows data for specific water consumption (m³/tonne of raw material) in various starch production installations.

![Figure 14.9: Specific water consumption (m³/tonne of raw material) in starch production](source: [193, TWG 2015])

Table shows the water consumption in the starch sector.

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Water consumption (m³/tonne of raw material used)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>Maize</td>
<td>1.7</td>
</tr>
<tr>
<td>Wheat</td>
<td>1.2</td>
</tr>
<tr>
<td>Potato</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Source: [63, CIAA, AAC-UEE 2002]

14.3.3 Waste

There are many factors that affect the amount of sludge after waste water treatment. It is reported that the type and the efficiency of the manufacturing process used is the most important. Also, practically no sludge is generated if there is anaerobic waste water treatment before discharging to the MWWTP. Some by-products, e.g. gluten produced in starch manufacturing, can be used in other food or animal feed processes, or sent for landspreading. Table 14.2 shows the solid outputs from the starch industry.
Table 14.2: Solid outputs from the starch industry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Solid output (kg/t raw material used)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>Stones*</td>
<td>1</td>
</tr>
<tr>
<td>Soil</td>
<td>8</td>
</tr>
<tr>
<td>Organic matters</td>
<td>0.5</td>
</tr>
<tr>
<td>Sand*</td>
<td>1.5</td>
</tr>
<tr>
<td>Waste water sludge**</td>
<td>0</td>
</tr>
</tbody>
</table>

*The highest values are for potato processing
**Data are expressed in dry substance

Source: [63, CIAA-AAC-UFE 2002]

14.3.4 Emissions to water

Waste water from the starch sector contains high emission levels of organic matter which is readily biodegradable. COD and BOD emission levels arise due to the hydrolysis and fermentation of, e.g. reduced sugars, volatile acids and aldehydes. The TSS content is not high.

Nitrogen is also present in the waste water. Its production is due to the compounds from the degradation of proteins, e.g. urea and ammonia. The nitrogen content appears to be higher for waste water from potato processing than for grain processing. Metals, e.g. Zn, Ni and Cr, can be found in very limited quantities. When found, they have arisen from the corrosion of metallic vessels and pipes, and from the raw material, e.g. corn, rice and potato.

Figure 14.10 shows reported data on specific waste water discharges (m³/tonne of raw material) from starch production installations.

Figure 14.10: Specific waste water discharge (m³/tonne of raw material) in starch production

Specific waste water discharge from starch production in Austria is at 1.4 m³/t of processed potato, i.e. average of a processing campaign, 1.8 m³/t of processed maize, i.e. yearly average, and 2.0 m³/t of processed wheat, i.e. yearly average [84, Austria 2002].
14.3.5 Emissions to air

Dust emission from starch driers is between 10–80 mg/Nm$^3$ [63, CIAA-AAC-UFE 2002].

14.3.5.1 Dust emissions from dryers

Bag filters and cyclones or a combination of them (cyclones as a first step) are mainly used as final abatement techniques for dust emissions from seed handling and preparation. Wet scrubbers, generally in combination with cyclones (as first step), are also applied in few cases. According to submitted data most starch dryers operate near atmospheric O$_2$ levels. A general overview of the data received for dust emission from dryers is shown in Figure 14.11.

![Figure 14.11: Total dust emissions to air from dryers](image)

The meaning of the symbols used in Figure 14.11 is indicated in Table 3.5.

14.3.5.2 Dust emissions from preparation of raw materials

Data from monitoring of dust emissions from preparation of raw materials are shown in Table 14.3.

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm$^3$)</th>
<th>% O$_2$ (dry basis)</th>
<th>Frequency of monitoring</th>
<th>Monitoring standard</th>
<th>Sampling duration (h)</th>
<th>Abatement technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>282-1</td>
<td>0.10</td>
<td>20.90</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>NI</td>
<td>Bag filters</td>
</tr>
<tr>
<td>284-1</td>
<td>2.80</td>
<td>20.90</td>
<td>Yearly</td>
<td>EN 13284-1</td>
<td>1.00</td>
<td>Bag filters</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.

Source: [193, TWG 2015]
14.4 Techniques to consider in the determination of BAT

14.4.1 Techniques to increase energy efficiency

14.4.1.1 Heat recovery for preheating the potato fruit juice

See also Section 2.3.2.1.1.

**Description**
Potato juice is heated up using the heat from the potato water during the protein separation stage.

**Technical description**
Preheating of potato fruit juice to about 100 °C is performed by reusing hot fruit juice, from where protein already has been extracted. Spiral exchangers can improve the heating significant compared to plate exchangers. Hereby energy can be saved.

This spiral exchanger is a fully-welded construction that differentiates itself by having a long channel duct, whereby precipitated protein maintains the same pace during the entire preheating session. At the same time the potato fruit juice is heated up slowly, which ensures a high uniform protein quality and also reduces potential precipitation in the exchanger due to pace. The heating medium on the opposite side of the channel allows heat to be recovered from the fruit water outlet that is cooled down. The preheated potato juice is then channelled via pipelines to a further heating.

**Achieved environmental benefits**
Reduction of energy consumption.

**Environmental performance and operational data**
Reduction of energy consumption for fruit juice heating of around 50 %.

**Technical considerations relevant to applicability**
Applicable to potato starch plants.

**Economics**
An investment cost of EUR 1 300 000 (capacity about 100 m³/h in terms of fruit juice) and annual savings of EUR 200 000 (reduction of natural gas consumption) have been reported (installations #149, #150, #151, #152).

**Example plants**
Installations #149, #150, #151, #152.

**Reference literature**
[ 193, TWG 2015 ], [ 274, NEWPOTATOPRO LIFE project 2007 ]

14.4.2 Techniques to reduce water consumption

14.4.2.1 Countercurrent water use/reuse in starch washing

See also Section 2.3.3.1.1.

**Technical description**
Countercurrent flow is a basic operation used in food and chemical engineering and means that two streams are running through the same space, but in opposite directions.
Countercurrent flow is commonly applied by using drinking water only at the end of the production line for treating the end-product, i.e. usually the cleanest part of the process. The water from this step is relatively clean and can be reused in another process step, for which the water is sufficiently clean, usually earlier in the process, i.e. the water flows countercurrently to the product, so that the final product only comes into contact with fresh drinking water. The technique may be operated either continuously or in batches.

Countercurrents are used for washing operations.

The advantage of a countercurrent flow is that for a given product quality the required amount of water is reduced to the lowest possible in principle and consequently the amount of waste water generated is minimised.

For instance, it is common practice to wash raw starch slurry, using a countercurrent flow, before it is dewatered and dried to produce refined starch. The starch is washed with drinking water, using a countercurrent flow, in a series of 4–6 centrifuges. At one end, raw starch is the input and process water is the output and, at the other end, refined starch is the output and fresh drinking water is the input. The countercurrent system uses much less water than either repeated washing with fresh drinking water or adding fresh drinking water at each stage.

Achieved environmental benefits
Reduces water consumption and consequently reduced waste water generation.

Environmental performance and operational data
TWG, please provide information.

Technical considerations relevant to applicability
Applicable when several washing stages are required, which need progressively cleaner water.

Driving force for implementation
Reduced water consumption.

Example plants
Numerous installations producing starch from maize, wheat or potatoes.

Reference literature
[ 94, Germany 2003 ], [ 116, CIAA, AAC, UFE 2003 ]

Reuse of gluten process water

Description
Reuse of gluten process water (in protein separation step) for germ and fibre washing and steeping process in maize starch processing.

Achieved environmental benefits
Reduces water consumption and consequently reduced waste water generation.

Driving force for implementation
Reduced water consumption.
14.4.2.2 Reuse of process water in potato starch manufacturing

Description
Where starch and starch derivatives are manufactured from potatoes, large volumes of potato starch manufacturing waste water may be produced. A system for reusing the potato fruit water and process water is summarised in Figure 14.12.

Figure 14.12: Water circuit in a potato starch installation

First the potato fruit water is treated by RO. The treated potato fruit water is then sent, together with the process water, for protein extraction, by coagulation. The next process step is concentration by evaporation of the deproteinised potato fruit water and the process water. The condensed vapours obtained from this evaporation step is cooled and the pH is adjusted before being fed to the biological WWTP. Some of the purified water undergoes further treatment where it is first filtered through a sand filter and then disinfected. The water recovered is mixed with fresh water and returned to the production process. Optionally, depending on product requirements, a second RO step can be performed.

Achieved environmental benefits
Reduction in both fresh water consumption and waste water volume.

Environmental performance and operational data
In an example installation, the design characteristics of the evaporation step are shown in Table 14.4 and the biological waste water treatment characteristics are shown in Table 14.5.
Table 14.4: Concentration of potato starch process water by evaporation–design data

<table>
<thead>
<tr>
<th>Inlet</th>
<th>Total inlet flow</th>
<th>213 m³/h (on the basis of continuous feed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process water from starch manufacturing</td>
<td>Flow volume 1 = 110–145 m³/h</td>
<td>Dry matter content = 1.8–2%</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>Inlet protein unit = 38–40 °C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>After protein unit = 86 °C</td>
</tr>
<tr>
<td>Coagulated potato fruit water from protein unit</td>
<td>Flow volume 2 = 100–115 m³/h</td>
<td>Dry matter content = 5.5–6%</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>Temperature leaving protein unit = 86 °C ± 1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output</th>
<th>Product</th>
<th>Potato protein liquid with at least 55 % dry matter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Condensate</td>
<td>As cool and as pure as possible</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance</th>
<th>Steam removal capacity</th>
<th>At least 230 t/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-evaporator</td>
<td>At least 196 t/h</td>
<td></td>
</tr>
<tr>
<td>Final evaporator</td>
<td>At least 34 t/h</td>
<td></td>
</tr>
<tr>
<td>Concentration temperature</td>
<td>Maximum 87 °C</td>
<td></td>
</tr>
<tr>
<td>Reserve capacity</td>
<td>At least 15 % in terms of steam removal capacity</td>
<td></td>
</tr>
<tr>
<td>Operation cycle</td>
<td>Operating time at least 120 h</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cleaning time maximum 9 h</td>
<td></td>
</tr>
</tbody>
</table>

Source: [35, Germany 2002]

Table 14.5: Biological waste water treatment characteristics in a potato starch installation

<table>
<thead>
<tr>
<th>Waste water type</th>
<th>Condensed vapours from concentration unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Activated sludge process</td>
</tr>
<tr>
<td></td>
<td>Sand filter</td>
</tr>
<tr>
<td></td>
<td>Disinfection</td>
</tr>
<tr>
<td>Basic design data</td>
<td></td>
</tr>
<tr>
<td>Waste water volume</td>
<td>200 m³/h</td>
</tr>
<tr>
<td>COD concentration</td>
<td>1500 ± 300 mg/l</td>
</tr>
<tr>
<td>COD load</td>
<td>7200 ± 1440 kg/d</td>
</tr>
<tr>
<td>Waste water characteristics</td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>&lt;25 mg/l</td>
</tr>
<tr>
<td>BOD₅</td>
<td>&lt;10 mg/l</td>
</tr>
<tr>
<td>Characteristics of the activated sludge treatment</td>
<td></td>
</tr>
<tr>
<td>2 basins, each of 1375 m³ (= 2750 m³)</td>
<td></td>
</tr>
<tr>
<td>aerobic volume including preceding selector</td>
<td></td>
</tr>
<tr>
<td>Hydraulic residence time</td>
<td>= 13.8 h</td>
</tr>
<tr>
<td>Hydraulic load</td>
<td>= 1.75 m³/m³ per day</td>
</tr>
<tr>
<td>COD volume load</td>
<td>= 2.6 kg/m³ per day</td>
</tr>
<tr>
<td>Sludge concentration</td>
<td>= 5000 g/m³</td>
</tr>
<tr>
<td>COD sludge load</td>
<td>= 0.52 kg COD/kg dry matter per day</td>
</tr>
<tr>
<td>Return sludge volume</td>
<td>= maximum 200 m³/h</td>
</tr>
<tr>
<td>Final sedimentation</td>
<td></td>
</tr>
<tr>
<td>Secondary sedimentation</td>
<td></td>
</tr>
<tr>
<td>1 circular transverse-flow sedimentation basin</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td>=23 m</td>
</tr>
<tr>
<td>Water depth</td>
<td>=5 m</td>
</tr>
<tr>
<td>Volume</td>
<td>=2076 m³</td>
</tr>
<tr>
<td>Surface area</td>
<td>= 415 m²</td>
</tr>
<tr>
<td>Residence time</td>
<td>= 10.38 h</td>
</tr>
<tr>
<td>Surface load</td>
<td>= 0.48 m/h</td>
</tr>
<tr>
<td>Sand filtration</td>
<td></td>
</tr>
<tr>
<td>3 units</td>
<td>In-feed flowrate</td>
</tr>
<tr>
<td></td>
<td>Washing water flowrate</td>
</tr>
<tr>
<td></td>
<td>Hydraulic load</td>
</tr>
<tr>
<td>Disinfection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UV disinfection and ClO₂ metering</td>
</tr>
</tbody>
</table>

Source: [35, Germany 2002]

Cross-media effects
Increased energy consumption and surplus sludge production.

Technical considerations relevant to applicability
Condensed vapours in the potato starch industry are highly degradable making the treatment by RO and evaporation stages dependent on the special properties of potato fruit water and process water.
Economics
It is reported that the cooling of treated condensed vapour may not necessarily be economical.

Driving forces for implementation
The reduction in fresh water consumption reduces costs. It is reported that the waste water had previously been disposed of by landspreading. This was not feasible because of the large volume produced, the high transport costs, and the high surface area requirement. The storage volume required using this method is small compared to landspreading, due to landspreading being limited to certain periods of time of the year. Unlike the landspreading option, this technique is independent of weather conditions.

Example plants
At least one installation manufacturing starch from potatoes in Germany.

Reference literature
[35, Germany 2002]

14.4.3 Techniques to reduce waste

14.4.3.1 Segregation Separation of residues outputs, to optimise use, reuse, recovery, recycling and disposal (and minimise water use and waste water contamination)

This technique is described in Section 2.3.5.3.

Reported examples of where the technique is applied
There are likely to be many other opportunities to apply this technique within the sector.

- some water diluted materials can be recovered, if the water is collected, e.g. potato starch can be recovered from starch water.

Technical considerations relevant to applicability
Applicable to potato starch installations.

Reference literature

14.4.4 Techniques to reduce emissions to air

14.4.4.1 Techniques to reduce dust emissions from dryers

14.4.4.1.1 Bag filter

The technique is generally described in Section 2.3.7.2.2.

Environmental performance and operational data
Table 14.6 shows installation-specific performance data related to the application of bag filters as dust abatement technique.
## Table 14.6: Total dust emissions to air from a dryer after treatment in a bag filter

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>O₂ content (%, dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>149-2</td>
<td>0.30</td>
<td>19.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Potato Native starch Flash dryer (starch drying) Natural gas</td>
</tr>
<tr>
<td>150-4</td>
<td>0.30</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Potato Native starch Rotary dryer (protein drying) Natural gas</td>
</tr>
<tr>
<td>280-1</td>
<td>0.40</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Wheat Native, hydrolysed starch Flash dryer (protein drying) Steam</td>
</tr>
<tr>
<td>280-2</td>
<td>0.52</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Wheat Native, hydrolysed starch Flash dryer (protein drying) Steam</td>
</tr>
<tr>
<td>486-4</td>
<td>&lt;1</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Four times a year</td>
<td>Wheat Flash dryer (protein drying) Natural gas</td>
</tr>
<tr>
<td>287-5</td>
<td>1.04</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Wheat Native, hydrolysed starch Flash dryer (protein) Steam</td>
</tr>
<tr>
<td>187-8</td>
<td>2.50</td>
<td>21.00</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Maize Native, modified, hydrolysed starch Flash dryer (starch drying) Hot air from exchanger Moisture content in exhaust air of dryer, around 1.6 %</td>
</tr>
<tr>
<td>187-5</td>
<td>2.75</td>
<td>15.00</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Maize Native, modified, hydrolysed starch Rotary dryer (fibre drying) Natural gas Moisture content in exhaust air of dryer, around 8.9 % Cyclone step before</td>
</tr>
<tr>
<td>284-4</td>
<td>3.90</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Pea Native starch, modified starch Flash dryer (fibre drying) Hot air from exchanger</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.
Source: [193, TWG 2015]
Reference literature
[193, TWG 2015]

### 14.4.4.1.2 Cyclone

The technique is generally described in Section 2.3.7.2.3.

#### Environmental performance and operational data

Table 14.7 shows installation-specific performance data related to the application of cyclones as dust abatement technique.

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>O₂ content (%) dry basis</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>149-1</td>
<td>0.16</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Potato Native starch Flash dryer (starch drying) Natural gas</td>
</tr>
<tr>
<td>281-4</td>
<td>0.20</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Once every four years</td>
<td>Wheat, maize Native, modified, hydrolysed starch Flash dryer (starch drying) Hot air from exchanger Sticky dust, 13% moisture</td>
</tr>
<tr>
<td>150-4</td>
<td>0.30</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Potato Native starch Flash dryer (protein drying) Natural gas</td>
</tr>
<tr>
<td>150-1</td>
<td>0.60</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Potato Native starch Flash dryer (starch drying) Natural gas</td>
</tr>
<tr>
<td>187-4</td>
<td>2.48</td>
<td>21.00</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Maize Native, modified, hydrolysed starch Flash dryer (starch drying) Hot air from exchanger Moisture content in exhaust air of dryer, around 1.6 %</td>
</tr>
<tr>
<td>395-2</td>
<td>3.00</td>
<td>21.00</td>
<td>EN 13284-1</td>
<td>Once every three years</td>
<td>Potato Native starch Flash dryer (starch drying) Steam</td>
</tr>
</tbody>
</table>
### Installation ID-point of release

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>O₂ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>283-3</td>
<td>8.00</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>Potato Native, modified starch, Flash dryer (fibre drying), Natural gas, Sticky dust</td>
</tr>
<tr>
<td>150-3</td>
<td>10.00</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Potato Native starch, Rotary dryer (fibre drying), Natural gas</td>
</tr>
<tr>
<td>283-1</td>
<td>12.00</td>
<td>20.90</td>
<td>NA</td>
<td>NA</td>
<td>Potato Native, modified starch, Flash dryer (starch drying), Hot air from exchanger, Sticky dust, 21% moisture</td>
</tr>
<tr>
<td>085-1</td>
<td>15.00</td>
<td>NI</td>
<td>EN ISO 16911-1</td>
<td>Yearly</td>
<td>Potato Native, modified starch, Flash dryer (starch drying), Hot air from exchanger, Dust particles with a residual humidity of 20%</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.

Source: [193, TWG 2015]

## Reference literature

[193, TWG 2015]

### 14.4.4.1.3 Wet scrubber

The technique is generally described in Section 2.3.7.3.1.

## Environmental performance and operational data

Table 14.8 shows installation-specific performance data related to the application of wet scrubbers as dust abatement technique.
Table 14.8: Total dust emissions to air from a dryer after treatment in a wet scrubber

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>O₂ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>187-5</td>
<td>0.74</td>
<td>21.00</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Maize, Native, modified, hydrolysed starch, Germ drying, Cyclone and bag filter step before</td>
</tr>
<tr>
<td>281-7</td>
<td>9.28</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Biennial</td>
<td>Wheat, maize Native, modified, hydrolysed starch, Steam dryer (maize protein drying), Hot air from exchanger, Sticky dust, Cyclone step before</td>
</tr>
<tr>
<td>486-2</td>
<td>19.16</td>
<td>NI</td>
<td>EN 13284-1</td>
<td>Monthly</td>
<td>Wheat, Native, modified, hydrolysed starch, Spray dryer (hydrolysed products drying), Natural gas</td>
</tr>
<tr>
<td>282-6</td>
<td>29.30</td>
<td>20.90</td>
<td>NI</td>
<td>Once every four years</td>
<td>Wheat, maize Native, modified, hydrolysed starch, Spray dryer (hydrolysed products drying), Hot air from exchanger, Sticky dust</td>
</tr>
</tbody>
</table>

NB: NI = no information provided.

Source: [193, TWG 2015]

Reference literature
[193, TWG 2015]

14.4.4.2 Techniques to reduce dust emissions from preparation of raw materials

14.4.4.2.1 Bag filters

The technique is generally described in Section 2.3.7.2.2.

Environmental performance and operational data
Table 14.9 shows installation-specific performance data related to the application of bag filters as dust abatement technique.
Table 14.9: Total dust emissions to air from raw material preparation after treatment in a bag filter

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm$^3$)</th>
<th>$O_2$ content (% dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>282-1</td>
<td>0.10</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>NA</td>
<td>Unloading of raw materials from train to silo</td>
</tr>
<tr>
<td>284-1</td>
<td>2.80</td>
<td>20.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Pea grinding machine (milling)</td>
</tr>
</tbody>
</table>

NB: NI = no information provided

Source: [193, TWG 2015]

Reference literature
[193, TWG 2015]
14.5 Emerging techniques

TWG, please provide information.
15 SUGAR MANUFACTURING

15.1 General information about the sector

Beet and sugar production in the EU is based on a market organisation, known as the common market organisation (CMO) of the sugar sector or Sugar CMO. In 2006, this CMO was thoroughly reformed leading to a large reduction in quota sugar production of around 6 million tonnes (-30 %). This left a remaining quota sugar production of around 13.3 million tonnes. Key to the reform was a 36 % cut in the reference sugar price (from EUR 631.9/tonne in 2006/2007 campaign to EUR 404.4/tonne in 2009/2010 campaign) and the removal of the intervention mechanism that guaranteed a minimum sugar price.

In the 2014/15 campaign beet sugar production was distributed among 49 EU Member States, with 70 % of the production concentrated in 4 countries (see Figure 15.1).

![Figure 15.1: Distribution of sugar production in EU-28 (2015)](image)

In the years leading up to and following the adoption of the CMO reform, the number of EU sugar factories has fallen as the industry has undergone major restructuring driven by the need to improve efficiency. In the period 2000-2008 151 factories were closed, resulting in an overall reduction of 60 % of European processing capacity. Since 2010, the number of factories has remained stable to 109 across the EU-28. Taking into account both direct and indirect employment the beet sugar industry in the EU supports about 180 000 jobs and contributes to the revenue of 140 000 farms [194, CEFS 2016].
15.2 Applied processes and techniques

Sugar (sucrose) is produced from two principal sources, sugar beet and sugar cane. Sugar beet tends to be grown in Europe and sugar cane in hotter climates [71, AWARENET 2002] such as the West Indies, so it is not extracted in Europe. Sucrose is also available in a liquid form as an aqueous solution, in some cases all or partially inverted. Sugar crystals may be ground to make powdered or confectioner’s sugars. Anti-caking agents such as maize starch are added to keep these sugars free flowing.

From common household white sugar, to high-tech products, the companies of the European sugar industry are active in the development of a wide range of products, all of which originate from sugar beet. These include food ingredients, animal feed, green chemistry products (replacing petroleum-based materials) and biofuels such as bio-ethanol and biogas (see Figure 15.2).

![Figure 15.2: Product range in a sugar factory](source: [199, CEFS 2010])

15.2.1 Sugar beet extraction

In general, the extraction of sugar from sugar beet and sugar cane is similar. The beets are cut into thin slices called cossettes. They are passed into a water-based countercurrent extraction apparatus called a diffuser and emerge as impure sugar juice and beet pulp. The fresh water used in the extraction process is actually condensed water from the subsequent evaporation steps together with recirculated water from the pulp pressing. The temperature inside the diffuser is 68 °C to 72 °C.

Three types of diffusers are used:

- horizontal diffusers are large revolving drums, separated into cells by a helix attached to the interior surface. As the drum and helix revolve, the juice, which stays at the bottom of the vessel, is transported countercurrently to the cossettes, i.e. the exhausted beet pulp leaves the diffuser at the same end where the fresh water enters;
- vertical diffusers are composed of an extractor with two main and distinct parts, i.e. the countercurrent mixer and the extraction tower. The tower is a 14
m to 20 m high cylinder. Inside the tower, a tubular shaft rotates slowly. Special helicoidal steel pieces, or flights, are fitted on the shaft and move the cossettes upwards. The juice and the cossettes move countercurrently;

- slope diffusers consist essentially of a U-shaped sloping vessel in which two overlapping screws with opposite pitches rotate. Fresh cossettes fall from a conveyor belt into the lower end. The cossettes are transported upwards by the two screws to a paddle wheel, which lifts the exhausted cossettes out of the extractor. Fresh water is introduced at the upper end and the sugar juice leaves the extractor through a screen at the lower end.

The crystallisation process takes place in vacuum pans in which the juice is boiled under vacuum to minimise the temperatures involved. The growth of the sucrose crystal only involves sucrose and water. The non-sugars contained in the sugar juice are not incorporated into the crystal structure, instead most of them remain in the liquid phase while some are released to the vapour phase. The sugar crystals are removed from the liquid phase by centrifugation.

Sugar to be stored in silos is dedusted and cooled to the storage temperature. This is carried out in a sugar cooler, which is a device in which warm and dried sugar is intensively aerated by cold filtered external air to cool the sugar to the storage temperature, approximately 20 ºC to 30 ºC. The most common systems in use are typically drum or fluidised bed coolers with chilling systems that have a countercurrent or cross-current phase flow.

15.2.2 Drying of sugar beet pulp

After extracting sugar from cossettes, the beet pulp is pressed. If it is pressed to give a solids content of 12–17 %, it is called wet pulp. If it is pressed to a solids content of 18–34 %, it is called pressed pulp. Both wet and pressed pulp may be sold as animal feed, e.g. sweet feed for cattle. This is normally carried out after drying the pulp.

Dried pulp can be obtained by drying the pulp to a solids content of 86–92 %. About 5.6 kg dried pulp with a solids content of 90 % can be produced out of 100 kg of sugar beet. If 1–3 % of molasses, based on the weight of the pulp, is added before drying, molassed dried pulp with a varying sugar content, e.g. 9–30 %, is obtained. Apart from the sugar content, the concentrations of HCl insoluble substances, calcium, and ash are controlled in each country according to feed regulations.

Pulp drying is generally carried out by convection drying, e.g. drying with air, flue-gas or steam. When drying with air or flue-gas, the drying gas is heated and then brought into contact with the pulp. Warm, dry air can take up water vapour until it is saturated. Heat and substance transfer take place simultaneously in the drying process. In the first drying period, the drying rate remains practically constant. During this period, unbound liquid is vaporised from the surface of the solid and carried away by the drying agent. When the moisture content is reduced below a critical value, the surface of the solid dries out, and further evaporation takes place in the interior of the porous solid. The drying rate decreases with decreasing moisture content. This is called the second drying period. The residual moisture in the solid is bound to it by sorption. The drying rate decreases rapidly with a decreasing moisture content and tends to zero as the hygroscopic equilibrium moisture content is approached. The regime between the maximum hygroscopic moisture content and the equilibrium value is designated as the third drying period. The lower the residual moisture content of the pulp is supposed to be, the lower is the necessary residual moisture level in the drying gas.

When drying with steam, the requirements for the drying gas are similar. High dry matter levels in the material being dried require high residual superheating of the steam, corresponding to the low relative humidity in the air.
A recent alternative is solar drying, which allows for savings in terms of electricity and gas consumption (see Section 15.4.1.3).

Options for beet pulp drying at sugar processing installations are described in Section 15.4.1. The decision about whether to dry sugar beet pulp depends on factors such as whether there is a nearby outlet for the wet pulp, e.g. for animal feed, or the climate conditions in the case of solar drying. The storage of wet pulp can cause odour problems and the transport of wet pulp is expensive. In several European countries, e.g. France, beet pulp may be dried in installations which usually belong to farmers and are not directly connected to the sugar production process.

### 15.2.3 Sugar cane

Raw cane sugar is usually separated, purified and crystallised in the country of origin. The cane sugar, which is in a crudely refined state, undergoes final processing when transferred to the country of use.

TWG, please provide information.

### 15.2.4 Sugar refining

Raw sugar is typically a minimum of 96 % sucrose. The impure crystals, with adhering molasses, are blended in a saturated sugar solution to soften the surface molasses film which can then be removed by centrifugation. The partly processed sugar is dissolved in reclaimed liquors, i.e. light water from the refining process.

Carbonatation then follows. Carbonatation is the introduction of the milk of lime, calcium hydroxide, and carbon dioxide gas (CO$_2$) into a liquid to form calcium carbonate and to precipitate and remove impurities. The effect of lime and CO$_2$ is the precipitation of insoluble calcium salts, the flocculation of colloidal components, the chemical degradation of other molecules such as invert sugar and amides, and the absorption of non-sugars on precipitated calcium carbonate. Lime and CO$_2$ are normally produced in lime kilns by the thermal dissociation of limestone.

The product after filtration contains the calcium carbonate and the non-sugars and is used in agriculture as a liming material to improve the structure of arable soil and to regulate soil acidity. Sugar factory lime may also be used for site recovery, e.g. filling quarry ditches, and for producing bricks or cement. For aspects relating to lime kilns, see the Cement and Lime BREF [166, COM 2013].

The sugar syrup is filtered and decolourised using ion exchange resins and activated carbon to produce a fine liquor, which may be sold as a finished product or passed on for crystallisation.

Decolourisation can be carried out by the addition of an active powder, e.g. powdered activated carbon, to the product in aqueous solution, which is then mixed under controlled conditions. Afterwards, the powder is removed by filtration, using static filters or rotary vacuum filters, while the decoloured product is processed further. This process is often carried out in multiple stages with the active material being reused until exhausted, often using a countercurrent system. The process can also be carried out by passing the product in aqueous solution through a column of active material, e.g. using granular activated carbon or ion exchange resin beads. Here, only minimal filtration is required after the process as the active material is held in place. Active material is withdrawn from the column at regular intervals and replaced by new or reactivated material.

The decolourisation process produces a filter residue consisting of the active material, any filter aid used and some residual product. This solid output is sometimes sent to landfill or for
landspraying/composting depending on its nature. Depending on the type of process/product, this solid output can also be used as animal feed.

General information about lime manufacturing can be found in the Cement, Lime and Magnesium Oxide BREF [166, COM 2013].

The fine liquor is concentrated by evaporation to produce a syrup of around 60–70% solids, known as thick juice. The juice is filtered and transferred to vacuum pans. When the liquor is slightly supersaturated, the pan is seeded with fine icing sugar to initiate crystallisation. The mixture is centrifugally separated to extract crystalline sugar, which is dried, conditioned for packaging or bulk loaded. Each pan boiling yields around 50% of the available sugar.

The liquor separated during centrifugation, also called jet, is re-boiled for further extraction. Three boilings yield white sugar. A fourth boiling yields off white industrial sugar. Jet four, together with liquor from blending, goes to a recovery house for three further boilings to produce brown sugars which go back to the start of the refining process and are treated as raw sugar. Various intermediary products from jets one to four and the corresponding syrups from recovery and boiling are sold as the starting materials for syrups such as molasses and treacle. Molasses are sometimes used in animal feed, alcoholic fermentation and a number of non-food products.

**Waste water treatment**

It is reported that depending on the configuration of the WWTP, waste water segregation (see Section 2.3.3.1.4) is sometimes carried out at sugar beet processing installations, before waste water treatment. The process water, i.e. the surplus condensate from the concentration, which is high in ammonia and the water from crystallisation; the fluming water and the wash-water are reportedly kept separate from the highly polluted fluming water. In some installations the condensate is used to wash beets.

**Example 1**
The soil is settled out from the transport water in sedimentation ponds (see Section 2.3.6.1.5). The decanted water is treated using both anaerobic and aerobic lagoons (see Section 2.3.6.2.1.4). The use of lagoons can make it possible to use the water to irrigate the land during dry weather, which also reduces the need for extracting water from the rivers or from the ground. For the treatment of process waters in southern Europe, it may be possible to use lagoons for natural water evaporation due to the high average temperatures.

Further treatment is needed if there is a risk of offensive odour or should the needs of the environment dictate a more stringent level of treatment. In this case, the previous treatment can be enhanced by surface aeration, possibly preceded by aerobic treatment (see Section 2.3.6.2.4).

**Example 2**
Should the environmental needs dictate that further levels of treatment are required, sedimentation (see Section 2.3.6.1.5), anaerobic treatment (see Section 2.3.6.2.5) followed by oxygenation and/or aerobic digestion (see Section 2.3.6.2.1) with a final sludge sedimentation process can be used.

The highly loaded supernatant passing from the sedimentation ponds is ideally suited for treatment using anaerobic techniques. Moreover, the betaines from the sugar beet, composed of organic nitrogen compounds, can only be degraded anaerobically. Consequently about half of the sugar factories in Germany are currently equipped with anaerobic systems [35, Germany 2002].

The organic material in the fluming water breaks down into shorter chain organic acids. Historically, pH correction was made using additives such as lime in a neutralisation process.
However, this “acidification” of the waste water stream is ideally suited for anaerobic treatment. “Acidogenesis” is an essential reaction that takes place in anaerobic conditions to break the longer chain organic material into more treatable organic acids. A number of anaerobic installations require an acidification tank upstream of the anaerobic reactor to initiate the acidogenesis stage. Hence pH correction of the fluming water is no longer required.

The biomethanation is undertaken at higher temperatures, e.g. 37 °C, although a lower rate of digestion can take place at 20 °C or less. Operating problems may occur as a result of changes in the composition of the organic constituents of the waste water and also its high calcium content.

In the methane reactor, the presence of calcium from the carbonation process which is present in the waste water in combination with the carbon dioxide formed in the reactor leads to the precipitation of calcium carbonate. Experience shows that regardless of the concentration of the incoming waste water and regardless of the process used, the calcium content is reduced to around 0.3 – 0.7 kg/m$^3$. This means annual calcium carbonate loads of 300 – 1000 tonnes remain in the reactor. This gives rise to problems with mixing in the system, and also to additional work and cost to keep the relevant pumps, heat-exchangers and pipes in good working order.

A portion of the anaerobically treated waste water can be recycled as fluming water. Furthermore, the methane produced as part of the anaerobic process can be used for drying beet pulp intended for use as animal feed. Low grade heat can be used to preheat the waste water entering the anaerobic reactor.

Sugar processing excess condensate is considered to be high in ammonia content, yet low in COD. The recommended process for reducing the ammonia levels is to use aerobic techniques configured to allow for the nitrification of the ammonia (see Section 2.3.6.3.1). For this to take place, the waste water stream needs to be dosed with an external carbon source. For those installations using anaerobic techniques for treating the fluming water, combining the waste water from the anaerobic process with the excess process water is usually sufficient to provide a feed of adequate balance onto the aerobic treatment stage.

Some factories use hydrocyclones to remove lime-laden bacterial sludge from the system. In nearly all factories it is necessary, during the off season period, to mechanically remove the lime that has formed in the reactors. This is carried out at regular intervals, every 2 – 5 years. The lime concentrations on removal are around 800 – 1000 kg/m$^3$ of carrier material. Since such operations are seasonal, the aerobic system downstream of the anaerobic system is activated accordingly at the start of the season. This is not necessarily the case with fluidised beds. Lime is precipitated almost entirely on the carrier material, which can then be drawn off during operation.

The final waste water from this stage may be of a high enough quality to be discharged to a watercourse. Alternatively, discharge would be to WWTP. For potential recycling of final waste water, tertiary treatment techniques (see Section 2.3.6.3) can be employed on some of the waste water.

Example 3
For those circumstances which demand additional control of nitrogen and its compounds, it is necessary to install suitably designed nitrification and denitrification systems. There are several biological and non-biological techniques, e.g., ammonia stripping (see Section 2.3.6.3.2) and biological nitrification/denitrification (see Section 2.3.6.3.1).

Example 4
First an anaerobic process is applied and the biogas produced is used as fuel. Later, an aerobic process is applied degrading nitrogen and phosphorus.
After waste water treatment, the water is either reused in the factory or discharged into rivers or the open sea.

Example 5
Figure shows a typical process flow diagram of the waste water treatment for a sugar beet processing installation.

![Figure: Typical options for treating sugar beet waste water](image)

[8, Environment Agency of England and Wales 2000], [159, CIAA-CEFS, 2003]
15.3 Current consumption and emission levels

Most of the information in this Section comes from the “Guide to Establishing BAT in the Sugar Industry; Comité Européen des Fabricants de Sucre (June 2001)” [31, CEFS 2001], unless otherwise stated.

15.3.1 Sugar beet

15.3.1.1 Energy consumption

Significant thermal energy is consumed for the evaporation and beet pulp drying. Electrical energy is needed for the pumps and for driving the centrifuges.

Figure 15.3 shows data on specific energy consumption (MWh/tonne of beet processed) in the various installations.

![Specific energy consumption (MWh/tonne of beet processed) in sugar beet](image)

Source: [193, TWG 2015]

According to CEFS, specific energy consumption was 31.49 kWh/100 kg beet in 1998 [159, CIAA-CEFS, 2003]. Table shows the energy consumption in Danish sugar factories.

<table>
<thead>
<tr>
<th>Total energy (kWh) consumed</th>
<th>Specific value per tonne of beet processed</th>
<th>Specific value per tonne of sugar produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>307</td>
<td>1987</td>
</tr>
<tr>
<td>Range</td>
<td>232–362</td>
<td>1554–2379</td>
</tr>
</tbody>
</table>

Table: Energy consumption in Danish sugar factories [139, Nielsen E.H. Lehmann, 2002]

In a Greek study, a figure of 280 kWh/t is given for the electrical part of the energy consumption in sugar manufacturing [74, Greek Ministry for the Environment, 2001].
15.3.1.2 Water consumption

The water requirement for fluming is about 500–800 % of the amount of beet. For washing, 150–200 % is needed, and for a single stone catcher 70–100 % water is needed based on the amount of beet. The mechanically clarified water is reused for fluming and washing, thus only 25–30 % beet based industrial water needs to be added during the last rinsing of the beets after washing.

Smaller losses are caused by evaporation of the cooling water and by discharging by-products and wastes containing water. However, the root body consists of about 75–78 % water, therefore, the beets carry sufficient water into the processing, which accumulates as condensate. Thus, an installation producing sugar is a net water producer, because the water contained initially in the beet becomes available as surplus cooling water [71, AWARENET 2002].

Figure 15.4 shows data on specific water consumption (m³/tonne of beet processed) in various sugar beet installations.

![Figure 15.4: Specific water consumption (m³/tonne of beet processed) in sugar beet](image)

While the overall water used is about 15 m³/t sugar beet processed, the consumption of fresh water is 0.25–0.4 m³/t sugar beet processed, or even less in modern sugar factories. Water consumption depends on the activities of each installation, e.g. more water is consumed in an installation that extracts and refines sugar beet, than one that does only one of those activities. In Austria, the consumption of water is of 1.5 m³/t of sugar beet processed, equivalent to 9 m³/t produced sugar, was reported [152, Austria, 2002]. Table shows the water consumption in Danish sugar factories.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specific value per tonne of beet processed</th>
<th>Specific value per tonne of sugar produced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Range</td>
</tr>
<tr>
<td>Water (m³)</td>
<td>0.37</td>
<td>0.33–0.50</td>
</tr>
<tr>
<td>Excluding cooling water (two factories)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Including cooling water (two factories)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table: Water consumption in Danish sugar factories
[139, Nielsen E.H. Lehmann, 2002]
15.3.1.3 Waste Solid output

During the reception and fluming of the sugar beet, soil, stones, sand and vegetable matter, e.g. seeds, beet tails and leaves, are removed. The amount of the earth adhering to the beet may vary greatly depending on, e.g. the weather conditions during harvesting and the design and operation of the harvester. In the annual processing of 500,000 tonnes of beets, an average of 60,000 tonnes of soil accumulates [51, Ullmann 2001]. The soil arriving at the installation is removed in settling ponds. The sediment may be re-applied to arable land or may be used for other purposes, such as horticulture or civil engineering works. The vegetable matter is separated from the fluming water for sale as animal feed or fertiliser.

The sugar content of the beets does not vary greatly, e.g. 18.4% in Austria and 13.9% in Greece [51, Ullmann 2001]. The efficiency of sugar extraction is about 90%. There are other substances either in the wastes or by-products, such as beet pulp. After sugar is taken out, the extracted beet pulp is pressed. The wet pulp may then be dried. Beet pulp is normally sold as sweet feed for cattle. Another by-product is carbonatation lime. Juice purification is done using lime. It may be pressed and sold to de-acidify or balance the pH of soil.

Sugar beets contain some soluble non-sugar substances, 30–40% of which are eliminated during purification of the juice with Ca\(^{2+}\) precipitable anions, pectins and proteins. The remainder is left in the juice and prevents the complete crystallisation of the sugar, leaving a final syrup, called molasses. This is the major single loss of sugar in the process. 10–18% of the sugar content of the beet is in molasses. About 38 kg molasses per tonne of sugar beet is generated. Molasses is about 80% solid material and 20% water.

In a study of Danish sugar factories, approximately 49% of the total production was reported to be primary products such as sugar, molasses and feed pills. While the remaining by-products such as lime, beet pulp and weeds were sold or reused [73, Nielsen et al. 2002]. Figure 15.5 shows a typical process flow diagram for a sugar beet processing installation and the production of waste water, wastes and by-products [71, AWARENET 2002].
15.3.1.4 Waste Emissions to water

Sugar beet is 75% water, and the extraction process, by definition, aims to release a high proportion of water contained in the beets. Approximately half of this water is lost due to evaporation or inclusion in various product streams. The remainder is, after usage for washing and fluming, a source of highly polluted waste water.

The beets are floated through the cleaning stage where stones, weeds and other gross contaminants are removed. The transport water pumped off with the soil sludge can be up to 70% of the beet. It has a high organic contamination due to the soil and sugar from damaged beets. Its COD is 5 000–20 000 mg/l.

The beets then enter the installation, where they are washed before being sliced into cossettes to maximise the surface area for the extraction process. The condensate from the evaporation and crystallisation stages is partly used as process water in several process stages, including beet washing. Process waste water is deemed to be the excess condensate from the concentration and crystallisation stages. This surplus condensate is high in ammonia and relatively low in COD content. Waste water with high BOD emission levels is produced in large volumes [8, Environment Agency of England and Wales 2000] and is cleaned in a WWTP.
Figure 15.6 shows data on specific waste water discharge (m³/tonne of beet processed) in various sugar beet installations.

![Graph showing specific waste water discharge](image)

Source: [193, TWG 2015]

Figure 15.6: Specific waste water discharge (m³/tonne of beet processed) in sugar beet

The performance of waste water treatment in a sugar industry of the Nordic countries is shown in Table.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>BOD (mg/l)</th>
<th>Total-N (mg/l)</th>
<th>Total-P (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before treatment</td>
<td>100</td>
<td>420</td>
<td>10</td>
</tr>
<tr>
<td>After anaerobic treatment</td>
<td>100</td>
<td>80</td>
<td>8</td>
</tr>
<tr>
<td>After anaerobic and aerobic treatment</td>
<td>2</td>
<td>10</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table: Performance of waste water treatment in a sugar industry of the Nordic countries [1, CIAA, 2002]

Figures per tonne of sugar beet processed in Danish sugar installations are given in Table.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total Average (range)</th>
<th>No-treatment Average (range)</th>
<th>After-anaerobic/ aerobic treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste water m³/t beets processed</td>
<td>0.79 (0.53–1.10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste water m³/t sugar produced</td>
<td>5.13 (3.73–6.98)</td>
<td>5.59 (3.76–6.98)</td>
<td></td>
</tr>
<tr>
<td>BOD kg/t sugar produced</td>
<td>10.3 (0.01–24.4)</td>
<td>14.6 (10.7–24.4)</td>
<td>0.04</td>
</tr>
<tr>
<td>Suspended solids kg/t sugar produced</td>
<td>1.25 (0.76–1.62)</td>
<td>1.16 (0.76–1.42)</td>
<td>n/a</td>
</tr>
<tr>
<td>Nitrogen kg/t sugar produced</td>
<td>0.22 (0.01–0.56)</td>
<td>0.33 (0.19–0.56)</td>
<td>0.03</td>
</tr>
<tr>
<td>Phosphate g/t sugar produced</td>
<td>31.3 (0.81–83.2)</td>
<td>40.4 (27.5–83.2)</td>
<td>1.32</td>
</tr>
</tbody>
</table>

Table: Waste water production and main characteristics in Danish sugar installations [139, Nielsen E.H. Lehmann, 2002]
Specific loads for waste water contaminants after biological waste water treatment are shown in Table.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sugar produced (kg/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD&lt;sub&gt;5&lt;/sub&gt;</td>
<td>0.24</td>
</tr>
<tr>
<td>COD</td>
<td>2.4</td>
</tr>
<tr>
<td>TOC</td>
<td>0.9</td>
</tr>
<tr>
<td>Nitrogen&lt;sub&gt;tot&lt;/sub&gt;</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Table: Waste water loads after biological treatment during a sugar beet processing campaign [152, Austria, 2002]

15.3.1.5 Emissions to air from beet pulp dryers

15.3.1.5.1 Dust emissions

Cyclones are basically used as an abatement technique for dust emissions from dryers. Wet scrubbers are also, less frequently, applied. The emitted dust is reported to be very sticky. Dryers have been reported to operate in various O<sub>2</sub> levels, in many cases less than 10%. A general overview of the data received for dust emissions from dryers is shown in Figure 15.7.

![Figure 15.7: Total dust emissions to air from beet pulp dryers](image)

The meaning of the symbols used in Figure 15.7 is indicated in Table 3.5.

15.3.1.5.2 TVOC emissions

Data from monitoring of stack TVOC emissions are shown in Table 15.1.
### Table 15.1: Average TVOC emissions to air from a beet pulp dryer (spot sampling)

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>TVOC (mg/Nm$^3$)</th>
<th>% $O_2$ (dry basis)</th>
<th>Frequency of monitoring</th>
<th>Monitorin standard</th>
<th>Sampling duration (h)</th>
<th>Additional info</th>
</tr>
</thead>
<tbody>
<tr>
<td>111-1</td>
<td>0.04*</td>
<td>7.93</td>
<td>Yearly</td>
<td>VDI 3481</td>
<td>0.50</td>
<td>High temperature dryer/natural gas Central chimney Wet scrubber</td>
</tr>
<tr>
<td>112-2</td>
<td>0.08*</td>
<td>6.90</td>
<td>NI</td>
<td>VDI 3481</td>
<td>0.50</td>
<td>Rotary dryer with 3 drums using heat within flue gases of the CHP plant and additional production of heat from burning of biogas, natural gas and heavy fuel oil Cyclones (no abatement efficiency for TVOC)</td>
</tr>
<tr>
<td>373-10</td>
<td>5.00</td>
<td>NI</td>
<td>Twice a year</td>
<td>NI</td>
<td>NI</td>
<td>Cyclones (no abatement efficiency for TVOC)</td>
</tr>
<tr>
<td>288-1</td>
<td>181.30</td>
<td>13.00</td>
<td>Monthly</td>
<td>EN 12619</td>
<td>3.00</td>
<td>Rotary dryer/coal Wet scrubber Wet gas</td>
</tr>
<tr>
<td>287-1</td>
<td>192.00</td>
<td>15.86</td>
<td>Yearly</td>
<td>EN 12619</td>
<td>0.50</td>
<td>Rotary dryer/coal Wet scrubber Wet gas</td>
</tr>
<tr>
<td>286-2</td>
<td>235.00</td>
<td>15.80</td>
<td>Monthly</td>
<td>EN 12619</td>
<td>3.00</td>
<td>Rotary dryer/natural gas Wet scrubber Wet gas</td>
</tr>
</tbody>
</table>

NB: * = kg of TOC/t of processed beet  
NI = no information provided  
*Source:* [193, TWG 2015]

### 15.3.1.5.3 NO$_X$ emissions

A general overview of the data received for dust emissions from dryers is shown in Figure 15.8. For most of the release points no technique for reduction of NO$_X$ emissions has been reported, except for three cases in which recirculation of exhaust gas has been implemented.
The meaning of the symbols used in Figure 15.8 is indicated in Table 3.5.

15.3.1.5.4 CO emissions

A general overview of the data received for CO emissions from beet pulp dryers is shown in Figure 15.9. For all the release points no implemented technique for reduction of CO emissions has been reported.

The meaning of the symbols used in Figure 15.9 is indicated in Table 3.5.
15.3.1.5.5 SO\textsubscript{X} emissions

A general overview of the data received for SO\textsubscript{X} emissions from dryers is shown in Figure 15.10. For most of the release points no technique for reduction of NO\textsubscript{X} emissions has been reported, except for three cases in where a wet scrubber has been implemented.

![Figure 15.10: Average SO\textsubscript{X} emissions to air from beet pulp dryers](image)

The meaning of the symbols used in Figure 15.10 is indicated in Table 3.5.

15.3.2 Cane sugar refining

The starting point is not sugar cane, but raw sugar, therefore less water is required than in sugar beet processing. The regeneration every 40–50 hours of the ion exchange resin cells used in the decolourisation process generates a difficult waste water as caustic brine is used as the regenerant [8, Environment Agency of England and Wales 2000]. There may be excess condensate and sweet water although these can be eliminated (see Section 15.4.2.1). Waste water is generated from the steam cleaning of the bulk road tankers used to transport liquid sugar products.

15.3.3 Dust emissions to air from handling and preparation of raw materials

Total dust emissions to air from handling and preparation of raw materials are shown in Figure 15.11. The received data are related to three installations (#328, #329 and #373). Installations #328, #373 are cane sugar ones. Emission points include releases from silos, transportation and packaging areas. Bag filters are commonly used as final abatement technique.
Figure 15.11: Total dust emissions from handling and preparation of raw materials

The meaning of the symbols used in Figure 15.11 is indicated in Table 3.5.
15.4 Techniques to consider in the determination of BAT

15.4.1 Techniques to increase energy efficiency

15.4.1.1 Pressing of sugar beet pulp

Description
The beet pulp is pressed to a dry matter content of typically 25–32%.

Technical description
Pressed beet pulp contains typically 20–32% of dry matter and could be a valuable feed, generally considered as a non-forage fibre source.

Achieved environmental benefits
Reduced energy consumption for beet drying.

Technical considerations relevant to applicability
Pressed pulps can be stored only for a few days, except if made into silage.

Example plants
Used in various sugar plants.

Reference literature
[234, Denmark 2015]

15.4.1.2 Steam drying of sugar beet pulp

Description
Drying of beet pulp by the use of superheated steam.

Technical description
Drying is achieved by using superheated steam. If the steam is at 130 °C, it expands and the temperature drops to 102–103 °C at around 0.1 MPa by the uptake of water. If the steam is at 260 °C at around 2.6 MPa, it expands and the temperature drops to 148 °C at around 0.37 MPa. FBDs can be used in steam drying.

Achieved environmental benefits
Reduced emissions of dust and odour, compared to HTD. As flue-gas is not used, NOx is not released. Another advantage is the lower overall energy consumption for drying compared to HTD and two-stage drying. The energy output, e.g. steam, can be reused in the sugar extraction process. Drying the pulp produces animal feed that can be stored for a longer time than moist feed.

Cross-media effects
Waste water production. Organic compounds are also emitted to air and water.

Environmental performance and operational data
The closed design of steam drying has the advantage of reducing the escape of gaseous emissions, e.g. dust and odour, however the venting of gases is required to maintain heat transfer in FBDs. It is reported that the concentration of malodorous compounds in the exhaust air of FBDs is 5–50 times higher than in HTD. It is reported that condensers can be used to reduce odour emissions, however, this technique is not described in this document.
In the case of steam dryers, the water content of the exhaust gases is normally removed by condensation. A significant amount of condensate is produced in this process. Figures for steam drying using FBDs show that about 0.6–0.7 tonne condensate per tonne of pressed pulp are generated with an organic load of 0.20–0.25 kg TOC per tonne of pressed pulp.

It is reported that due to the quantities of steam required for the steam drying of sugar beet pulp it is only viable to use this technique at installations which also refine sugar.

In a pressurised steam fluidised bed drying (PSFD) reactor, the steam drying of the beet pulp takes place in a closed fluid-bed system which allows for fully remaining the energy used for the drying process. The steam generated by the drying process (evaporated from the beet pulp) is used in the sugar factory.

The PSFD makes use of the availability of high pressure superheated steam in the factory. The energy potential of the HP-steam is used to dry the pulp under a relatively low pressure of 3.5 bar and 150 °C in a closed pressure vessel. This method of drying needs a high intensity contact between the pulp and the steam. This is achieved in a fluid bed, where the pulp is kept in suspension by the circulating steam. As the pulp particles are dried to the desired moisture content, they will be conveyed out of the dryer by a screw conveyer.

The operating principle of the PSFD is shown in Figure 15.12.

![Pressurised steam fluidised bed dryer](image)

**Figure 15.12:** Pressurised steam fluidised bed dryer

Three main streams leave the dryer:
- the product, the dried beet pulp;
- the steam from the water evaporated from the pressed pulp. This is used as energy source elsewhere in the sugar installation;
- the condensate from the steam used for running the dryer. This goes into the normal condensate system of the installation and is returned to the boiler.
Technical considerations relevant to applicability

Applicable for drying pulp in the sugar sector. Steam drying using FBDs with an integrated steam system can be used in new sugar installations. For existing installations it may require complete reconstruction of the energy generation and heat switching facilities. Retrofitting involves reconstructing the steam generation and electricity production sections including, e.g. revising the entire heat transfer arrangements within the installation.

Economics

Steam drying with FBDs and two-stage drying have practically the same NPV, while HTD is cheaper by about 6 %. However, if the calculations are done with a longer operational life, i.e. 18 years, for the dryers and the gas turbine, the NPV of steam drying with FBDs is the lowest, e.g. lowest cost.

Driving force for implementation

- Savings in costs and energy.
- Drying the pulp produces animal feed that can be stored for a longer time than moist feed.

Example plants

Used in six German various sugar plants installations.

Reference literature

[35, Germany 2002 ], [233, Denmark 2015 ], [234, Denmark 2015 ]

15.4.1.3 Solar drying

Description

Use of the solar energy to dry the beet pulp.

Technical description

The pulp solar drying uses the solar energy to dry the beet pulp which allows decreasing the energy consumption in the traditional pulp dryer. Due to this new technology, the pulp dryers are turned off.

The solar drying process usually begins during the campaign on summer as follows:

- pressed pulp loading is transported to the drying area;
- pulp is spread in the drying field (normally a concrete field);
- the pulp is stirred and turned over;
- dried pulp is picked up and transported to a pelletized area.

In some cases the pressed pulp is ensiled during the campaign on autumn/winter, and when the meteorology conditions are favourable, the pulp is transported to the drying area. Ensiling may also be applicable before the final pelletisation.

Achieved environmental benefits

Stopping the conventional pulp dryer has a significant decrease of gas and electricity consumption, CO₂, particles and odour emissions.

Environmental performance and operational data

In some sugar installations in Spain the technique has been implemented and the quality of the dry pulp is controlled under specific control plans. The final results are of good quality. The yield of solar drying can be between 50 and 80 t/ha-day, depending on the weather conditions (e.g. wind and relative humidity of air) and the operating conditions (e.g. spreading time and thickness) [240, COM 2015 ].
A reduction of about 15% to 25% of the total fuel consumption (natural gas) can be achieved, resulting in about less 10,000 tonnes to 15,000 tonnes of CO\(_2\) emitted (#181, #182). Normally there are no significant dust and odour emissions when using this technique.

**Cross-media effects**
It requires extra resources for spreading the pulp (staff, specific machinery and fuel). 

**Technical considerations relevant to applicability**
Climate conditions play a key role in applying this technique.

**Economics**
Costs of around EUR 2,000,000 (mainly construction cost of concrete area) for a drying area of 14 ha.

**Driving force for implementation**
Reduction in CO\(_2\) foot print and of energy costs of the installation.

**Example plants**
Sugar installations in Spain (#181, #182).

**Reference literature**
[ 193, TWG 2015 ], [ 240, COM 2015 ]

### 15.4.1.4 High temperature drying (HTD) of sugar beet pulp

**Description**
The drying gas, e.g. air or waste gas, has a temperature between 900 °C and 1,000 °C.

**Technical description**
In high temperature drying (HTD), the drying gas, e.g. air or flue-gas, is heated to a temperature of up to 950 °C by direct firing and then cooled to approximately 100 °C by evaporation of water from the pulp in the dryer. Dryers generally operate at 900 to 1,000 °C to maximise evaporation efficiency and product throughput (below 900 °C efficiency is reduced). Dryers are operated at 100 % capacity. Co-currently operated rotary drum dryers with preceding firing are used for drying pressed pulp. Pressed pulp enters a slightly inclined rotating drum. Hot air (produced from the combustion of gas, oil or coal) is passed co-currently through the drum. The action of the drum and the hot gases cause the pulp to pass through the drum. The dried pulp passes to a conveying system at the end of the drum.

The drying gas used can be a mixture of firing gas which is formed during the combustion of fuel in the dryer firing system; recycled dryer flue-gas; boiler flue-gas from steam generation and a small proportion of ambient air which is drawn into the drum due to the design of the system. Cooling air is used in exceptional cases only. The flue-gas from the steam generation is, apart from the molasses-treated pulp, the sole connection between the drying unit and the rest of the sugar installation.

In the drying process, the firing gas accounts for about 25% of the stream mass and about 75% of the stream energy. The steam generator flue-gas supplies about 70% of the stream mass to the flue-gases and about 25% of the stream energy for the drying gases.

**Achieved environmental benefits**
Drying the pulp produces animal feed that can be stored for a longer time than moist feed.

**Cross-media effects**
Energy is consumed. Waste water is produced. Dust and odour are emitted to air. NO\(_X\), CO and organic compounds are emitted when flue-gas is used.
Environmental performance and operational data
The amount of heat required for the evaporation of 1 kg of water depends on the temperature gradient between the inlet and outlet of the drum. The higher the combustion gas temperature at the inlet of the drum, the greater is the thermal efficiency of the equipment. Typically, drying at temperatures of up to 750 ºC is considered to be HTD, except in the UK, where drying is carried out at 950 ºC. It is reported that this gives a 15–18 % benefit in energy efficiency over drying at 750 ºC. However, excessively high entrance temperatures may lead to strong scaling of the internal parts and burning of the material to be dried. For inlet temperatures of 600 ºC, approximately 0.972 kWh (3 500 kJ) per kilogram of water to be evaporated are used. In the drums, 150–180 kg of water evaporates per hour per cubic metre of drum contents. At the end of the process, the temperature of the drying gas is around 100 ºC. The material being dried has a temperature of 60 to 70 ºC during the drying process [192, COM 2006].

When flue-gas is used for drying, NO\textsubscript{X} is released. The emission level of NO\textsubscript{X} within the flue-gas is a function of the type of fuel, the burner type, primary, secondary and tertiary air split and the location of any recycled exhaust gases used. For example, in five German sugar production installations using natural gas, the average NO\textsubscript{X} content was about 70 mg/Nm\textsuperscript{3} in the exhaust gas and in 12 sugar installations using heavy fuel, it was about 270 mg/Nm\textsuperscript{3}. The emission of organic compounds is about 50–600 mg/Nm\textsuperscript{3} and the emission of CO is about 210–1 050 mg/Nm\textsuperscript{3}. The dust concentration in the air after cyclone treatment of the five sugar installations using natural gas was about 35 mg/Nm\textsuperscript{3}, while two factories using coal for their boiler and heavy oil/natural gas for the drying, had an average dust concentration of about 82 mg/Nm\textsuperscript{3}. The emissions of 50–60 mg/Nm\textsuperscript{3} wet dust and 0.88 kg TOC/t of sliced beet have been reported from Germany, measured under reference conditions 12 vol-% O\textsubscript{2} content of air.

The dust in the exhaust air of a dryer also depends on the moisture content of the dried pulp. A solid content above 91 % may lead to higher dust in the air. The solid content needs to be higher than 86 % because a higher moisture content can reduce the biological stability of the pulp [192, COM 2006].

The major environmental issue is the energy consumption. The energy consumption may be reduced by reducing the initial water content of the beet pulp. When the dry solid content of the pulp after pressing is 25 %, 2.6 tonnes of water per tonne dried pulp has to be evaporated in the drying process to achieve 90 % solids content. When the pressed or pre-dried pulp has 35 % solids, only 1.6 tonnes of water needs to be evaporated to produce one tonne of dried pulp. With lower amounts of water to be evaporated, lower amounts of air or flue-gas are needed and consequently lower amounts of condensed water are generated. In consequence, less air and waste needs to be treated [192, COM 2006].

A specific energy demand of 295 KWh/tonne of sugar beet processed has been reported for a HTD. The relative value for PSDF reactor would be around 174 KWh/tonne of sugar beet processed [234, Denmark 2015].

Technical considerations relevant to applicability
HTD is the most commonly used technique in Europe. It is applicable for drying pulp in the sugar sector. This technique can be operated independently of the method of operation of the sugar installation and the steam generators.

Economics
An annual operating cost of around EUR 5 200 000 (cost of fuel, electricity, consumables, labour and maintenance) has been reported for the operation of three dryers, each of them having a fan capacity of 210 000 cubic feet per minute [193, TWG 2015].

Steam drying with FBDs and two stage drying have practically the same NPV, while HTD is cheaper by about 6 %. However, if the calculations are done with a longer operational life, i.e. 18 years, for the dryers and the gas turbine, the NPV of steam drying with FBDs is the lowest, e.g. lowest cost.
Driving force for implementation
The equipment and the process constitute a robust and reliable technology. A wealth of experience exists with these drying systems and the process itself. Drying the pulp produces animal feed that can be stored for a longer time than moist feed.

Example plants
Used in most of the sugar sector.

Reference literature
[35, Germany 2002], [51, Ullmann 2001], [193, TWG 2015], [224, Denmark 2015]

15.4.1.5 Two-stage drying of sugar beet pulp

Description
The outgoing steam from high temperature drying (HTD) step is used for low temperature drying (LTD).

Technical description
For molasses-treated pulp drying, the first step is an LTD of the pulp using a belt dryer. LTD can be used as a preliminary step before HTD, in the two-stage drying of sugar beet pulp.

In LTD of sugar beet pulp, large quantities of drying gas, e.g. air or flue-gas, with an inlet temperature of about 50 °C, are saturated. The outlet temperature is about 25–30 °C. Belt dryers (or FBD) are used for LTD.

Molasses are mixed to the pulp, and then the whole mixture is dried with HTD in a rotary drum dryer. LTD is used as a first step to make use of the lower energy heat from the HTD step and from the sugar production processes.

Achieved environmental benefits
Reduced energy consumption and air pollution compared to HTD. Drying the pulp produces animal feed that can be stored for a longer time than moist feed.

Cross-media effects
Dust and odour are emitted. NOX, CO and organic compounds are emitted when flue-gas is used. Waste water is produced.

Environmental performance and operational data
If two-stage drying is applied, about 30 % energy can be saved by using the vapours of the HTD step for the first step, LTD. Most belt dryers operate with hot air at approximately 60 °C, which can be heated using the heat streams from the evaporation station and crystallisation unit of the sugar installation, which would otherwise be lost to the environment as waste heat.

Table 15.2 shows examples of the air states for LTD and HTD of sugar beet pulp.
Table 15.2: Characteristic LTD and HTD of sugar beet pulp

<table>
<thead>
<tr>
<th>Parameters of the drying gas</th>
<th>LTD</th>
<th>HTD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In</td>
<td>Out</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>50</td>
</tr>
<tr>
<td>Relative humidity of the gas</td>
<td>%</td>
<td>9.0</td>
</tr>
<tr>
<td>Water vapour load</td>
<td>kg/kg</td>
<td>0.0070</td>
</tr>
<tr>
<td>Enthalpy of moist air in relation to dry air</td>
<td>kJ/kg</td>
<td>68.8</td>
</tr>
<tr>
<td>Enthalpy of moist air in relation to dry air</td>
<td>kWh/kg</td>
<td>0.019</td>
</tr>
<tr>
<td>Air/water evaporated ratio</td>
<td>kg/kg</td>
<td>1/Δy = 0.0111⁻¹ = 89.9</td>
</tr>
</tbody>
</table>

NB: * Not defined because critical temperature exceeded.  
Δ: increase of the function.  
NI: no information provided.  
Source: [35, Germany 2002]

The waste water produced by the condensation of the vapours created at the HTD step is either sent to a WWTP or for landspreading.

Technical considerations relevant to applicability  
Applicable for drying molasses-treated pulp in the sugar sector.

Economics  
Steam drying with FBDs and two-stage drying have practically the same NPV, while HTD is cheaper by about 6%. However, if the calculations are done with a longer operational life, i.e. 18 years, for the dryers and the gas turbine, the NPV of steam drying with FBDs is the lowest, e.g. lowest cost.

Driving force for implementation  
Drying the pulp produces animal feed that can be stored for a longer time than moist feed. This use of secondary energy from the sugar production process shows an advantage to beet pulp drying of carrying out sugar production and beet pulp drying at the same installation. This may be done if the heat is not reused within the sugar production process.

Example plants  
This system exists only in two installations. One is an experimental installation and the other has a very specific configuration, e.g. it was set up as an alternative to a customary falling water circuit.

Reference literature  
[35, Germany 2002]

Low temperature drying of sugar beet pulp

Description  
Large quantities of drying gas, e.g. air or flue-gas, with an inlet temperature of about 50 °C, are saturated.

Technical description

Achieved environmental benefits  
Drying the pulp produces animal feed that can be stored for a longer time than moist feed.

Cross-media effects
Energy is consumed. Dust and odour are emitted to air. NO\textsubscript{X} is emitted when flue-gas is used. LTD uses about 30 times more gas volume than HTD (see Section).

Environmental performance and operational data

Technical considerations relevant to applicability
Applicable for drying pulp in the sugar sector.

Driving force for implementation
Drying the pulp produces animal feed that can be stored for a longer time than moist feed.

Example plants
Used in two German sugar installations, in combination with HTD.

Reference literature
[35, Germany 2002]

Comparison of steam, HTD and two-stage drying of beet pulp

Description
Three German installations are analysed. The first uses steam drying with FBDs (see Section). The second uses HTD with a rotating drum dryer (see Section). The third uses a two-stage drying process (see Section).

The first installation applies steam drying using two FBDs. The drying unit begins with the delivery of cossettes from the pressing station. The steam supply of 25 bar comes from the boiler house turbine of the sugar installation. At the end of the drying unit, the molasses-treated cossettes are transferred to the pelletising station and vapour recovery units. The molasses treatment facilities are part of the drying unit.

At the start, the cossettes from the pressing station are fed to the FBD by means of a conveyor and metering facilities. They pass through a cellular wheel sluice and a screw conveyor to the first of 16 cells arranged around the superheater. A fan, which is the only moving part in the FBD apart from the cellular wheel sluice, blows steam, which has been superheated by the off-take steam from the steam turbine, through the perforated base plates and into the cells. This keeps the cossettes suspended and allows them to be easily transported. The evaporation of moisture from the cossettes takes place in this FBD at 3 bar with a saturated steam temperature of approximately 135 °C.

Heavy particles at the lower level pass through the open cell walls of cells 1 to 16, whereas the light particles are propelled upwards into the conical part of the FBD and pass via inclined surfaces and guide rails to cell 16. The circulated steam is directed via guide vanes into the upper part of the FBD, which takes the form of a cyclone, to separate the dust particles. These gather at the outer wall of the cyclone, where they are collected by an ejector and fed to cell 16. From cell 16 the dried material passes via a screw conveyor and sluice into a cyclone. From here the dried cossettes pass through another cellular wheel sluice into a molasses screw conveyor where the molasses is added. The cossettes are then returned to the pelletising station via a conditioning screw conveyor. The steam removed from the driers has a pressure of approximately 3 bar.

The height of the drier is approximately 18 m, 7.1 m for the lower part and 10.4 m for the upper part. The weight is 320 t. Figure shows a scheme of an FBD used for drying sugar beet cossettes.
Figure 1. Schematic diagram of steam drying with FBDs used for drying sugar beet cossettes.

About 2/3 of the total spent steam is used in the driers at a pressure of 25 bar and converted to process steam at a pressure of 3 bar. Thus the pressure or enthalpy gradient from 25 bar to 3 bar cannot, as is usual in sugar factories, be used to generate electrical energy. To meet the installation’s own requirements, including the high electricity consumption of the driers, it is necessary to find a different solution from the usual counter-pressure steam-powered generating unit. One variant is to use a gas turbine which is designed for the maximum additional electricity requirements. Since a gas turbine has high exhaust gas losses, the downstream steam generator is designed as a waste heat boiler to make use of the heat energy from the gas turbine exhaust gases. The boiler has supplementary heavy fuel oil firing equipment, but due to a special firing system equipped with special burners, it succeeds in complying with the waste gas limits in the operating permit without the need for flue gas purification equipment. Figure shows a CHP and steam system of a sugar installation where cossettes are steam dried.
The hot steam, which produced a pressure of 85 bar and a temperature of 525 °C with a maximum mass flow of 110 t/h, is fed to the downstream counter-pressure offtake steam turbine. The turbine is able to draw off, via the bleed system, the necessary quantity of steam, with a pressure of between 11 and 25 bar, to heat the evaporative drier. The vapours released in the driers are reused in the evaporating station in the sugar extraction process. The vapours which contain organic substances, e.g. acids, are passed through a downstream steam converter and then used to heat the first stage of the evaporating station. The non-condensable gases containing a certain amount of water vapour are discharged to air from the steam converter.

In the second installation, HTD is used. Pressed pulp is mixed with molasses and then dried in a co-current drum drier using direct heating. A mixture of the flue gas from the furnace and flue gas from steam generation is used. Another portion of the drying media is the so-called leaking or cooling air. Air leaks in because the fixed mixing chamber and the rotating drum reportedly cannot be sealed completely. The cooling air, approximately 20 % of the drying gas volume, is also necessary to provide a sufficient flow for the transportation of the particles to be dried.

A flow sheet and data for the operation and energy use of HTD are shown in Figure. The figures were standardised and simplified for the sake of comparison with the other two methods of drying used in the two other installations of the case study. If the pulp of a factory with a capacity of 10 000 t/d (417 t/h) was dried at the installation, about 46 t/h water would be evaporated in the drier. As can be seen in Figure, the furnace gas represents about 30 % of the total gas flow and about 84 % of the energy input.
Chapter 15

Figure: HTD of sugar beet pulp

At the third German sugar installation, beet pulp is dried using two-stage drying. Beet pulp is first dried in a low temperature belt drier, which is operated countercurrently. The drying air for the low temperature drier is heated by means of vapours, e.g. water steam, and condensates from the sugar manufacturing evaporation and crystallisation stations. In this way, it is possible to use secondary energy and to reduce the use of primary energy for HTD. Molasses are mixed to the pulp and the second stage is HTD, similar to that of the previous example.

The flow sheet of a two-stage pulp drying process can be seen in Figure. The data are again standardised for a factory with a capacity of 10 000 t/d (417 t/h) of sugar beet pulp. Here, about 62% of the total water is evaporated in the HTD stage.
Achieved environmental benefits
See Sections.

Cross-media effects
See Sections.

Environmental performance and operational data
For the purposes of energy considerations regarding the three examples outlined above, the framework data of the installations are standardised, as shown in Table.

Table: Standardised framework data of the three example German installations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beet processing</td>
<td>10000 t/d (417 t/h)</td>
</tr>
<tr>
<td>Campaign length</td>
<td>90 d/yr</td>
</tr>
<tr>
<td>Pressed pulp mass flow</td>
<td>160 kg/t beet processed = 66.7 t/h</td>
</tr>
<tr>
<td>Dry substance content of the pressed pulp</td>
<td>31 %</td>
</tr>
<tr>
<td>Dry substance content of the dried pulp</td>
<td>90 %</td>
</tr>
<tr>
<td>Steam demand sugar factory</td>
<td>200 kg/t beets processed = 83.4 t/h</td>
</tr>
<tr>
<td>Live steam pressure</td>
<td>85 bar</td>
</tr>
<tr>
<td>Live steam temperature</td>
<td>525 ºC</td>
</tr>
<tr>
<td>Thermal value of the fuel</td>
<td>11.2 kWh/kg (40195 kJ/kg)</td>
</tr>
<tr>
<td>Electric energy demand of the sugar factory</td>
<td>without drying</td>
</tr>
<tr>
<td></td>
<td>10.4 MW = 24.96 kWh/t beets processed</td>
</tr>
</tbody>
</table>

The standardisation also assumes the complete crystallisation of the concentrated juice in the beet campaign. These standards assume that the following technical equipment is used:

- a steam generator at 85 bar and 525 ºC
- a corresponding back pressure turbine
• 3 bar of back pressure for supplying the evaporator station, or 3 bar back pressure and 25 bar extraction pressure for supplying the evaporation dryer
• a gas turbine for lowering the supply of electric energy during the use of an evaporation dryer
• a WWTP that is capable of processing the condensate from the vapours of the evaporation dryer.

Table shows the energy demand and production data for the three installations. For comparison purposes, data for an installation without drying the pressed pulp are also included.

Table : Comparison of energy balances of three different options for beet pulp drying and for an installation without drying in Germany

<table>
<thead>
<tr>
<th>Process step</th>
<th>Units</th>
<th>Steam drying with FBDs</th>
<th>HTD</th>
<th>Two-stage drying</th>
<th>Installation without drying</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beet processing</td>
<td>t/d</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
</tr>
<tr>
<td>Evaporation station steam demand</td>
<td>t/h</td>
<td>83.33</td>
<td>83.33</td>
<td>83.33</td>
<td>83.33</td>
</tr>
<tr>
<td>Electric energy demand for drying</td>
<td>MW</td>
<td>1.15</td>
<td>0.80</td>
<td>1.70</td>
<td>0</td>
</tr>
<tr>
<td>Electric energy demand for rest of installation</td>
<td>MW</td>
<td>10.40</td>
<td>10.40</td>
<td>10.40</td>
<td>10.40</td>
</tr>
<tr>
<td>Total electric energy demand</td>
<td>MW</td>
<td>11.55</td>
<td>11.20</td>
<td>12.10</td>
<td>10.40</td>
</tr>
<tr>
<td>Specific electric energy demand for beet processing per tonne of beets</td>
<td>kWh/t</td>
<td>27.72</td>
<td>26.88</td>
<td>29.04</td>
<td>24.96</td>
</tr>
<tr>
<td>Fuel energy HTD</td>
<td>MW</td>
<td>0</td>
<td>44.70</td>
<td>37.67</td>
<td>0</td>
</tr>
<tr>
<td>Steam generator fuel energy</td>
<td>MW</td>
<td>57.12</td>
<td>67.13</td>
<td>67.13</td>
<td>67.13</td>
</tr>
<tr>
<td>Gas turbine fuel energy</td>
<td>MW</td>
<td>16.60</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total thermal energy</td>
<td>MW</td>
<td>73.82</td>
<td>111.83</td>
<td>104.80</td>
<td>67.13</td>
</tr>
<tr>
<td>Steam turbine electric energy output</td>
<td>MW</td>
<td>7.92</td>
<td>11.66</td>
<td>11.66</td>
<td>11.66</td>
</tr>
<tr>
<td>Gas turbine electric energy output</td>
<td>MW</td>
<td>4.68</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total electric energy output</td>
<td>MW</td>
<td>12.60</td>
<td>11.66</td>
<td>11.66</td>
<td>11.66</td>
</tr>
<tr>
<td>Electric energy supply</td>
<td>MW</td>
<td>0</td>
<td>0</td>
<td>0.44</td>
<td>0</td>
</tr>
<tr>
<td>Electric energy output</td>
<td>MW</td>
<td>0.37</td>
<td>0.46</td>
<td>0</td>
<td>1.26</td>
</tr>
</tbody>
</table>

With regards to the electric energy requirement, two stage drying has the highest consumption, followed by steam drying using FBDs and followed by HTD, which needs the least electricity. In comparison with the electrical energy need of an installation without drying, it can be seen that the additional electrical energy needed for each technique is:

- HTD: 0.8 MW
- Steam drying using FBDs: 1.15 MW
- Two-stage drying: 1.7 MW.

With regards to the thermal energy requirement, HTD is the highest, followed by two-stage drying and then by steam drying with FBDs, which consumes considerably less thermal energy. In comparison with the thermal energy need of an installation without drying, it can be seen that the additional thermal energy needed for each technique is:

- HTD: 44.7 MW
- Steam drying using FBDs: 6.59 MW
- Two-stage drying: 37.67 MW.

The thermal energy output available for conversion into electrical energy is as follows. HTD has the highest output, followed by two-stage drying and finally by steam drying with FBDs.
In steam drying using FBDs, only 6.59 MW is needed for drying, out of a total thermal energy consumption of 73.72 MW. With the application of co-generation, the electrical energy balance of the installation is positive, that is 0.37 MW more electricity is produced as an output. Although a considerable portion of the steam that is put out by the back pressure turbine at approximately 27 bar is not fully available for conversion into electrical energy.

In HTD, 44.7 MW is needed for drying, out of a total thermal energy consumption of 111.83 MW. The specific thermal energy demand for water evaporation is low, e.g. about 1.03 kWh/kg vapour (3.7 MJ/kg).

For two-stage drying, 38% of the water is evaporated in the LTD step but 9.7 times more air is needed in this stage than in the HTD stage. The LTD step has a higher specific energy demand. The 34 MW thermal energy demand in LTD represents about 1.9 kWh/kg (7 MJ/kg) vapour specific consumption, while the 41 MW in the HTD stage gives about 1.4 kWh/kg (5.2 MJ/kg) vapour specific energy consumption.

Technical considerations relevant to applicability
See Sections.

Economics
In Table, the selected data for a feasibility comparison of the example installations are summarised. The quoted figures are only valid for the conditions given above. Possible minor differences in revenue for by-products are disregarded.

**Table : Comparison of the energy costs of different ways of drying beet pulp**

<table>
<thead>
<tr>
<th>Units</th>
<th>Steam drying with FBDs</th>
<th>HTD</th>
<th>Two-stage drying</th>
<th>Installation without driers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total electricity demand</td>
<td>MW</td>
<td>11.55</td>
<td>11.20</td>
<td>12.10</td>
</tr>
<tr>
<td>Total thermal energy demand</td>
<td>MW</td>
<td>73.72</td>
<td>111.83</td>
<td>104.80</td>
</tr>
<tr>
<td>Total electricity output</td>
<td>MW</td>
<td>11.48</td>
<td>11.66</td>
<td>11.66</td>
</tr>
<tr>
<td>Electric energy supply</td>
<td>MW</td>
<td>0.07</td>
<td>0</td>
<td>0.44</td>
</tr>
<tr>
<td>Electric energy output</td>
<td>MW</td>
<td>0</td>
<td>0.46</td>
<td>0</td>
</tr>
<tr>
<td>Fuel costs</td>
<td>EUR/h</td>
<td>1180</td>
<td>1789</td>
<td>1677</td>
</tr>
<tr>
<td>Electrical power costs</td>
<td></td>
<td>0</td>
<td>0</td>
<td>18.00</td>
</tr>
<tr>
<td>Electricity output</td>
<td>EUR/h</td>
<td>0</td>
<td>9.4</td>
<td>0</td>
</tr>
<tr>
<td>Total energy costs</td>
<td>EUR/h</td>
<td>1172</td>
<td>1780</td>
<td>1695</td>
</tr>
<tr>
<td>Fuel costs</td>
<td>EUR 000/yr</td>
<td>2548</td>
<td>3865</td>
<td>3622</td>
</tr>
<tr>
<td>Electric energy supply costs</td>
<td>EUR 000/yr</td>
<td>0</td>
<td>0</td>
<td>38.9</td>
</tr>
<tr>
<td>Electricity output earnings</td>
<td>EUR 000/yr</td>
<td>-16.3</td>
<td>-20.3</td>
<td>0</td>
</tr>
<tr>
<td>Total energy costs</td>
<td>EUR 000/yr</td>
<td>2532</td>
<td>3845</td>
<td>3661</td>
</tr>
</tbody>
</table>

Price of thermal energy = EUR 16.00/MWh
Price of electric energy = EUR 40.90/MWh
Campaign length = 2160 hours/yr
Price of electricity output = EUR 20.40/MWh

With regards to pressure and temperature, standard conditions are 85 bar and 525 ºC, respectively. In a number of installations, co-generation produces lower steam pressure, e.g. 40 to 60 bar. In these cases, the above savings are not expected.

In addition, the electrical energy balance of an installation can only be structured in an equalised way with an evaporation drier when a gas turbine is operated. The subsequent steam generator is able to benefit the exhaust gas flow of the gas turbine. If a gas turbine is not used, 3.63 MW...
electrical energy input is needed instead of actually producing 0.37 MW energy. The cost of that energy consumption is EUR 2.9 million per year. The savings would then drop to EUR 0.95 million per year.

Vapours from driers are condensed. The condensate requires treatment. If the existing WWTP capacity is not sufficient to treat the amount produced, then an additional treatment capacity is needed. However, note that the costs of waste water treatment and other related investments are not included in the calculations given above.

Summarising the table given above, energy costs are the lowest for steam drying with FBDs, followed by two-stage drying and finally HTD, which has the highest energy cost. However, overall, the investment costs are the highest for steam drying with FBDs and the lowest for HTD.

There are several methods for evaluating the expenditure costs. One is to calculate the net present value (NPV). NPV is the value of investment calculated as a sum of discounted future payments minus the investment’s current cost:

$$\text{NPV} = \text{cost of investment} + \sum_{i=1}^{n} \left( \frac{\text{income}_i}{(1+r)^i} \right)$$

where:

- **NPV** = net present value
- **income** = net income; this may be negative when taking into account all the costs
- **r** = discount rate (interest in %/100)
- **i** = year
- **n** = operational life of a plan in years

Table shows a comparison of expenditures expressed as NPV for the three techniques.

Table: Comparison of expenditures expressed as NPV

<table>
<thead>
<tr>
<th></th>
<th>Steam-drying with FBDs</th>
<th>HTD</th>
<th>Two-stage drying</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Investment costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drier</td>
<td>16</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td><strong>Operational costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>-2.5</td>
<td>-3.8</td>
<td>-3.7</td>
</tr>
<tr>
<td>Other</td>
<td>-0.6</td>
<td>-0.4</td>
<td>-0.5</td>
</tr>
<tr>
<td>Total</td>
<td>-3.1</td>
<td>-4.2</td>
<td>-4.2</td>
</tr>
</tbody>
</table>

**Operational life of an installation = 10 years**

Discount rate, **r** = 0.08

<table>
<thead>
<tr>
<th>Net present value (NPV)</th>
<th>EUR million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam-drying with FBDs</td>
<td>-40.9</td>
</tr>
<tr>
<td>HTD</td>
<td>-38.4</td>
</tr>
<tr>
<td>Two-stage drying</td>
<td>-40.7</td>
</tr>
</tbody>
</table>

Steam drying with FBDs and two-stage drying have practically the same NPV, while HTD is cheaper by about 6%. However, if the calculations are done with a longer operational life, i.e. 18 years, for the driers and the gas turbine, the NPV of steam drying with FBDs is the lowest, e.g. lowest cost.

**Reference literature**

[35, Germany 2002]
15.4.2 Techniques to reduce water consumption

15.4.2.1 Water recycling

See also Section 2.3.3.1.1.

Technical description
For sugar beet processing, one of the major sources of waste water is the flume water used for transporting beet through the initial stages of the process. The flume water can be reused approximately 20 times before it is discarded. The ultimate goal for consumption of transport water may be zero extraction from external water sources.

On many sites, transport water is reused in extensive circuits, usually only after intermediate purification via settling ponds. Due to the formation of organic acid compounds within the flume water, it has been historical practice to correct the pH, usually with lime. Installations using biological treatment for waste water have, however, found that the need for pH correction has been eliminated. If care is taken to minimise beet damage during transport, this reduces sugar leaching into the transport water and consequently reduces the COD emission levels and the extent of waste water treatment before reuse.

It is reported that in most cases it is feasible, assuming there is enough storage capacity, to retain enough water from the previous year’s campaign to start the new campaign. This prevents the need to extract water from a river or underground sources. Surplus water that cannot be used for the next campaign is discharged into an outlet leading to a watercourse. Some installations send the mixture of soil and water for landspreading.

Condensate from the evaporation and crystallisation stages is partly used as process water in several stages, including beet washing. Condensate may also be considered as a source of low grade water. For example, it is reported that sugar refineries can be made very water efficient so that all the fresh water is used in the process and a total recycling of condensate is achieved. Sugar beet is 75% water, and the extraction process, by definition, aims to release a high proportion of that water. Approximately half of this water is lost due to evaporation or is included in various product streams.

Achieved environmental benefits
Reduced water consumption.

Environmental performance and operational data
In modern sugar factories, fresh water consumption is 0.25–0.4 m³/t beet processed. For new installations, 0.1 m³/t beet processed water consumption may be achieved.

Technical considerations relevant to applicability
Applicable in installations producing sugar from sugar beet.

Driving force for implementation
Reduced costs associated to water treatment. Reduced water consumption.

Example plants
Applied in many installations producing sugar from sugar beet.

Reference literature
[1, CIAA 2002], [8, Environment Agency of England and Wales 2000], [31, CEFS 2001], [71, AWARENET 2002]
Chapter 15

15.4.3 Techniques to reduce waste

15.4.3.1 Recovery and reuse of filter cake in sugar refining

Description
Filtered residue is reused, replacing calcium oxide in sugar refining.

Technical description
Calcium oxide (CaO) is used for elimination of non-sugar substances from crude juice extracted from sugar beet and it is also used for refining of crude sugar. Calcium oxide is normally obtained from natural limestone by calcination in lime works at temperatures of 1200–1300 K. The quantity of calcium oxide used is around 1.5–2.5 % CaO per sugar beet; the quantity of natural limestone is more than double for production of calcium oxide.

Waste (including approximately 75 % CaCO$_3$ in dry basis) is obtained using a filter press in the proportion of 6–7 % sugar beet and is landspread to agricultural fields. For elimination of non-sugar substances from crude juice a big amount of calcium oxide is replaced by the refined waste from filter press, in the proportion of 0.3–1.0 % sugar beet. Consumption of calcium oxide will decline then to 0.6–0.7 % CaO per sugar beet.

Achieved environmental benefits
Reduction of natural limestone consumption, energy consumption and disposed waste.

Environmental performance and operational data
The following data have been reported from the implementation of this technique (for each 100 000 tonnes of sugar beet):

- reduction of limestone consumption: 1 800 tonnes
- reduction of coal consumption: 160 tonnes
- reduction of waste: 2 500 tonnes
- reduction of carbon dioxide emissions: 580 tonnes

Driving force for implementation
Reduction of natural limestone usage and carbon dioxide emissions.

Example plants
Technique used in various European and U.S.A. installations.

Reference literature
[232, LIMEX 2007]

15.4.3.2 Reducing sugar beet soil tare

Description
By a combining technical, economic and plant breeding measures, the amount of solids delivered to the installation is reduced.

Technical description
Large quantities of soil, gravel and stones are transported to sugar factories as part of beet deliveries. Handling of this unwanted material consumes a lot of resources at the site, e.g. energy and water. A clean beets project, combining technical, economic and plant breeding measures, can reduce the amount of soil delivered to the installation.

Achieved environmental benefits
Reduced amount of waste, water and energy consumption.
Environmental performance and operational data
A Swedish example sugar beet installation has focused on reducing soil tare since the early 1980s. A clean beets project has resulted in a reduction of soil tare of 150,000 tonnes. In Denmark, the reported figure is even higher due to a larger beet growing area. Performance levels are now 50% below those typical 10 years ago.

In addition, a special bonus system is used in Sweden and Denmark to promote harvesting in good weather conditions and the optimal use of harvesters. Tests run at an example installation indicate, that once new harvesters are used appropriately, it is possible to achieve a 5% soil tare (95% purity) under almost all weather conditions. Figure 15.13 shows the reduction of soil tare in Sweden.

![Soil Tare (%)](image)

*Figure 15.13: Reduction of soil tare in Sweden*

Parallel to this work, these installations are working on improving the shape of sugar beets to ensure that less soil attaches to the tuber. Breeding using traditional breeding techniques has focused on the root groove of the beet, which is the main problem in beet washing.

**Technical considerations relevant to applicability**
Applicable in sugar manufacturing.

**Economics**
Reduced energy and water costs.

**TWG, please provide information.**

**Driving force for implementation**
Reduced energy and water costs.

**Example plants**
Sugar manufacturers in Sweden and Denmark.

**Reference literature**
[1, CIAA 2002]
15.4.4 Techniques to reduce emissions to air

15.4.4.1 Reduction of dust emissions from beet pulp dryers

15.4.4.1.1 Cyclone

The technique is generally described in Section 2.3.7.2.3.

Environmental performance and operational data
Table 15.3 shows installation-specific performance data related to the application of cyclones as dust abatement technique.

Table 15.3: Total dust emissions to air from a beet pulp dryer after treatment in a cyclone

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>% O₂ content</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>415-1</td>
<td>20.40</td>
<td>12.80</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Rotary dryer/natural gas Very sticky dust Measurements refer to wet gas Dust fraction is 45.5 % PM_{10} and 24.4 % PM_{2.5}</td>
</tr>
<tr>
<td>415-2</td>
<td>30.40</td>
<td>15.70</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Rotary dryer/natural gas Very sticky dust Measurements refer to wet gas Dust fraction is 45.5 % PM_{10} and 24.4 % PM_{2.5}</td>
</tr>
<tr>
<td>414-1</td>
<td>40.50</td>
<td>17.40</td>
<td>EN 13284-1</td>
<td>Monthly</td>
<td>Rotary dryer/natural gas Very sticky dust Measurements refer to wet gas Dust fraction is 46.5 % PM_{10} and 37 % PM_{2.5}</td>
</tr>
<tr>
<td>413-2</td>
<td>50.50</td>
<td>15.40</td>
<td>EN 13284-1</td>
<td>Monthly</td>
<td>Rotary dryer/fuel oil Very sticky dust Measurements refer to wet gas Dust fraction is 55 % PM_{10} and 20 % PM_{2.5}</td>
</tr>
<tr>
<td>412-3</td>
<td>73.80</td>
<td>16.50</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Rotary dryer/natural gas Very sticky dust Measurements refer to wet gas Dust fraction is 36.30 % PM_{10} and 32.70 % PM_{2.5}</td>
</tr>
<tr>
<td>352-1</td>
<td>75.50</td>
<td>15.89</td>
<td>PN-Z-04-30-7</td>
<td>Yearly</td>
<td>Drum dryer/coal</td>
</tr>
<tr>
<td>352-2</td>
<td>80.70</td>
<td>15.47</td>
<td>PN-Z-04-30-7</td>
<td>Yearly</td>
<td>Drum dryer/coal</td>
</tr>
<tr>
<td>413-1</td>
<td>103.00</td>
<td>7.50</td>
<td>EN 13284-1</td>
<td>Monthly</td>
<td>Rotary dryer/coal Very sticky dust Measurements refer to wet gas Dust fraction is 55 % PM_{10} and 20 % PM_{2.5}</td>
</tr>
<tr>
<td>412-1</td>
<td>104.00</td>
<td>16.90</td>
<td>EN 13284-1</td>
<td>Yearly</td>
<td>Rotary dryer/coal Very sticky dust Measurements refer to wet gas Dust fraction is 36.30 % PM_{10} and 32.70 % PM_{2.5}</td>
</tr>
<tr>
<td>414-2</td>
<td>134.00</td>
<td>14.00</td>
<td>EN 13284-1</td>
<td>Monthly</td>
<td>Rotary dryer/coal Very sticky dust Measurements refer to wet gas Dust fraction is 55 % PM_{10} and 20 % PM_{2.5}</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]
15.4.4.1.2 Wet scrubber

The technique is generally described in Section 2.3.7.3.1.

Environmental performance and operational data

Table 15.4 shows installation-specific performance data related to the application of a wet scrubber as dust abatement technique.

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>Dust (mg/Nm³)</th>
<th>% O₂ content</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>111-1</td>
<td>38.50</td>
<td>7.90</td>
<td>VDI 2066</td>
<td>Yearly</td>
<td>Central chimney, two high temperature dryers/natural gas, lignite measurements refer to wet gas, cyclone step before</td>
</tr>
<tr>
<td>329-1</td>
<td>64.24</td>
<td>16.30</td>
<td>EN 13284-1</td>
<td>Monthly</td>
<td>Rotary dryer/natural gas, cyclone step before</td>
</tr>
<tr>
<td>286-2</td>
<td>109.00</td>
<td>14.50</td>
<td>NF X 44 052</td>
<td>Monthly</td>
<td>Rotary dryer/natural gas</td>
</tr>
<tr>
<td>288-1</td>
<td>144.00</td>
<td>13.90</td>
<td>NF X 44 052</td>
<td>Monthly</td>
<td>Rotary dryer/coal measurements refer to wet gas</td>
</tr>
<tr>
<td>287-1</td>
<td>265.00</td>
<td>14.60</td>
<td>MO/E/504/002</td>
<td>Monthly</td>
<td>Rotary dryer/coal measurements refer to dry gas</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

Reference literature
[193, TWG 2015]

15.4.4.1.3 Fuel choice

Description
Switching from the combustion of one fuel to a less harmful one in terms of emissions (low sulphur, low ash content or better ash quality).

Technical description
Choosing or switching to low-sulphur fuel, keeping the other basic fuel parameters (e.g. lower heating value, ash and moisture content) within the boiler design fuel range, is a measure which can significantly reduce SO\textsubscript{2} emissions. In cases where supply is available, a choice or change of fuel may be a viable option. This may include fuels with high internal desulphurisation due to the limestone (or other active compounds) content of the fuel ash. For coal, 5% limestone content is typical. For lignite and peat, desulphurisation effects may be higher than for coal, even up to 80%, depending on the fuel and the combustion system.
Natural desulphurisation can reduce SO$_2$ emissions by as much as 90%, e.g. by burning some low-quality lignites and peat with a low sulphur and a high alkaline ash content, resulting in very low SO$_2$ emissions, comparable to those achieved by the application of common secondary techniques.

**Achieved environmental benefits**
Reduction of dust and SO$_X$ emissions to air.

**Environmental performance and operational data**
The combustion of natural gas is associated to dust emission levels lower than those associated to the combustion of coal or lignite, as shown in Table 15.3 and Table 15.4.

**Technical considerations relevant to applicability**
In general, the use of fuels with a lower content of ash, sulphur, nitrogen, carbon, mercury, etc. is an option to consider. The possibility of choosing a fuel or switching fuel from solid to liquid or gas, or from liquid to gas, is considered subject to conditions in this document, as the technical, economic and political feasibility of a fuel switch or choice is largely determined by local circumstances. The possibility to change the fuel is also subject to a strategic evaluation of the fuel policy at a national level and to market availability.

**Economics**
TWG, please provide information.

**Driving force for implementation**
To meet legal requirements from competent authorities.

**Example plants**
See Table 15.3 and Table 15.4.

**Reference literature**
[193, TWG 2015], [256, COM 2016]

15.4.4.2 Reduction of TVOC emissions from beet pulp dryers

15.4.4.2.1 Wet scrubber

The technique is generally described in Section 2.3.7.3.1.

**Environmental performance and operational data**
Table 15.5 shows installation specific performance data related to the application of a wet scrubber as TVOC abatement technique.
Table 15.5: Average values of periodic measurements of TVOC emissions to air from a beet pulp dryer after treatment in a wet scrubber

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>TVOC (mg/Nm$^3$)</th>
<th>% O$_2$ content (dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>288-1</td>
<td>181.30</td>
<td>13.00</td>
<td>EN 12619</td>
<td>Monthly</td>
<td>Rotary dryer/coal Wet gas</td>
</tr>
<tr>
<td>287-1</td>
<td>192.00</td>
<td>15.86</td>
<td>EN 12619</td>
<td>Yearly</td>
<td>Rotary dryer/coal Wet gas Cyclone step before</td>
</tr>
<tr>
<td>286-2</td>
<td>235.00</td>
<td>15.80</td>
<td>EN 12619</td>
<td>Monthly</td>
<td>Rotary dryer/natural gas Wet gas</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

Reference literature
[193, TWG 2015]

15.4.4.3 Techniques to reduce NO$_X$ emissions from beet pulp dryers

15.4.4.3.1 Exhaust gas-recirculation (EGR)

The technique is generally described in Section 2.3.7.1.2.

Environmental performance and operational data

Table 15.6 and Table 15.7 show installation-specific performance data related to the application of FGR.

Table 15.6: Average values of periodic measurements of NO$_X$ emissions to air from beet pulp dryer after EGR

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>NO$_X$ (mg/Nm$^3$)</th>
<th>% O$_2$ content (dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>352-3</td>
<td>34.70</td>
<td>15.55</td>
<td>EN 14792</td>
<td>Yearly</td>
<td>Drum dryer/coal</td>
</tr>
<tr>
<td>352-4</td>
<td>35.80</td>
<td>15.96</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>352-1</td>
<td>43.39</td>
<td>15.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>354-2</td>
<td>50.40</td>
<td>15.47</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

Table 15.7: Average values of continuous measurements of NO$_X$ emissions to air from beet pulp dryer after EGR (from a CHP plant)

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>NO$_X$ (mg/Nm$^3$)</th>
<th>O$_2$ content (%, dry basis)</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>112-2</td>
<td>69.71</td>
<td>9.77 (yearly average)</td>
<td>Rotary dryer with 3 drums using heat within flue-gases of the CHP plant and additional production of heat from burning of biogas, natural gas and heavy fuel oil</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]
15.4.4.4 Techniques to reduce SO\textsubscript{X} emissions from beet pulp dryers

15.4.4.4.1 Exhaust gas-recirculation (EGR)

The technique is generally described in Section 2.3.7.1.2.

Environmental performance and operational data
Table 15.8 shows installation-specific performance data related to the application of EGR.

Table 15.8: Average values of periodic measurements of SO\textsubscript{X} emissions to air from beet pulp dryer after EGR

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>SO\textsubscript{X} (mg/Nm\textsuperscript{3})</th>
<th>% O\textsubscript{2} content (dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>352-1</td>
<td>27.70</td>
<td>15.89</td>
<td>ISO 10396</td>
<td>Yearly</td>
<td>Drum dryer/coal</td>
</tr>
<tr>
<td>352-3</td>
<td>28.70</td>
<td>15.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>354-2</td>
<td>30.60</td>
<td>15.47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>352-4</td>
<td>30.90</td>
<td>15.96</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

Reference literature
[193, TWG 2015], [256, COM 2016]

15.4.4.4.2 Wet scrubber

The technique is generally described in Section 2.3.7.3.1.

Environmental performance and operational data
Table 15.9 and Table 15.10 show installation-specific performance data related to the application of a wet scrubber as SO\textsubscript{X} abatement technique.

Table 15.9: Average values of periodic measurements of SO\textsubscript{X} emissions to air from a beet pulp dryer after treatment in a wet scrubber

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>SO\textsubscript{X} (mg/Nm\textsuperscript{3})</th>
<th>% O\textsubscript{2} content (dry basis)</th>
<th>Monitoring standard</th>
<th>Frequency of monitoring</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>287-1</td>
<td>200.00</td>
<td>14.30</td>
<td>NI</td>
<td>Yearly</td>
<td>Rotary dryer/coal</td>
</tr>
<tr>
<td>288-1</td>
<td>320.50</td>
<td>13.40</td>
<td>EN 14791</td>
<td>Monthly</td>
<td></td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]

Table 15.10: Average values of continuous measurements of SO\textsubscript{2} emissions to air from a beet pulp dryer after treatment in a wet scrubber

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>SO\textsubscript{2} (mg/Nm\textsuperscript{3})</th>
<th>O\textsubscript{2} content (% dry basis)</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>111-1</td>
<td>Yearly average 47.00</td>
<td>Max 204.00</td>
<td>7.96 (yearly average)</td>
</tr>
<tr>
<td></td>
<td>95th percentile 74.50</td>
<td>High temperature dryer/natural gas</td>
<td></td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]
15.4.4.4.3 Fuel choice

The technique is generally described in Section 15.4.4.1.3.

Environmental performance and operational data

The combustion of natural gas is associated to SO\textsubscript{X} emission levels lower than those associated to the combustion of coal or lignite, as shown in Table 15.11.

Table 15.11: Average values of periodic measurements of SO\textsubscript{X} emissions to air from a beet pulp

<table>
<thead>
<tr>
<th>Installation ID-point of release</th>
<th>SO\textsubscript{X} (mg/Nm\textsuperscript{3})</th>
<th>% O\textsubscript{2} content (dry basis)</th>
<th>Type of dryer</th>
<th>Type of fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>412-3</td>
<td>0.09</td>
<td>16.5</td>
<td>Rotary dryer</td>
<td>natural gas</td>
</tr>
<tr>
<td>352-1</td>
<td>3.1</td>
<td>20.83</td>
<td>Rotary dryer</td>
<td>coal</td>
</tr>
<tr>
<td>414-2</td>
<td>24.2</td>
<td>14.2</td>
<td>Rotary dryer</td>
<td>coal</td>
</tr>
<tr>
<td>181-1</td>
<td>33.12</td>
<td>12.8</td>
<td>Rotary dryer</td>
<td>natural gas</td>
</tr>
<tr>
<td>287-1</td>
<td>200</td>
<td>14.3</td>
<td>Rotary dryer</td>
<td>coal</td>
</tr>
<tr>
<td>242-1</td>
<td>295</td>
<td>12.2</td>
<td>Rotary dryer</td>
<td>fuel oil</td>
</tr>
<tr>
<td>413-1</td>
<td>325.3</td>
<td>7.5</td>
<td>Rotary dryer</td>
<td>coal</td>
</tr>
</tbody>
</table>

Source: [193, TWG 2015]
15.5 Emerging techniques

TWG, please provide information.
16 ADDITIONAL SECTORS (THUMBNAILD DESCRIPTIONS)

[Note to the TWG: the following sections describe different sectors in a short form. The sectors have been selected based on the conclusions of the kick-off meeting. Sectors where environmental issues or the number of installations were not relevant at European level should be included in the reviewed FDM BREF but in a so-called thumbnail description].

The descriptions have been restricted to a brief outline of the sector including products produced, processes applied, any significant emissions or consumptions, and specific techniques for pollution prevention or control. Since the descriptions aim to give an initial overview of the processes, they do not necessarily describe all production routes. The descriptions are, therefore, a starting point in the determination of BAT and additional information may be needed, in accordance with Articles 14(5) and 14(6) of the IED.
16.1 Preserved products from mixed raw materials (of animal and vegetable origin)

TWG, please provide information.
Chapter 16

16.2 Dry pasta

The basic raw material for the production of high quality pasta products is semolina from durum wheat. 1.04–1.05 tonnes semolina are used to produce 1 tonne of pasta. Water and other ingredients are added to make a stiff dough containing approximately 31 % water. The dough is forced under pressure through dies of an extrusion auger. The major environmental issue in this sector is energy consumption as all pasta manufacturing processes involve drying.

16.2.1 Main processes and techniques

In modern pasta factories, the manufacturing process is continuous. Semolina is stored in silos. It is then sent by pneumatic conveyers to the production area. Semolina is sieved and then mixed with water to form dough. Semolina has a starting moisture content of 10 to 14 %. In the mixing operation, 22 to 30 kg of water are added per 100 kg semolina. The moisture content during mixing varies between 30 and 35 %, depending on the quality and the type of semolina, and the shape of the pasta being produced. The weight of semolina and the flow of water being fed to the process are continuously monitored and automatically regulated using microcomputers. At this stage in the process, it is important for the semolina to be well hydrated and in a uniform way, to maintain an equal consistency in the dough. This ensures the quality of the final product, e.g. by preventing brittleness, surface defects and poor cooking quality.

The final mixing operation is degassing in a vacuum mixer, which removes the air that has been introduced during the earlier mixing operation. This prevents oxidation of the semolina pigments, or of the egg, in the case of egg pasta and gives a shiny appearance to the product. The pasta is pressed, extruded or laminated, depending on the shape of the final product. This is carried out using a worm screw within a cylinder which is cooled from outside. This physical action also causes the hydrated proteins to interact to form gluten. The dough is extruded at pressures varying between 4 and 12 MPa through a bronze or steel die corresponding to the shape of the product. If the holes of the die are faced with Teflon, a smooth pasta is obtained, otherwise a pasta of rough appearance is produced. The pasta comes out of the die with a moisture content of about 30 %. The final moisture content should not exceed 12.5 %, to achieve the required specific consistency and enable a long shelf-life. This, and the cooking characteristics of the product, are achieved by drying the pasta in three distinct stages, known as pre-drying, central drying and final drying.

Pre-drying comprises intensive ventilation to create a thin dry surface area which prevents the various pasta pieces from crushing or sticking to each other. Filtered air, devoid of dust and other impurities is used. The temperature and humidity are both controlled to regulate the evaporation rate and prevent fragility, which happens if the pasta is dried too quickly. Formation of mould occurs if the process is too slow. Pre-drying takes 10 to 60 minutes and removes 15 to 20 % of the moisture present. This phase is not needed for long pasta since it is transported hanging from canes, and there is less danger of sticking and deformation.

Central drying is achieved by another hot airflow repeated after alternate phases of rest, known as tempering. Tempering allows the moisture remaining inside the pasta to be redistributed uniformly on the surface. In some pasta production lines, tempering is not needed. During central drying, up to 60 % of the moisture present is removed.

During final drying, the pasta is passed through several chambers, where it is subject to a powerful hot and dry airstream that removes up to 25–30 % of the initial moisture. This last phase is carried out at variable temperatures, which may exceed 80 ºC. The temperature and the duration of the cycle vary according to the type of technology employed and the type of pasta required. Depending on the kind of production line, drying can be performed in separate chambers or in an uninterrupted tunnel, subdivided into three continuous stages.
Chapter 16

The design of production lines vary depending on the shape of the pasta, e.g. lines for long pasta have spreaders to hold the strips straight and to keep them apart, and lasagne, nest and tangle pasta lines have special layouts and lines producing short pasta so have initial kneaders. At the end of the drying line, a cooling chamber lowers the temperature of the dried pasta before it is conveyed to storage silos. The pasta is then transferred for primary packaging, using sheets of plastic or cardboard boxes, before secondary packaging, palletisation and storage prior to dispatch. The dry pasta production process is summarised in Figure 16.1.

For egg pasta, the production process is the same as that for other dry pastas, except for the presence of an automatic measurer for the egg mixture [82, Unione Industriali Pastai Italiani 2002].

![Figure 16.1: Summary of the dry pasta production process](image)

16.2.2 Energy consumption

The drying step utilises about 85–90% of the thermal energy and 50–60% of the electricity consumption of the installation. These figures may even be higher for lines producing special products such as nests or lasagne. Air conditioning of the workspace needs 35–50 kWh/t product.

In evaluating energy consumption in the sector, the results of a study on pasta factories with a production capacity of over 75 t/d led to the estimated consumption of electricity, expressed in kWh/t of product, and of thermal energy, expressed in kWh/t and MJ/t shown in Table 16.1.

Table 16.1: Energy consumption in the Italian pasta industry

<table>
<thead>
<tr>
<th>Estimated energy consumption</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>140–220 kWh/t</td>
</tr>
<tr>
<td>Thermal energy (measured at the boiler)</td>
<td>0.417–0.527 kWh/t</td>
</tr>
<tr>
<td></td>
<td>1.5–1.9 MJ/t</td>
</tr>
</tbody>
</table>

Source: [64, CIAA-UNAFPA 2002], [82, Unione Industriali Pastai Italiani 2002]
16.2.3 Water consumption

Water consumption is between 22–30 m$^3$/t product. Water is mainly used as an ingredient. The production of process related polluted waste water is reported to be insignificant \textsuperscript{[64, CIAA-UNAFPA 2002].}

16.2.4 Emissions to air

Thermal energy is obtained in boilers generally using natural gas. Superheated water, of 130–160 °C and 4–7 bar as measured in a hydraulic air vessel, is used to dry pasta. Typical air emission values are shown in Table 16.2.

Table 16.2: Emissions to air from pasta manufacturing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>130–160 kg CO$_2$/t product</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>Lower than 100 mg/Nm$^3$*</td>
</tr>
<tr>
<td>NO$_X$</td>
<td>Lower than 350 mg/Nm$^3$*</td>
</tr>
</tbody>
</table>

* At 3 % O$_2$ concentration

\textit{Source:} \textsuperscript{[64, CIAA-UNAFPA 2002], [82, Unione Industriali Pastai Italiani 2002]}

WORKING DRAFT IN PROGRESS
16.3 Bakery goods bread

One of the main bakery products is bread. Bread includes several bakery products and the types vary significantly from country to country.

16.3.1 Main processes and techniques

In France, about 80% of bread is still produced in small bakeries. The most common traditionally eaten bread is the baguette. It is produced with four basic materials, i.e. flour, water, salt and yeast. It represents more than 50% of French bread production. Other French speciality breads include fine wheat bread or “pain de gruau”, viennese bread, and biscuits [87, Ullmann, 2001].

In Germany, baked products are divided into two types. The production of bread allows a maximum of 10 parts sugar and/or fat to 90 parts flour. Products with more than 10 parts sugar and/or fat to 90 parts flour are called fine bakery wares or “Feine Backwaren”. Bread is divided into five main groups:

- wheat breads, at least 90% wheat
- mixed wheat and rye breads, at least 50% wheat
- mixed rye and wheat breads, at least 50% rye
- rye breads, at least 90% rye
- bread specialities.

Each of the first four groups were established based on the proportion of wheat and rye in the formula. These groups are further classified into subgroups according to the type of milled raw materials used, i.e. low extraction flour bread, meal bread, and wholemeal bread. Speciality breads can also be prepared. These contain, e.g. nonbread grains, such as oat, barley, rice and maize; raw materials of plant origin, such as oilseeds, germ and raisins, materials of animal origin, e.g. milk, butter, yogurt and whey. Otherwise they may be produced by using special baking techniques, e.g. a wood-heated oven; steam oven or stone oven. From the total German bread consumption, about 15% is eaten as small rolls and its consumption is increasing. Recently, the so-called nonbread grain breads have become very popular. Also the production of dark breads such as wholemeal flour breads is on the increase [87, Ullmann, 2001].

The typical UK sandwich bread has a high volume, soft texture, very fine porous crumb structure and is also characterised by long shelf life properties. Speciality breads comprise germ breads with the addition of 10–25% wheat germ and high protein breads with wheat gluten, milk, or sometimes soy protein. Malt bread produced in the UK is a sticky, sweet, dark loaf that might also contain dried fruit pieces. UK rye bread is usually made from a 50:50 mixture of white wheat flour and rye flour [87, Ullmann, 2001].

Bread is made by combining flour, water, salt and yeast. Wheat is the most important cereal grain produced and traded in the world for the production of bread and other baked products. Commercial production of bread may also involve the addition of preservatives and additives to improve flavour, texture and prevent microbiological growth. Production of most baked products containing wheat flour begins by mixing the ingredients to form a dough. Incorporation of air during dough mixing is necessary to achieve a baked loaf of good volume, structure, and texture. As dough becomes cohesive, it starts to incorporate air and, thus, decreases in density.

After bulk fermentation, the dough is divided into individual loaf-sized pieces, and then given time to allow the dough to relax before moulding. The moulding operation is essentially sheeting followed by curling, rolling and application of pressure. As the dough is sheeted, i.e. passed between rolls to be flattened during the various processes, it is sheeted in different
directions. Continued machining in one direction would align the protein fibrils and result in a
dough that was strong in one direction but weak in the direction of a 90° angle to the sheeting.
After being moulded, the loaf is ready for proofing. This is usually accomplished at 30 to 35 °C
and at 85 % relative humidity. Because the dough now has only limited viscous-flow properties,
it fills the pan by expansion. Proofing usually takes about 55 to 65 minutes; the dough increases
greatly in volume. After proofing, the dough is ready for baking.

Baking times and temperatures and baking temperature profiles vary largely, depending upon
the type of bread. For example, a wheat bread is usually baked for 35 to 40 minutes at
220 to 230 °C. The energy usage for baking normally ranges from 0.125–0.167 kWh/kg of
product (450–600 kJ/kg). In the UK, baking normally takes place at around 220 to 270 °C for
21 to 30 minutes. Heat is transferred by direct or indirect heat to the loaf. The most common
energy source is the combustion of natural gas, although electricity may also be used.
Combustion gases and volatiles from the oven are released via a stack. After cooling, the bread
may be sliced before being wrapped ready for distribution.

In a baking oven, the moisture at the surface is evaporated and removed by the hot air. When
the rate of moisture loss at the surface exceeds the rate of transport of moisture from the interior
of the product to the surface, the surface dries out and a crust is formed. There are four types of
ovens; direct heating, indirect heating, electric and infrared ovens. All oven types can be batch
or continuous in operation. In batch ovens, the walls and the base are heated. In continuous
ovens, radiators are located above, alongside and below the conveyor belt. Batch ovens incur
higher labour costs than continuous ovens. Another disadvantage can be the non-uniformity in
baking times, caused by the delay in loading and unloading the oven.

In direct heating ovens, air and combustion gases are recirculated by natural convection or by
fans around the product to be baked. The temperature in the oven is controlled by adjusting the
air and fuel flowrates to the burner. The fuels normally used are natural gas, propane and
butane. The gas is burned in ribbon burners above or sometimes below the conveyor belt and
product. The advantages of direct heating ovens are their short baking times, high thermal
efficiencies, rapid start-up and good temperature control. Good management and care is
necessary to prevent contamination of the food by undesirable products of combustion.

In indirect heating ovens, the air in the baking chamber is heated via a heat exchanger, by steam
or by burning a fuel. The air in the baking chamber is typically recirculated through the baking
chamber and the heat exchanger. Other methods include passing the combustion gases through
radiator tubes in the baking chamber, or burning the fuel between a double wall whilst
exhausting the combustion gases from the top of the oven.

Electric ovens are heated by induction, heating radiator plates or bars.

Typical methods for making bread are the straight dough, sponge dough, sour dough, and
Chorleywood process.

In the straight dough process, the dough is allowed to ferment for 2 to 3 hours. After
fermentation, the dough is divided into loaf sized pieces, rounded into a ball, given an
intermediate proofing time of 10 to 20 minutes, and then moulded and panned.

In the sponge dough process, a sponge is prepared from approximately 65 % flour, water, and
yeast. The sponge is only mixed enough to have a uniform mixture and then allowed to ferment
for 3 to 4r hours. After fermentation, the sponge is returned to the mixer and mixed with the rest
of the formula ingredients. At this stage, the dough is mixed to optimum development. After
mixing, the dough is allowed to relax for 15 to 20 minutes.

Utilisation of the sour dough process is the traditional leavening method in bread making. Bread
doughs containing higher proportions of flour or meal require more acidification than is
generally achieved by a sour dough process. During sour dough fermentation, a typical
microflora develops that includes lactic acid bacteria, *lactobacilli*, and yeasts. Various sour dough processes, such as multi, two and single-stage varying from 2 hours up to 24 hours, were designed to increase the growth of yeast and lactic acid bacteria to give the final sour dough proper acidity, especially the lactic acid/acetic acid ratio, and achieve the desired dough consistency. Often baker’s yeast, *Saccharomyces cerevisiae*, is added to accelerate the leavening process. Consequently, proof time of sour dough bread is often long, in the order of several hours. For the production of rye bread, acidification is required.

In the UK, the majority of commercial bakers employ the Chorleywood process. In this process, dough mixing and development take place in a single operation in the presence of an oxidising agent such as potassium iodate, potassium bromate, or ascorbic acid. This process requires a high quality wheat flour with a protein content of 12.5% dry matter together with a high level of starch damage and hence high water absorption. An oxidising improver, fat or emulsifier, and extra water and yeast are mixed in at this stage. The whole mixing and development process lasts between 2 to 5 minutes. All short time systems require high levels of oxidants. The dough ingredients are mixed together with an intensive energy input and transferred to a hopper which is sometimes sprayed with oil. The dough is divided into loaf sized pieces. A preliminary rounding is given to the dough at this stage. The dough is then allowed to rest, first proof, before being given a final moulding and normally placed into tins. The tins may be sprayed with oil before filling. The dough is allowed to ferment a second time, second proof, and may be cut before baking.

For additional information please consult the Sectoral Reference Document on Best Environmental Management Practices for the food and beverage manufacturing sector [275, COM 2015].
16.4 Coffee manufacturing

Commercial coffees are grown in tropical and subtropical climates at altitudes of up to around 1 800 metres. Coffees from different producing regions possess different characteristic flavours. Roasting coffee beans and the production of instant coffee are energy intensive processes.

For additional information please consult the Sectoral Reference Document on Best Environmental Management Practices for the food and beverage manufacturing sector [275, COM 2015].

16.4.1 Main processes and techniques

The main processing steps in the manufacture of roasted and instant coffee are the following [271, European Coffee Federation 2016]: blending, roasting, grinding and packing. Instant coffee is produced from a water extract of roasted ground coffee.

- Sorting and removal of foreign matter;
- Mixing/blending;
- Decaffeination;
- Roasting;
- Grinding;
- For instant coffee manufacturing: Extraction using water;
- For instant coffee manufacturing: Concentration by evaporation;
- For instant coffee manufacturing: Drying/freeze-drying;
- Packing and filling (including gas-flushing and/or packing under vacuum)

Roasting coffee

Green coffee is received and sorted to remove extraneous matter. Coffees from different varieties or sources are blended before or after roasting. Roasting is usually carried out by hot combustion gases in rotating cylinders. The final bean temperature is around 200 to 220 °C. A water or air quench terminates the roast. Most of any added water is evaporated from the heat of the beans. Fluidised bed systems may greatly reduce roasting times from around 8 to 15 minutes to 1 to 3 minutes. Finished coffee is transferred to storage bins. Any residual foreign bodies are removed before grinding, usually by air classification methods. Most coffees are ground in steel cutting rollers which are scored, once longitudinally and once across the circumference. Cracking rolls break the beans before they are fed into a further series of rollers. For fine grinds, the coffee may pass into further sets of rollers, being scored on each subsequent pair of rollers and becoming progressively finer as the coffee travels through the system. Roasted and ground coffee in Europe is typically vacuum packed in flexible pouches of plastic-laminated foil.

Roasting is a time-temperature-dependent process whereby chemical and physical changes are induced in the green coffee beans in particular:

- the volume increases up to 80 %;
- the specific weight decreases of 15–20 % due to the release of water and volatile substance;
- the colour changes from light green to dark brown;
- the surface becomes shiny for the run-off of organic oils and the structure becomes more porous due to the development of CO₂.

These modifications occur in different steps of the roasting process while temperature of coffee increases, as described in Table 16.3.
Table 16.3: Why and how coffee beans change during roasting process

<table>
<thead>
<tr>
<th>Modification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drying of the beans</td>
<td>At a temperature of 50–55 °C of the coffee beans, the proteins denature and the water evaporates.</td>
</tr>
<tr>
<td>Development of the brown colour</td>
<td>Starting from 100 °C, the browning phenomenon occurs due to the pyrolysis (degradation of organic compounds) and water continues to evaporate, leading to beans swelling.</td>
</tr>
<tr>
<td>Decomposition</td>
<td>At 140 °C the decomposition of organic compounds due to the reaction between sugars and proteins starts from the bean surface (also known as Maillard reactions), causing the development of hundreds of volatile organic compounds (VOC). By increasing the temperature up to 200 °C the decomposition continues interesting the inner part of the beans. The content of humidity is decreased up to 1–3 %.</td>
</tr>
<tr>
<td>Full roasting</td>
<td>From 200 °C the oils are released and the surface of the beans becomes shiny with the typical red-brownish colour. Roasting ends at 200–250 °C according to the characteristics of the desired final product.</td>
</tr>
</tbody>
</table>

Source: [200, IT 2016]

Raw coffee can be roasted in a batch or continuous operation. Discontinuous methods involve the use of batch roasting machines, which process a fixed amount of coffee in a defined time cycle (called roasting cycle), while the continuous methods involve the use of continuous roaster where the coffee is continuously fed at the entry point of the machine, roasted and discharged at the output point. No waste water is produced during roasting.

In a batch roaster, the coffee is fluidised and heated to roasting temperature with hot air entering tangentially. The roasting process is stopped by feeding water into the roasting chamber. The coffee is then emptied into the cooler. The coffee skin that is flaked off during the roasting process is kept from the roasting cyclone. The air is recirculated through a heating oven. The excess air is treated before being emitted to the environment. The roasting cycle is 1–5.5 min. The refilling of the roasting chamber with raw coffee only takes place after the completion of the roasting, or alternatively after the emptying of the roasting chamber.

Batch roasters have a wide roasting range which facilitates the processing of the most varied types of raw coffee with the most varied roasting results. For example, in an installation in Germany, a roaster with a capacity of up to 4,000 kg/h is used. This roaster is particularly suitable for roasteries with a large variety of products, high quality expectations and high production outputs. The layout of the batch roaster used in Germany is illustrated in Figure.
In a continuous roaster, raw coffee is supplied without interruption, and roasting and cooling take place when passing through the roaster. The coffee passes through a roasting drum containing small batch compartments in small doses. The coffee is mixed by the movement of the drum and the injection of hot air. Since the roasting takes place in mini batches, no replacement of product is possible without interrupting the roasting process. Dust and skins are removed using a cyclone. Continuous roasters are particularly advantageous where only a few types of coffee are roasted and the roasting takes place in a multiple shift operation.

The outlet of both the roaster and the cooler contain odour components, CO₂, NO₂ and VOCs. The concentration of VOCs causing this odour is higher for the roaster outlet than for the cooler outlet. VOC emission levels are higher when the product is roasted to a higher degree, e.g. when the product temperature at the end of the roasting process is higher. The difference in emissions between a low roasted and a very high, i.e. very dark, roasted product can be as much as a factor 10. For batch roasters, the highest concentrations are emitted just before the end of the roasting process. In continuous roasters, the emissions are also continuous. The absolute emission level of VOCs depends on the product temperature at the end of the roasting; the amount of air used for roasting, which has a diluting effect; the product itself and the roasting time. The emissions of organic substances and the organic roasting losses result from the decomposition or chemical reaction of, e.g. chlorogenic acid, citric acid, oxalic acid, crude proteins and trigonellin. Nitrogen-based compounds, e.g. amines and sulphur-based compounds, e.g. mercaptans contribute considerably to the odours emitted by coffee roasting installations. In the raw gas, odorant contents of up to 300 000 OUₑ/Nm³ have been measured. TOC mass concentrations of up to 10 000 mg/Nm³ are produced. Ammonia, nitrogen oxides, carbon dioxide and carbon monoxide are also produced. Dust emissions may also be a problem.

In Germany, continuous roasters can reportedly process up to 4 000 kg/h and roasting times are in the region of one to eight minutes. The layout of a continuous coffee roaster used in Germany is illustrated in Figure.
**Instant coffee**

Instant coffee is subjected to similar processing, namely blending, roasting and grinding, although processing details such as particle size after grinding may differ. During extraction of coffee for the production of soluble coffee, water is the extracting solvent. The coarsely ground coffee is extracted in a battery of batch percolating columns. The process is operated semi-continuously with water in a countercurrent flow to the coffee, from the most extracted cell to the one just filled with fresh roast and ground coffee.

The extract is recovered from the fresh or least extracted cell. One consequence of using high temperatures is that the system must be kept under pressure, so, the individual cells and associated pipework has to be designed accordingly. Once a batch of solids has been extracted, the exhausted cell is separated from the train and the spent grounds are discharged. At the same time, a cell containing fresh roast and ground coffee is added to the train. The extraction yield is expressed as the amount of recovered water-soluble dry solid content of roasted coffee as a percentage of roasted coffee (dry weight). Yields of 40 to 56 % are obtainable. Some manufacturers vacuum-concentrate the extract. The extract is dried, typically by spray-drying or freeze drying. The powder may be agglomerated to improve solubility. The final product is then packed into containers.

The following paragraphs describe the manufacture of instant coffee in an example installation which produces 18000 tonnes of green coffee per year. A diagram of the process is shown in Figure.
The arriving green coffee is picked up by discharge hoppers and mechanically cleaned through sifting and air separation before it reaches the silos. The raw coffee is roasted to enable its characteristic aromas and flavours to be appreciated. Then, after the coffee beans are ground, hot water is added to produce an extract. The extract is clarified and concentrated. A portion leaves the company in its now liquid form. This portion is transported by a road tanker to other installations for further processing.

The separation of the extract from water can be carried out by means of spray drying or freeze drying. Spray drying is carried out in a 30 metres high tower. The liquid coffee extract produced during the extraction is injected at the top, the drops fall downwards and reach a hot zone in which the water is extracted. On the floor, the dry, now powdered form of the product, is drawn off. The heat utilised can be partially recovered through countercurrent heat-exchangers. Also, the water used in the extraction process can be collected after drying to be reused during production.

After drying, a portion of the end-product is transported for pelleting/agglomeration. With the aid of agglomeration processes, the fine grained powder particles that are created during drying combine into coarser particles. The particles are moistened through the addition of steam and water and conglomerated on rotating surfaces or belts. During this process, the residual moisture of the products is raised again, so subsequent drying in vibration driers is necessary.

During freeze drying, the extract is first frozen and reduced in size. In the subsequent drying step, the moisture is extracted under a high vacuum. For the freezing of the extract, extremely low temperatures, e.g. <-50 ºC, are required. In the example installation, the cold temperature is produced by ammonia adsorption refrigeration plants, so the use of chlorofluorocarbons can be avoided. The removal of the ice is carried out under vacuum. The vapour is evacuated from the drying chamber by means of special high performance vacuum pumps. The exhaust air resulting from this, as well as containing volatile coffee ingredients, also contains quantities of oil from the pump system. The oil mists are intercepted in oil filters, and the separated oil content is recirculated. This process results in a granular final product.

Finally, the dried instant products are filled into bulk packaging, e.g. aluminium containers and big bags, of approximately 350–400 kg and prepared for shipping.
Decaffeinated coffee
Green beans are moisturised by steam or water to a moisture content of around 20 %. Solvents are then used to extract the caffeine from the wet beans. Decaffeination of coffee is carried out by extraction with decaffeinating agents, such as water or another solvent such as methylene chloride, coffee oils, ethyl acetate or supercritical CO₂. Extraction yields of 97 % of the caffeine can be obtained. Steaming or stripping is used to remove solvent from the beans. Two main extraction methods for decaffeination can be distinguished, i.e. the direct and indirect methods. The beans are then re-dried to their original moisture content prior to roasting. Solvent extraction of the caffeine, from the extract used to make instant coffee rather than from the bean itself, may also be applied.

The direct method is called solvent decaffeination. In this method, solvents, such as methylene chloride, coffee oils, ethyl acetate or supercritical CO₂, are used. The main process parameters are temperature and time. These vary depending on the type of coffee and on the type of solvent. For example, when coffee oil is used as the decaffeinating agent the process may take 6 to 9 hours at 95 to 105 °C, whereas supercritical CO₂ is used under high pressure at 40 to 80 °C for 5 to 30 hours.

Table 16.4 summarises the process.

<table>
<thead>
<tr>
<th>Action</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Green beans are first soaked with water and steam</td>
<td>Beans swell by 30–40 %</td>
</tr>
<tr>
<td>2 A decaffeinating agent is added to the wet beans</td>
<td>The agent solubilises the caffeine from the beans</td>
</tr>
<tr>
<td>3 The agent is drained or steamed away</td>
<td>The agent, together with 97 % of caffeine, are removed from the beans</td>
</tr>
<tr>
<td>4 The beans are dried by hot air or vacuum drying</td>
<td>The beans are dried and are now ready for roasting</td>
</tr>
</tbody>
</table>

Source: [ 192, COM 2006 ]

The indirect method is called water decaffeination. In this method, water is used as the extraction solvent. The process is described in Table 16.5.

Table 16.5: Water decaffeination process

<table>
<thead>
<tr>
<th>Action</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Green beans are first soaked with water and steam</td>
<td>The water extracts the caffeine, but also some soluble coffee solids</td>
</tr>
<tr>
<td>2 The beans are separated from the aqueous solution</td>
<td>The water extract containing caffeine and coffee solids is separated</td>
</tr>
<tr>
<td>3 Water extract is passed over an activated charcoal bed. A solvent, e.g. methylene chloride, may be used instead of activated carbon</td>
<td>The caffeine is removed from the solution by activated carbon filtration or methylene chloride. The coffee solids remain in the aqueous solution</td>
</tr>
<tr>
<td>4 The decaffeinated extract is concentrated and added back to the pre-dried decaffeinated beans</td>
<td>Beans and coffee solids, now without the caffeine, are ready for roasting</td>
</tr>
</tbody>
</table>

Source: [ 192, COM 2006 ]

Freeze-drying
If the incoming product is a liquid, e.g. coffee extract, it is frozen in two steps, at two freezing temperatures and times, and then it is ground. For more information, see Section 7.2.1.
16.4.2 Water consumption

The water consumption for the abrupt interruption of the roasting process amounts to 10 to 15 % of the weight of the raw coffee.

16.4.3 Residues

The coffee skins produced during the roasting process, which can be up to 2 % depending on the type of coffee, are used as incineration fuel or composted.

In instant coffee production, during the extraction of soluble solid matter from the roasted coffee, a large quantity of coffee grounds is produced in addition to the fluid coffee extract. These are utilised as fuel in special grate firing installations. The ground coffee is used, in balance with heating oil and natural gas, as a special fuel.

16.4.4 Emissions to air

Air environmental issues of coffee manufacturing are related to the release of various types of air pollutants (NO\textsubscript{X}, VOCs, CO, dust) from roasting. The quantity of pollutants contained in the exhaust gas depends on the roasting cycle performed, the blend of coffee beans employed as well as the efficiency of the abatement. More specifically [200, IT 2016]:

- NO\textsubscript{X} concentrations from roasting process are extremely variable and aleatory, making difficult to predict deterministically the concentrations in function of coffee origins, blends, process temperature, desired roasting grade, and pollution abatement equipment installed, etc.;
- generally, NO\textsubscript{X} emissions from decaffeinated coffee roasting are lower that from regular one;
- to ensure a VOC emission level lower than 50 mg/Nm\textsuperscript{3} and to contain odour impact, for batch roasting process, catalytic systems continue to be the best available technique, although it gives rise to NO\textsubscript{X} formation in high concentration. Oxidative catalysts contribute to generating NO\textsubscript{X} by oxidizing the nitrogen compounds developed during roasting process, starting from molecules naturally present in coffee (mainly pyridine, pyrazine and caffeine). Emission of NO\textsubscript{X}, which is negligible in all the steps of the roasting cycle until the catalytic converter, is dramatically increased by the converter itself, whereas the CO concentration is effectively reduced;
- along the manufacturing process, coffee beans are moved by mechanical or pneumatic transports. These operations involve dust emissions. Dust generated by green coffee handling needs to be treated, while dust generated by roasted coffee beans handling is abated only via a hopper.

Figure 16.2 shows data related to CO and NO\textsubscript{2} emissions from an Italian installation.
The following issues should be taken into account in relation to the measurement of NO\textsubscript{X} emissions from coffee roasting, [272, European Coffee Federation 2016]:

- The cyclic nature of the roasting process. This means that gas emissions are rapidly changing in both volume and time;
- The effects of water vapour in the sampling and measuring system. This is particularly relevant in industrial roasters including water quenching at the end of the roasting cycle. Unless specifically designed for the instantaneous moisture loads (and standard portable systems are not) then the effects of water vapour are unknown;
- Sampling system issues: at the high temperatures of many roaster exhausts the gasses can react with the sample pipe material. Unreactive materials are not supplied as standard with portable systems for example;
- Interference of other gasses with NO\textsubscript{X} measurement. The mix of other gasses in coffee roaster exhausts is much more complex than other stationary systems such as steam boilers and internal combustion engines.

**Consumption and emission levels (BREF 2006)**

See extraction in Section 0, roasting in Section 0 and drying in Section.

**Techniques to consider in the determination of BAT (BREF 2006)**

**Waste heat reuse in instant coffee manufacturing**

**Description**

The instant coffee manufacturing process is highly energy intensive (for a description of instant coffee manufacturing see Section). Waste heat, e.g. from the extraction unit and air
compressors, can be reused during production, e.g. for extraction, and as a heating source, e.g. in offices and storage areas. A standard procedure for waste heat utilisation is also the recirculation of partial streams of exhaust air within the installation such as spray drying, e.g. using countercurrent heat exchangers and within the roasting sector.

**Achieved environmental benefits**
Reduced energy consumption, e.g. heat is reused.

**Environmental performance and operational data**
In an example installation in Germany, the hot liquid coffee extract produced during extraction is pumped over heat exchangers that extract the heat from the coffee and, at the same time, heat the process water required for extraction. In addition, the heating of site offices and social rooms takes place using waste heat from the production. Also, the waste heat of the air compressors is used for heating the storage halls.

**Technical considerations relevant to applicability**
Low grade heat is widely reused in the FDM sector.

**Economics**
Reduced energy costs.

**Example plants**
One example installation in Germany.

**Reference literature**
[35, Germany 2002]

**Abatement of emissions to air from agglomeration during instant coffee manufacturing**

**Description**
During instant coffee manufacturing, after drying, a portion of the end-product is transported for agglomeration. A relatively high dust content results during agglomeration, which is largely recirculated. Subsequent fibre filter systems (see Section 2.1.6.2.2) with integrated dust collectors prevent dust particles from reaching the exhaust air.

**Achieved environmental benefits**
Reduced dust emissions.

**Environmental performance and operational data**
Fibre filters provide a very high degree of efficiency. The reported residual dust content of the exhaust air is in the region of <1 mg/Nm³.

**Example plants**
One example installation in Germany.

**Reference literature**
[35, Germany 2002]

**Biofilter – used in coffee processing**

For further information on the technique, see Section 2.3.7.3.4.

**Description**
In an example installation, biofilters are used to prevent odours being emitted from coffee processing. The main contaminants in the exhaust air from coffee roasting are CO$_2$, dust and formaldehyde. The emissions depend on the composition of the raw coffee, the degree of roasting and the residual moisture content. The main operations where emissions to air are expected are: preheating of the roasting container, roasting, precooling of the product by means of finely sprayed water, drying of the product, emptying of the roasting container and cooling. During cooling with air, a considerable amount of air is produced that needs subsequent treatment.

The installation operates grinding and vacuum chambers with forced ventilation. CO$_2$ emissions and the remaining unburned hydrocarbons can be captured easily in a closed system. In the example installation, 8600 m$^3$/h of air is treated by a biofilter in expanded modules. This consists of a cross-current humidifier with polyethylene packaging material. The filter material is composted bark mulch. The filter modules are cylindrical in shape, made of stainless steel and have a total volume of 198 m$^3$. The equipment also includes a 15 kW radial ventilator and a control panel. A maximum of 43.5 m$^3$ exhaust air can be treated per m$^3$ of filter material. At this load, no odour emissions are detected.

The odour of coffee is still very much in evidence as low as 3.5 OU/m$^3$.

**Achieved environmental benefits**

Odour emissions are eliminated completely.

**Cross-media effects**

Disposal of the filter material. Used material is composted to reduce the organic pollution and then sent for landspreading. Condensation water is recycled, otherwise it requires treatment.

**Environmental performance and operational data**

A maximum of 43.5 m$^3$ exhaust air can be treated per m$^3$ of filter material. At this load, no odour emission is detected after treatment. No data are available about other emission levels.

**Economics**

The price of the total system was EUR 63,480 (Germany 2001).

**Reference literature**

[35, Germany 2002] [170, InfoMil, 2001]

**Coffee roasting**

**Recirculation of air during coffee roasting**

**Description**

In terms of the feeding of roasting air, a distinction is drawn between non-recirculating and recirculating machines. Recirculating roasters consume less energy and produce a lower volume of waste gas for treatment.

**Achieved environmental benefits**

Recirculating roasters consume less energy and produce a lower volume of waste gas for treatment than non-recirculating roasters.

**Environmental performance and operational data**

Recirculating roasters consume up to 25% less energy than non-recirculating roasters. Table shows the mass concentration of dust from recirculating and non-recirculating roasters.
Dust concentration after the cyclone (mg/Nm³)

<table>
<thead>
<tr>
<th></th>
<th>Recirculating roaster</th>
<th>Non-recirculating roaster</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20–150</td>
<td>200–400</td>
</tr>
</tbody>
</table>

Table: Mass concentration of dust after the cyclone

Technical considerations relevant to applicability
Applicable in all coffee roasting installations.

Economics
Reduced energy and waste gas treatment costs.

Example plants
Used predominantly in the German coffee sector compared to non-recirculating roasters.

Reference literature
[35, Germany 2002]

Water mist cooling of roasted coffee

Description
Finely atomised water is fed into the chamber to cool the product. When the air–water aerosol comes into contact with hot roasted coffee, the water drops evaporate.

Achieved environmental benefits
Reduced air pollution and energy consumption compared to air cooling.

Environmental performance and operational data
In contrast to air cooling, water mist cooling uses significantly lower volumes of air and so less waste gas needs to be treated and lower emissions are reduced. Table shows the composition of the waste gas from air cooling, i.e. higher levels than for water mist cooling, before treatment. Less energy is consumed compared to air cooling (see Table). No waste water is produced during this process.

<table>
<thead>
<tr>
<th>Waste gas temperature (ºC)</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste gas volume (m³/kg)²</td>
<td>2–7.5</td>
</tr>
<tr>
<td>TOC emissions (mg/Nm³)</td>
<td>20</td>
</tr>
<tr>
<td>Dust emissions (mg/Nm³)</td>
<td>75</td>
</tr>
</tbody>
</table>

²10 vol % of roasting gas volume

Table: Composition of the cooling waste gases from air cooling, before treatment

The emissions produced by the water mist cooling are removed by the roasting waste air treatment system.

Technical considerations relevant to applicability
The cooled coffee leaves the roaster at approximately 60 ºC and is not optimal for ground coffee. For some coffees, the 60 ºC final temperature can produce an acceptable taste, but for many other coffees it does not. More than 90 % of the roasted coffee market in Europe is ground coffee. This cooling system can, therefore, only be used under certain circumstances. The process is predominantly used in densely built-up residential areas.

Economics
Reduced costs with regard to energy and waste gas treatment compared to air cooling.

Example plants
Used in the German coffee sector.
Coffee roasting followed by catalytic oxidation of the waste gases

Description

A newly constructed large-scale coffee roasting example installation in Germany, which will be called Plant A in this section, uses recirculating (see Section) batch and continuous roasters and has a roasting capacity of around 12000 t/yr during dual-shift operation. Roasting, storage and transportation of the roasted or ground coffee takes place under inert conditions, i.e. a low oxygen environment. To achieve a low oxygen environment, approximately 2 l/kg roasted coffee of carbon monoxide captured during the grinding process is added to the air for the pneumatic transportation of the ground and roasted coffee containers. Pipelines and containers need to be gas-proof to retain the released gas within the system. Waste gas is treated using catalytic incineration.

Plant B is another large-scale coffee roasting example installation, where 500 g vacuum packs are exclusively produced. The annual capacity is 44500 tonnes of roasted coffee during 3900 hours of operation and the average production is 140 tonnes of roast coffee in two shifts per day. Five roasting lines, with a total capacity of 13640 kg/h are used. The roasting plants consist of recirculating (see Section) batch roasters, with a capacity of approximately 2200 kg/h, and roasters with water mist cooling (see Section) with a capacity of approximately 3080 kg/h. The waste gases are treated using a catalytic incinerator, which carries out a substantial removal of odour emissions. The CO2 from the ground coffee plants is collected and used as a protective gas against oxygen for the ground coffee until it is vacuum packed.

Achieved environmental benefits

See Section 2.3.7.3.7.

Cross-media effects

See Section 2.3.7.3.7.

Environmental performance and operational data

Table shows a comparison of consumption and emission levels of different coffee roasting processes.

<table>
<thead>
<tr>
<th>Consumption and emission levels</th>
<th>Unit</th>
<th>Emission levels from a roaster before waste gas treatment</th>
<th>Plant A Batch with recirculation and air cooling</th>
<th>Plant A Continuous, with recirculation and air cooling</th>
<th>Plant B Batch with recirculation and water mist cooling (data from 2001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total water consumption</td>
<td>l/t</td>
<td></td>
<td>169.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roasting water consumption</td>
<td>l/t</td>
<td></td>
<td>130</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling system water consumption</td>
<td>l/t</td>
<td></td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating oil input</td>
<td>l/t</td>
<td></td>
<td>42.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total energy consumption</td>
<td>kWh/t</td>
<td>490</td>
<td>470</td>
<td>115.24</td>
<td></td>
</tr>
<tr>
<td>Roasting energy consumption</td>
<td>kWh/t</td>
<td></td>
<td>49.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packing energy consumption</td>
<td>kWh/t</td>
<td></td>
<td>19.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grinding energy consumption</td>
<td>kWh/t</td>
<td></td>
<td>19.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Noise emissions in roaster (dB(A)) | 75 | 75 | 75
---|---|---|---
Noise emissions in ventilators (dB(A)) | 96 | 96 | 96
Waste sent for composting after being pressed into pellets, e.g. coffee skins (kg/t): 5–10*

All the following air emission levels were measured after catalytic incineration, except:

- **Dust emissions** (mg/Nm$^3$): ≤20 | ≤50
- **Dust load** (kg/h): 0.1 | 0.01–0.275
- **TOC emission** (concentration) (mg/Nm$^3$): 10000 | ≤50 | <50 | 3.8–29.2
- **TOC emission (load)** (kg/t): 0.00963
- **Odour emissions**
  - The odour of coffee is still very much in evidence as low as 3.5 OU$E$/Nm$^3$ | 150000 | 577–1138
  - GE/Nm$^3$: 300000 | 1455–2276
- **Carbon dioxide (CO$_2$)** (V/V): 1–3
- **Carbon monoxide (CO)** (mg/Nm$^3$): 500–3000

*per unit of raw coffee

*the type of roaster is not specified, e.g. batch or continuous

*in accordance with VDI guideline 3881–sheet 1 to 4

*25 l/kg, particle size >100 µg

| Table: Comparison of consumption and emission levels of different coffee roasting processes |
|---|---|---|---|

**Economics**

In plant B, the investments to reduce emissions during the roasting process amounted to approximately 5 to 10% of the total investments of the roasting and packing lines, excluding building components.

**Reference literature**

[35, Germany 2002] [170, InfoMil, 2001]
16.5 Distilled beverages

The use of distillation in the FDM sector can be illustrated by the following two examples: the distillations of Scotch whisky and cognac.

All ethyl alcohol used in the production of spirit drinks are coming from agricultural raw materials which are further defined by EC Regulation. Main raw materials used for the production include agricultural raw materials (cereals, grape, fruits, sugar cane, potato, etc.), water and yeast.

The information sources for this sector are [35, Germany 2002], [196, spiritsEUROPE 2015].

16.5.1 Main processes and techniques

Processing raw material
Raw cereals may initially be milled, cooked, mashed or slurried for the purposes of deriving solubilised sugars. This process may involve the use of natural or additional enzymes.

Fermentation of sugars or starch
Soluble sugars are converted (ethanol yield observed 90–95% theoretical) through action of various, product specific, yeast strains to alcohol. Proceeds according to Gay-Lussac Equation:

\[ C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2 \]

Distillation
Distillation is the process of concentrating alcohol by boiling and condensing the resulting vapours. The condensing process can realise differing flavour profiles and can also be product specific. There are three main types of distillation apparatuses used for the production of spirit drinks:

- pot stills;
- pot stills with additional column(s);
- column – allowing possible continuous distillation.

Flavouring/Colouring
Some spirit drinks may include the addition of permitted flavourings and colourants.

Mixing or blending
Spirit drinks may be mixed, meaning combining two or more different drinks to make a new product. Spirit drinks may also be blended, meaning combining two or more spirit drinks of the same category, distinguished only by minor differences in composition due to one or more of the following factors: (a) the method of preparation; (b) the stills employed; (c) the period of maturation or ageing; (d) the geographical area of production. The spirit drink so produced shall be of the same category of spirit drink as the original spirit drinks before blending.

Ageing/Maturation
Spirit drinks may be maturated/aged which means allowing certain reactions to develop naturally in appropriate containers, thereby giving the spirit drink in question organoleptic qualities previously absent.

Addition of water
Spirit drinks may have water added before and/or after the maturations phase usually in the form of potable demineralised water produced using small scale treatment plant.
16.5.2 Energy consumption

The production of spirit drinks consumes energy for the following processes:

- steam generation;
- production equipment: cooking, mashing, distillation;
- pumping/conveying materials;
- cooling/ventilation;
- ancillary operations;
- lighting.

Energy may be produced onsite utilising gas turbine, boiler plant or including more novel renewable technologies including anaerobic digestion, CHP or biomass generation. Within such facilities it is common practice to maximise heat recovery and energy efficiency.

16.5.3 Water consumption

A large proportion of spirit drinks production have once-through cooling water system. Other water uses include production water used to make the distilled spirits and process water for cleaning of the plant and equipment and other ancillary use. The flavour profile of the product being manufactured may dictate the production water source based on quality/flavour profile etc.

16.5.4 Residues

Minimal quantities of waste are derived from the distilling process. Normal engineering maintenance and other common food manufacturing wastes will be derived. A variety of by-products can be produced including:

- spent raw materials left after the mashing process to remove all the fermentable sugars. This is a valuable by-product and has been traditionally sold off as animal feed;
- liquid residues arising from still distillation that may be used direct as a nutritional benefit to land or processed further for use within animal feed. Solid materials may be processed and/or blended with liquids to produce animal feed.

Bioenergy facilities, such as biomass and AD plants can convert mashing/distillation residues into renewable energy. Carbon dioxide produced during fermentation may be captured and processed within some facilities for use within the food and drink manufacturing sector.

16.5.5 Emissions to water

Effluent produced may contain:

- COD / BOD;
- variable suspended solids loading;
- variable pH;
- trace metal elements.

It has been reported that in a molasses distillery, a two-stage (see Section 2.3.6.2.3.2) waste water treatment system, anaerobic following aerobic, is used. The main treatment is an EGSB reactor (see Section 2.3.6.2.2.7) in which the organic load is largely degraded to methane gas, which may be used on site and only small quantities of sludge are produced. The COD and nitrogen loads are then reduced further in an activated sludge reactor (see Section 2.3.6.2.1.1).
Figure 16.5.6 shows a flowchart and dimensions of the anaerobic/aerobic waste water treatment system at a distillery.

Source: [35, Germany 2002]

Figure: Anaerobic/aerobic waste water treatment system at a distillery

16.5.6 Emissions to air

Emissions to air include:

- dust arising during materials handling (minimal);
- carbon dioxide arising from fermentation processes;
- NMVOC releases arising during distillation;
- ethanol releases during the maturation process;
- emissions associated with combustion plant;
- emissions associated with residue handling plant.

CO₂ emissions from the fermentation process can generally be regarded as carbon neutral owing to the sequestering which took place during the cereal growth. Releases from distillation are minimal and controlled using condensing technology. Dust releases are minimal and controlled using existing cyclone/dust filtration technology.
Ethanol releases during the aging process can approximate at 2% per year. This process is essential to the overall flavour profile of the final product. Factors such as cask type, nature and location of aging site all impact on the degree of release.

There are minimal odours associated with these production processes, including animal feed plant which may be co-located at the same facility. Various abatement techniques have been successfully applied to larger facilities including wet scrubbing, cold-plasma and thermal oxidation.

**Scotch whisky**

Distillation units in the production of scotch whisky range from simple pot stills to continuous multicolumn stills. Energy is introduced in the form of steam to the bottom of the still and selectively volatilises the alcohol and other components from the fermented liquids and pre-distilled alcohol/water mixtures. The volatile components are recirculated within the still to achieve the correct separation, selection and concentration of alcoholic/aqueous compounds for the many varied and desirable congener profiles required by the various types and brands of products. Stills can be operated singly or in series. The volatile components are condensed by heat-exchange with water in condensers and removed as a liquid spirit. The residual material known as pot ale, spent lees, stillage or spent wash, is discharged from the bottom of the still. In column stills other fractions are also removed such as fusel oils and high feints. The high feints are fed back into the stills and the fusel oils, which are mainly amyl alcohol, are sold as a co-product.

**Cognac**

Cognac is obtained by the distillation of white wines harvested in the controlled appellation area. The distillation of Cognac is a two-stage process. In the first stage, a first distillate, known as “brouillis” is obtained. This has an alcoholic strength of between 28 to 32% volume. In the second stage, the brouillis is returned to the boiler for a second heating, known as “la bonne chauffe”. The distillation heads, secondes and tails are separated, leaving only the heart of the spirit. There is a restriction on the maximum strength of distillation, which must not exceed 72 vol.% alcohol. The time of each stage is about 12 hours.

Distillation is carried out in two separate heatings or chauffes in a special Charentais copper pot still comprising a characteristically shaped boiler, heated with a naked flame and topped with a cowl shaped like a turban, an olive or an onion. A Charentais still often has an energy saving wine reheater. This device, in which the heat is provided by the alcohol vapours passing through it, preheats the wine, which is to be distilled in the next cycle. The final day for distillation is 31 March of the year following harvesting.

Maturation must be carried out in Limousin or Tronçais oak casks. As with other brandies and matured wine spirits, maturation was aided by the use of oak extracts, but this practice is becoming less common in Cognac. French regulations prohibit the use of additives in the final product, other than water and sugar or caramel, and restrict the minimum strength to 40 vol.% alcohol.
Chapter 16

16.6 Wine production

This section includes red and white wine manufacturing [71, AWARENET 2002], [195, CEEV 2015]. Fresh grapes and eventually oenological practices are the raw materials used for the production of wine.

16.6.1 Main processes and techniques

Reception
When grapes are received at the winery, they are sorted by variety, quality and quantity. Containers are emptied directly into either crushing or transport equipment. Emptied containers are cleaned. The cleaning water is drained.

Grape crushing and destemming
Grape crushing or mashing takes place in grape mills. If maceration is intended, the mash can be stored in mash containers. To prevent the mash from oxidation H₂SO₃ is added. The decision as to whether destemming of the white grapes is necessary before the grape mash is made, and it depends on the variety and ripeness of the grapes as well as on the further processing of the mash.

Pressing
For white wine, the mash is transported to the wine press. The resulting unfermented grape juice is referred to as must. Sulphur dioxide is often added at this stage at the rate of 100–150 mg/l to suppress undesirable microorganisms, e.g. grape skins are often covered with bacteria and moulds, as well as the yeasts used in the process. The solid residues, e.g. pomace and marc, are then separated.

For red wine, when the fermentation process is finished, i.e. when the sugar levels are under 0.1 %, the wine is taken from the bottom of the tank and the marcs are transferred to the wine press to extract the remaining wine.

Fining
The fining agents used in winemaking are gelatine, casein, isinglass, chitin, albumin or egg white; natural mineral adsorbents, e.g. bentonite, diatomaceous earth or silica; and synthetic polymers, e.g. PVPP. It is reported that sediments from clarification are separated by centrifugation or filtration. This removes unwanted particles left in suspension.

Fermentation
Alcoholic fermentation takes place in large stainless steel fermentation reactors or vats with or without the addition of pre-cultivated yeast, e.g. usually Saccharomyces cerevisiae, and under rigorous temperature control. White wine is fermented after marc separation, while red wine is fermented together with grape marcs. Red wine, and sometimes white wine as well, goes through a second malolactic fermentation. This is a bacterial fermentation that converts the malic acid into lactic acid.

Ageing
After fermentation, wine is cooled to 4–5 ºC and transferred to barrels or wooden vats made of oak for ageing. This allows the wine to stabilise and to develop softer tannins and complex flavours. Lees are separated from the wine every 3 to 4 months. The barrels are then washed and refilled.

Cold stabilisation
Cold stabilisation involves rapid cooling of the wine to near freezing temperatures to precipitate tartrate crystals which are undesirable in the bottled wine, whether present in the cork or in the bottom of the bottle. Tartrate precipitates in the tanks and is removed with an alkaline cleaning solution of 10 % caustic soda.
### Bottling

Before bottling, wine is passed through a filtration system to remove remaining solid and insoluble turbid compounds. Bottling involves the microbial stabilisation of the wine and preserves the wine from important changes in taste and chemical composition.

For additional information please consult the Sectoral Reference Document on Best Environmental Management Practices for the food and beverage manufacturing sector [275, COM 2015].

#### 16.6.2 Energy consumption

The production of wine consumes energy for the following processes: crushing, pumping/conveying materials, cooling/ventilation, and ancillary operations.

#### 16.6.3 Water consumption

Cleaning water and, in a smaller proportion, cooling water in fermentation tanks, constitute the main water uses in wineries.

#### 16.6.4 Emissions to water

Effluent produced may contain TOC/COD, BOD, variable suspended solids loading, and variable pH.

Residual solids, e.g. grape or pomace residues, filter cakes and sediments which are not removed at source, can be removed by screening.

Primary treatment is used to remove easily decanting TSS. The following techniques can be used:

- screening (see Section 2.3.6.1.1)
- flow and load equalisation (see Section 2.3.6.1.3)
- neutralisation (see Section 2.3.6.1.4)
- sedimentation (see Section 2.3.6.1.5)
- centrifugation (see Section)
- precipitation (see Section 2.3.6.1.8).

After primary treatment, the waste water may be sent to the MWWTP if acceptable, or further treated on site. During secondary treatment, the yeast can provoke severe problems; the activated sludge can die and be washed out. Therefore, the separation of yeast and other solids is a necessary primary treatment step.

Anaerobic processes (see Section 2.3.6.2.2) and particularly anaerobic lagoons (see Section 2.3.6.2.2.1) and anaerobic filters (see Section 2.3.6.2.2.3) are reported to be the most suitable treatments for winery waste water. Alternatively, aerobic processes (see Section 2.3.6.2.1) can be used, e.g. aerated storage for three months is used at small wineries with low waste water volumes. Activated sludge (see Section 2.3.6.2.1.1) or trickling filters (see Section 2.3.6.2.1.5) are used. Activated sludge systems tend to be over dimensioned, due to the seasonal variations and are, therefore, expensive to install and operate. Trickling filters are reported to be 70% effective and, therefore, require further polishing.

Tertiary treatment (see Section 2.3.6.3) is used as a polishing stage for remaining pollution removal. The use of landspreading and evaporation lagoons have been reportedly used in vineyards.
16.6.5 Emissions to air

Emissions to air include:

- dust arising during materials handling (minimal);
- biogenic carbon dioxide arising from fermentation processes;
- emissions associated with residue handling plant.

There are minimal odours associated with these production processes.

16.6.6 Residues

Minimal quantities of waste are derived from the wineries. Normal engineering maintenance and other common food manufacturing wastes will be derived.

The main by-products produced are grape marc and lees. Traditionally these 2 by-products have been sold off to distilleries. An alternative is the use of grape marc in bioenergy facilities. This viability of such treatment plant depends on throughput amongst other factors.

Techniques to consider in the determination of BAT (BREF 2006)

Reuse of cleaning solution from the cold stabilisation tanks

Description

Cold stabilisation involves rapid cooling of the wine to near freezing temperatures, to precipitate calcium and potassium tartrate crystals, which may be present but which are undesirable in the bottled wine. The tartrate precipitates during ageing/racking and stabilisation.

After the vessel is emptied, a 10% caustic solution is added, to remove the tartrate crystals. This alkaline cleaning solution can be reused if the tartrate salts are recovered from the solution. Alternatively, tartrate elimination from wine is done with the application of electrolysis and avoiding the use of the alkaline solution. This achieves a lower energy cost when compared to wine cooling.

Achieved environmental benefits

Reduced water consumption, alkaline cleaning solution consumption and waste water pollution.

Environmental performance and operational data

The method of recovering the tartrate salts is not described, however, it is reported that if it is not recovered, the solution is discharged to the WWTP creating undesired pH shifts. Tartaric acid produced as a by-product can be used in the pharmaceutical and building industries.

Technical considerations relevant to applicability

Applicable in all winemaking installations carrying out ageing/racking and stabilisation.

Example plants

Used in wine processing installations.

Reference literature

[134, AWARENET, 2002]
Gradual discharge of cleaning solution from the cold stabilisation tanks to the WWTP

Description
During ageing/racking and cold stabilisation, calcium and potassium tartrate crystals are precipitated and are then removed using an alkaline cleaning solution. To avoid undesired pH shifts, the spent cleaning solution is discharged gradually to the WWTP.

Environmental performance and operational data
If the alkaline cleaning solution is discharged suddenly to the WWTP, undesired pH shifts are created in the waste water, which can disrupt the operation of the WWTP.

Technical considerations relevant to applicability
When the alkaline cleaning solution is no longer effective, even after the recovery of tartrate salts and when the opportunity for self-neutralisation is not available.

Driving force for implementation
Reduced disruption of the WWTP operation.

Example plants
Used in wine processing installations.

Reference literature
[134, AWARENET, 2002]
16.7 Citric acid production

Citric acid, a tricarboxylic acid, exists widely in nature and is produced in almost all living cells as an intermediate substance in the metabolic cycle. Most plant and animal tissues, as well as human serum, contain citric acid in a significant quantity.

16.7.1 Main processes and techniques

The most economical method to produce citric acid is fermentation, which employs a strain of *Aspergillus niger* as an inoculum, to convert sugar to citric acid. The fermentation feedstock or substrate is a carbohydrate, usually molasses, crystalline sugar, glucose from wheat, maize or potato starch, or isomerose. There are two types of fermentation processes, i.e. submerged and surface fermentation. Submerged fermentation is preferred to surface fermentation. Submerged fermentation consists of three main phases, i.e. fermentation, recovery, and purification of citric acid. The flowchart for this process is presented in Figure 16.3. The major environmental issues are water pollution and the generation of solid wastes. During fermentation a high content of nutrients and oxygen is needed. Further advantages are low concentrations of Fe$^{2+}$ ions and a low pH level which both inhibits the enzyme aconitase that is responsible for the catalysis of citrate to isovitrate [264, Austria 2015].

In citric acid fermentation, the substrate is prepared in a tank and then sterilised. The inoculum is produced under controlled aseptic conditions. The inoculum and the substrate are transferred aseptically to the production fermenter. The fermentation process requires 3 to 14 days. Finally, the biological solids called mycelium are removed by filtration.

In the recovery of citric acid, the dissolved citric acid is separated from residual sugars, proteins and other soluble impurities by the addition of lime precipitating calcium citrate. Then, the slurry containing calcium citrate is filtered. The filtrate is washed to remove soluble impurities. The waste water generated is discharged. Sulphuric acid is added and this converts the calcium citrate to calcium sulphate and citric acid. Finally, the precipitated calcium sulphate or gypsum is filtered from the slurry and the remaining citric acid solution is further treated.

Ultimately, the citric acid solution is purified by ion exchange and carbon adsorption. The citric acid solution is evaporated and crystallised from the solution (first crystallisation). The citric acid crystals are centrifuged. Later, citric acid is dissolved in water and crystallised again from the solution (second crystallisation). The crystals are centrifuged yet again and are dried, milled and sieved. The resultant citric acid is then packaged.
16.7.2 Water consumption

Specific water consumption is around 40 m³ per tonne of installation citric acid production capacity.

16.7.3 Residues

The main solid wastes are the mycelium of the mould filtered from the fermentation broth, the gypsum generated during citric acid purification and the solid wastes produced during waste water treatment, i.e. anaerobic sludge and sulphur from biogas. Minor quantities of filtering aids are derived from polishing filtration. The solid wastes and by-products from citric acid fermentation are shown in Table 16.6.
### Table 16.6: Solid wastes and by-products in the citric acid fermentation process

<table>
<thead>
<tr>
<th>Solid waste and by-product</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mycelium</td>
<td>kg dry matter/t citric acid</td>
<td>100</td>
</tr>
<tr>
<td>Gypsum (CaSO₄ x 2H₂O)</td>
<td></td>
<td>1000</td>
</tr>
<tr>
<td>Waste water sludge from anaerobic pretreatment</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Sulphur from desulphurisation</td>
<td></td>
<td>3–4</td>
</tr>
</tbody>
</table>

*Source: [83, Austrian contribution 2002]*

### 16.7.4 Emissions to water

The waste water generated has high COD emission levels, compounds containing calcium and sulphur derived from precipitation and decomposition, and a high concentration of NH₄-N from the raw material (molasses) and fermentation [83, Austrian contribution 2002]. About 25% of the crude waste water volume is highly polluted and represents about 90% of the total COD load.

The highly polluted waste water is first pretreated using anaerobic digestion, which produces biogas with a high sulphur content. The waste water treated in the anaerobic reactor and other waste water are then mixed and treated further. Waste water emission levels, after treatment, per tonne of installed production capacity are shown in Table 16.7.

### Table 16.7: Treated waste water emission levels per tonne of installed production capacity in citric acid fermentation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Average value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>m³/t</td>
<td>40</td>
</tr>
<tr>
<td>COD</td>
<td>kg/t</td>
<td>20</td>
</tr>
<tr>
<td>BOD₅</td>
<td>kg/t</td>
<td>1</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>kg/t</td>
<td>0.2</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>kg/t</td>
<td>0.08</td>
</tr>
<tr>
<td>PO₄-P</td>
<td>kg/t</td>
<td>0.04</td>
</tr>
</tbody>
</table>

*Source: [83, Austrian contribution 2002]*
16.8 Yeast

Yeasts are single cell fungi used in a wide range of fermentation processes such as baking, beer brewing and the manufacture of wines and spirits. Yeast is usually supplied to food and ethanol manufacturers either in a crumbled/compressed/liquid form or as active dry yeast. Although methods vary, the essential steps in conventional processing are as described below.

16.8.1 Main processes and techniques

Propagation takes approximately 6 to 8 days on a commercial scale using propagators sized between 91 000 and 227 000 litres. Yeast production initially involves a series of small propagations. The yeast produced at each stage being used to seed the subsequent propagation. Ingredients typically added to the fermenter are cane and beet molasses, blended and clarified before addition, ammonia, phosphoric acid, vitamins, minerals, and de-foaming agents. Aeration of the fermenter is essential to achieve optimum growth. Air is introduced by bubbling through a series of parallel pipes fitted at the bottom of the vessel. In agitated vessels, air is usually introduced through a doughnut shaped sparger, located just underneath the stirred blades. In general, 100 grams of dry yeast matter require 102.5 grams of oxygen to be supplied during fermentation. Temperature and acidity is regulated to optimise yields. Typically, fermentation is carried out at 30 °C and at a pH of 4.5–6.5. Water may be used in external heat exchangers or internal coils to maintain the fermentation temperature, which otherwise tends to rise due to the yeast growth.

After propagation, the fermenter contents are cooled and the yeast crop is removed by centrifugal separators. The yeast cream is washed to improve its colour and cooled. Crumbled yeast is produced by pressing in a plate and frame filter or a vacuum filter. Alternatively the crumbled yeast may be mixed with emulsifiers and extruded to produce yeast blocks. Dried yeast is produced in a similar manner but is extruded through a perforated plate to produce strands of around 3 mm diameter and 0.3 to 1 cm long. The strips are usually dried in rotary or tunnel dryers before grinding and packaging. Dried yeast is usually packed in hermetically sealed containers or film with a headspace of nitrogen to extend its active shelf-life. Yeast can also be supplied in a concentrated liquid form where some of the water is removed after propagation using a centrifuge, typically in the range 18–25 % dry matter.
16.9 Confectionary

16.9.1 Main processes and techniques

**Biscuits**
The principal ingredients used in the manufacture of biscuits are wheat flour, fat and sugar. Water plays an important role in the biscuit making process but is largely removed during baking. Baked goods are normally decorated and ingredients like dried and wet fruit, cream and custard are utilised.

There are two basic dough types are hard doughs and short doughs. Whatever the dough type, the basic process steps involved in the manufacture of biscuits are dough mixing, formation of the dough pieces, baking, cooling and packaging. The methods used at each stage vary considerably depending on the product type. Raw materials are usually received in bulk and automatically metered into dough mixers. Small ingredients such as salt and sodium bicarbonate may be weighed and added by hand. The ingredients are blended and, in the case of hard doughs, mixed to promote a gluten network in the dough. In the case of short doughs, mixing is such that gluten development is deliberately limited. The formation of dough pieces varies depending on the biscuit type. Crackers and semi-sweet biscuits are cut from continuous sheets of rolled hard dough. Crackers require considerable processing as they are built up in a series of thin layers. Most short doughs are formed by rotary moulding, but soft doughs for biscuits are usually wire cut. The biscuits are baked, usually in tunnel ovens. The times and temperatures used vary depending on the product. Ovens may be direct or indirect fired, gas or electric. The baked biscuits are cooled and packed or transferred for secondary processing, e.g. layering of cream fillings. Crackers may be oil sprayed immediately after baking. Cooling is typically achieved by conveying the biscuits around the installation for a set time period.

**Cakes**
The main ingredients used in the manufacture of cake are wheat flour, fat, eggs, sugar, milk powder, water flavourings and raising agents. Cakes are generally made using either the sugar batter or flour batter method. In the sugar batter method, the fat and sugar are creamed together and eggs are added in stages. Several alternate additions of flour and liquid are carried out throughout the mixing. In the flour batter method, the fat and flour are blended together. The eggs and sugar are whisked together and then blended into the fat and flour in stages. The required quantities of liquids are then added in small amounts as mixing progresses.

In continuous mixing systems such as the Oakes and Mondo cake mixers, the ingredients are given a preliminary mix and then fed in a continuous even stream, into the head of the mixer. All-in high speed cake mixing is being increasingly used. In this method, all ingredients except fruit are added and a fixed amount of mixing is carried out. The fruit is then added in short bursts.

Batters are typically deposited into oil sprayed trays or continuous sheets for products such as Swiss rolls. After baking, the cakes are removed from the tins and cooled. The empty tins are cleaned, rinsed, dried and cooled.

**Cocoa**
Drinking cocoa typically consists of cocoa powder, vanillin, cinnamon, salt, cassia and other powdered spices. Raw beans are received and subjected to a series of washing operations to remove extraneous matter such as fibre, stones, grit, metal, bean clusters and immature beans. The latter two materials may be used for the manufacture of cocoa butter. The beans are roasted. Roasting conditions vary depending on the equipment and the desired product, but are typically in the range of 100 to 140 °C for 4 to 6 minutes. Whole beans or the separated nibs may be roasted.

Winnowing is the separation of the outer shell of the bean from the edible nibs and typically consists of cracking the roasted bean between rollers, followed by air classification to remove
the shell fragments. The nibs are ground to produce a cocoa liquor whose particle size is further reduced by grinding mills, which are water-cooled. The particle size is important for the manufacture of chocolate drink but less important for chocolate since this requires some further refining. The liquor or nibs from roasted or unroasted beans are likely to be subjected to a process known as alkalisation which increases the dispensability of cocoa powder in milk or water when used in drinks. It is also used to modify the colour of the cocoa. Only permitted acids, alkalis and emulsifiers may be used for this process.

Cocoa powder is produced by the hydraulic pressing of cocoa liquor to express cocoa butter and to reduce the fat content of the press cake to the desired level. The expressed cocoa butter is used in the manufacture of chocolate. The press cake is pulverised to produce a cocoa powder. The final product is then packaged.

**Chocolate**

The basic ingredients for the manufacture of chocolate include cocoa liquor, sugar, other sweeteners, cocoa butter, butter fat, milk powder, milk crumb and emulsifiers. The basic operations involved in chocolate production are the preparation and mixing of ingredients, refining and conching. Conching involves agitating the refined material to induce desirable physical changes in the final product and to improve the flavour. Chocolate production has traditionally been undertaken in a device called a melangeur, which accommodates all of the steps involved. Melangeurs are, however, being increasingly replaced by large specialist machines.

The refining stage in the manufacture of chocolate is intended to reduce the size of the particles of cocoa solids in the mix, thus ensuring that the mixture has a smooth consistency. This is achieved by passing the mixture through vertically mounted rollers which need to be water cooled to prevent distortions arising from frictional heating. A number of systems are available for conching, which is a specialised activity inducing complex changes in the chocolate. Processing milk chocolate in a traditional batch conch takes in excess of a day, whilst modern, continuous systems achieve the same result in around 4 hours. Finished chocolate is typically stored in bulk and is tempered through a cooling and warming cycle before final use.

Chocolate products may be produced by casting the chocolate into moulds, followed by cooling and demoulding. Such methods may be used to produce solid chocolate blocks or shells, which may be hollow or filled with a confectionery such as fondant. Alternatively, liquid chocolate may be used to coat confectionery using units known as enrobers.

**Boiled sweets**

Boiled sweets are highly concentrated solutions of sugar, glucose syrup and sometimes invert sugar, with added flavourings. These are metered into continuous dissolvers. This mixture feeds cookers, of which there are a number of designs such as thin film, coil cookers or batch vacuum cookers. Water is rapidly evaporated from the syrup, which is then discharged and partially cooled due to evaporative cooling. The boiled sweet mass is transferred to water-cooled tables and acid, flavour and colours, are added to the partially cooled mass in a batch or continuous process. The mix is then transferred to forming machinery. The formed sweets are cooled and wrapped in moisture proof packs as rapidly as possible.

For additional information please consult the Sectoral Reference Document on Best Environmental Management Practices for the food and beverage manufacturing sector [275, COM 2015].
16.10 Malting

Malt is made from malting grade cereals, usually barley or wheat, although occasionally other cereals such as rye and oats may be used. There are five product groups:

- white malts (malted barley, malted wheat, malted oats, malted sorghum, high enzymatic malt);
- peated or smoked malt;
- coloured malts (such as crystal and caramel malts);
- roasted malts (range including both light and dark roasts);
- also produced: roasted barley.

Malt extracts are fermented to make beers or may be fermented and then distilled to make spirits such as whisky. Malts are also used in a range of foods such as malted milk drinks, breakfast cereals, breads, biscuits, cakes, vinegar, confectionery, sauces, baby foods, as well as animal feeds and cosmetics.

The information source for this sector is [197, EUROMALT 2015].

Malt is a product derived from germinated grain, e.g. barley, oats or wheat, which is dried in kilns. Malts are fermented to make beers and lagers or may be fermented and then distilled to make spirits such as whisky. Malts may also be used in a range of foods such as non-alcoholic malted drinks, breakfast cereals, baby foods and animal feeds.

Malting activates and develops a number of enzymes including amylolytic and proteolytic enzymes. Amylolytic enzymes break down starch to fermentable carbohydrates. Proteolytic enzymes act as flavour precursors and as nutrients for yeast in subsequent fermentations. Malting involves controlled wetting by steeping, germination and drying of the grain. The process must be carefully controlled to induce the desired physico-chemical changes required, whilst at the same time minimising weight loss due to germination and respiration. The malted grain is dried to halt growth, stop enzymic activity and produce a stable product with the desired colour and flavour. Drying is followed by cooling down to 25 to 35 ºC and by the removal of malt sprouts.

Two types of malt are generally produced on a commercial scale, i.e. brewers’ and distillers’ malts. Both types use barley as the starting raw material. Other cereals, such as wheat or rye, can also be used. Brewers’ malt is made from plumper, heavier barley kernels with a friable starch mass. The barley is cleaned and then steeped in water at around 16 ºC ranging from 10 to 25 ºC for about 1 to 3 days. The actual temperature and steeping periods depend on the equipment, the process parameters, the raw material and the finished malt to be obtained. Steeping may occur in alternate stages of wet and dry periods. The barley is germinated at moisture contents of about 45 %, ranging from 30 to 50 %, depending on the same issues.

The resulting green malt is air-dried in kilns. Hot air, is blown through a layer of green malt of about 50 to 150 cm thickness, without any fluidisation of the batch. The blowing lasts around 16 to 24 hours in one-floor kilns and 32 to 48 hours in two-floor kilns. For pale coloured malts, resulting in a moisture content of 3 to 6.5 %, the starting air temperature is around 50 ºC and it is increased to around 70 to 85 ºC. To obtain darker coloured malts, with lower humidity levels, the temperature is increased further to 130 ºC. Kilning is carried out in several stages to ensure that moisture is removed effectively without unduly reducing the enzymatic activity. In general, the airflow rate reduces and the air temperature increases as the kilning progresses. At the end of the kilning process, the dried malt is cooled down to about 25 to 35 ºC and the malt culms are removed.

Distillers’ malt, also called high diastatic malt, is made from small kernelled barley which is high in protein and enzymic potential. The barley is steeped at higher moisture levels ranging from 45 to 49 % and dried at lower temperatures, ranging from 49 to 60 ºC to a higher final
moisture content ranging from 5 to 7%. Brewers’ malt tends to be darker than distillers’ malt and has an increased flavour and aroma.

Germination of the steeped grain can be brought about with a range of equipment, but essentially the process consists of subjecting the grain to a stream of humidified air at around 10–30 °C, depending on the equipment, the process parameters, the raw material and the finished malt to be obtained. The grain temperature varies between 15 and 45 °C due to the heat developed from respiration. Periodically, the grain is slowly turned and, in some cases, humified to ensure an even temperature distribution and to prevent matting of rootlets. Germination has traditionally been carried out on concrete floors in cool moist rooms with the grain turned manually, but this method is now being replaced by more modern mechanised techniques.

After kilning, malt sprouts are removed in a cleaning stage to yield the final malted grain. This grain may be milled to produce malt flour. Malt extract is produced by hot water extraction from the finished malt, as carried out in the first stage of the brewing process, and then by concentrating the resultant extract, by means of the evaporation of water in evaporation vessels. The raw grain, the green malt or the finished malt can further be processed in the roasting drum to produce roasted barley, caramel malt or roasted malt of different colours and flavours.

16.10.1 Main processes and techniques

The main processes applied in malting installations are cleaning, steeping, germination and kilning. Malts may also be roasted.

Cleaning
Barley and other cereals received directly from the field are first cleaned to remove foreign material. This may include dust, soil, stone, metal etc. Cleaned grain is then screened to remove broken or undersized grains, loose husk and cereal fines. This material is collected and used in animal feed.

Steeping
To steep the grain, the grain is immersed in water at about 16 ºC, ranging from 10 to 25 ºC, depending on the equipment, the process parameters, the raw material and the finished malt to be obtained. During steeping, the moisture content increases from 12 to 15 % to anywhere between 30 to 50 %, depending again on the above conditions. During steeping, the water in the steep tanks is changed up to three times. Alternate wet and dry stages are applied. During the wet stage, the grain is aerated continuously or at intervals. During the dry stage, the grain can be aerated or the CO₂ can be extracted. The steeping process takes one to three days. The actual temperature and steeping periods depend on the equipment, the process parameters, the raw material and the finished malt to be obtained.

Germination
The cleaned, steeped grain is then transferred into germination vessels with perforated steel plate floors for pneumatic malting, or onto germination floors for floor malting. The grain is layered from about 70 to 150 cm thick for pneumatic malting and from about 5 to 15 cm for floor malting. The germination step generally lasts between 96 and 200 hours. Depending on the equipment, the process parameters, the raw material and the finished malt to be obtained, the germination process can be shorter or longer. Conditioned air, i.e. cooled or heated and humidified, is blown through the grain layer in pneumatic malting, or over it, in floor malting, to control the temperature and the moisture content during germination. To prevent the grain kernels from matting or felting, the layer of grain is turned from time to time, during which water spraying can also be applied. The germination process is stopped by drying.

Kilning
The resulting green malt is air-dried in kilns. Hot air is blown through a layer of green malt of about 50 to 150 cm thickness, without any fluidisation of the batch. This drying process lasts
around 16 to 48 hours. For pale malts, resulting in a moisture content of 3 to 6.5 %, the starting air temperature is around 50 °C and it is increased to around 70 to 85 °C. To obtain darker coloured malts, with lower moisture levels, the temperature is increased further to 130 °C. Kilning is carried out in several stages to ensure that moisture is removed effectively without unduly reducing the enzymatic activity. In general, the air flow rate reduces and the air temperature increases as the kilning progresses.

Malts may be roasted to increase the colour and flavour as required for certain applications. Roasting will take place in small batches, and involves heating to temperatures from 130 °C to 230 °C depending on the specification of the finished product. Crystal malts are produced by roasting of green (partially germinated) malts after an amylolytic stand at around 65 °C. Malt intended for distilling use may have peat smoke introduced into the airflow through the malt kiln, to give the particular characteristics needed by the whisky to be made from it. Other smokes may be used to give different characteristics for beers and other malt products.

16.10.2 Energy consumption

The kilning and roasting processes rely on thermal energy and electrical power. Natural gas is the usual primary fuel, with gas oil or fuel oil as alternative.

16.10.3 Water consumption

Water is a key input material to the steeping and the germination process.

16.10.4 Residues

The by-products of the malting process are widely used in the animal feed industry. They comprise blends of:

- malting barley screenings;
- malting wheat screenings;
- malting barley husks;
- malting wheat husks;
- malting barley and malt fines;
- malting wheat and malt fines;
- malt rootlets (culms);
- wheat rootlets.

16.10.5 Emissions to water

Emissions to water may include waste steep water, although this is often treated before discharge or sent to a treatment works.

16.10.6 Emissions to air

There are emissions from the malting process to air, including CO₂ from combustion in heating process air, short-cycle CO₂ from germination, NOₓ from combustion, SO₂ if used in kilning and anyway if fuel oil is the primary fuel; dust and particulate matter from aspiration systems and cyclones, VOC from roasting and germination, and odour from kilning and roasting.
17 BAT CONCLUSIONS

SCOPE

These BAT conclusions concern the activities specified in Sections 6.4 (b) and (c) of Annex I to Directive 2010/75/EU, namely:

6.4 (b) Treatment and processing, other than exclusively packaging, of the following raw materials, whether previously processed or unprocessed, intended for the production of food or feed from:

(i) only animal raw materials (other than exclusively milk) with a finished product production capacity greater than 75 tonnes per day;

(ii) only vegetable raw materials with a finished product production capacity greater than 300 tonnes per day or 600 tonnes per day where the installation operates for a period of no more than 90 consecutive days in any year;

(iii) animal and vegetable raw materials, both in combined and separate products, with a finished product production capacity in tonnes per day greater than:

— 75 if A is equal to 10 or more; or,
— \[300 - (22.5 \times A)\] in any other case,

where ‘A’ is the portion of animal material (in percent of weight) of the finished product production capacity.

Packaging shall not be included in the final weight of the product.

This subsection shall not apply where the raw material is milk only.
(c) Treatment and processing of milk only, the quantity of milk received being greater than 200 tonnes per day (average value on an annual basis).

In particular, these BAT conclusions cover the following issues:

- environmental management systems;
- energy efficiency;
- water saving;
- waste water management, collection and treatment;
- by-products, residues and waste management;
- waste gas treatment;
- noise and vibration emissions;
- odour emissions.

These BAT conclusions do not address the following activities or processes:

- on-site combustion plants generating waste gases that are not used for direct contact heating, drying or any other treatment of objects or materials; this may be covered by the BAT conclusions for Large Combustion Plants (LCP);
- production of primary products from animal by-products, such as rendering and fat melting; fish-meal and fish oil production; blood processing and gelatine manufacturing; this may be covered by the BAT conclusions for Slaughterhouses and Animals By-products Industries (SA);
- the making of standard cuts for large animals and cuts for poultry; this is covered by the BAT conclusions for Slaughterhouses and Animals By-products Industries (SA);
- ethanol production taking place on an installation not covered by the activity description in 6.4 (b) (ii) of Annex I to the IED or as a directly associated activity; this is covered by the BAT conclusions for the Large Volume Organic Chemical Industry (LVOC).

Other BAT conclusions and reference documents which could be relevant for the activities covered by these BAT conclusions are the following:

- Large Combustion Plants (LCP);
- Slaughterhouses and Animals By-products Industries (SA);
- Large Volume Organic Chemical Industry (LVOC);
- Waste Treatment (WT);
- Production of Cement, Lime and Magnesium Oxide (CLM);
- Monitoring of emissions to air and water from IED-installations (ROM);
- Economics and Cross-Media Effects (ECM);
- Emissions from Storage (EFS);
- Energy Efficiency (ENE);
- Industrial Cooling Systems (ICS).
## DEFINITIONS

For the purposes of these BAT conclusions, the following definitions apply:

<table>
<thead>
<tr>
<th>Term used</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochemical oxygen demand (BOD₅)</td>
<td>Amount of oxygen needed for the biochemical oxidation of the organic matter to carbon dioxide in 5 days. BOD is an indicator for the mass concentration of biodegradable organic compounds.</td>
</tr>
<tr>
<td>Chemical oxygen demand (COD)</td>
<td>Amount of oxygen needed for the total oxidation of the organic matter to carbon dioxide. COD is an indicator for the mass concentration of organic compounds.</td>
</tr>
<tr>
<td>Dust</td>
<td>Total particulate matter (in air).</td>
</tr>
<tr>
<td>Existing plant</td>
<td>A plant that is not a new plant.</td>
</tr>
<tr>
<td>Hexane</td>
<td>Alkane of six carbon atoms, with the chemical formula C₆H₁₄.</td>
</tr>
<tr>
<td>hl</td>
<td>Hectolitre (equal to one hundred litres).</td>
</tr>
<tr>
<td>New plant</td>
<td>A plant first permitted at the site of the installation following the publication of these BAT conclusions or a complete replacement of a plant following the publication of these BAT conclusions.</td>
</tr>
<tr>
<td>NOₓ</td>
<td>The sum of nitrogen monoxide (NO) and nitrogen dioxide (NO₂), expressed as NO₂.</td>
</tr>
<tr>
<td>Residue</td>
<td>Substance or object generated by the activities covered by the scope of this document, as waste or by-product.</td>
</tr>
<tr>
<td>SOₓ</td>
<td>The sum of sulphur dioxide (SO₂), sulphur trioxide (SO₃), and sulphuric acids aerosols, expressed as SO₂.</td>
</tr>
<tr>
<td>Total nitrogen (TN)</td>
<td>Total nitrogen, expressed as N, includes free ammonia and ammonium (NH₄-N), nitrates (NO₂⁻-N), nitrates (NO₃⁻-N) and organic nitrogen compounds.</td>
</tr>
<tr>
<td>Total organic carbon (TOC)</td>
<td>Total organic carbon, expressed as C (in water).</td>
</tr>
<tr>
<td>Total phosphorus (TP)</td>
<td>Total phosphorus, expressed as P, includes all inorganic and organic phosphorus compounds, dissolved or bound to particles.</td>
</tr>
<tr>
<td>Total suspended solids (TSS)</td>
<td>Mass concentration of all suspended solids, measured via filtration through glass fibre filters and gravimetry.</td>
</tr>
<tr>
<td>TVOC</td>
<td>Total volatile organic carbon, expressed as C (in air).</td>
</tr>
</tbody>
</table>
GENERAL CONSIDERATIONS

Best Available Techniques

The techniques listed and described in these BAT conclusions are neither prescriptive nor exhaustive. Other techniques may be used that ensure at least an equivalent level of environmental protection.

Unless otherwise stated, the BAT conclusions are generally applicable.

NOTE: Whilst cross-references are provided to other parts of this document in order to aid the work of the TWG, they will not be included in the final BAT conclusions themselves. Such cross-references are consequently displayed in italic red in square brackets.

NOTE: In order to avoid repetition, this section contains general considerations that are essential to the understanding of the BAT conclusions taken as a stand-alone document, such as:
- reference conditions for emissions to air (e.g. dry gas, standard temperature/pressure, oxygen concentration);
- averaging periods;
- sampling times;
- conversions to reference conditions;
- units in which performance levels are expressed.

Emission levels associated with the best available techniques (BAT-AELs) for emissions to air

Unless stated otherwise, emission levels associated with the best available techniques (BAT-AELs) for emissions to air given in these BAT conclusions refer to concentrations, expressed as mass of emitted substance per volume of waste gas under the following standard conditions: dry gas at a temperature of 273.15 K and a pressure of 101.3 kPa, without correction for O₂, and expressed in the unit mg/Nm³.

The equation for calculating the emission concentration at the reference oxygen level is:

\[ E_R = \frac{21 - O_R}{21 - O_M} \times E_M \]

where:
- \( E_R \): emission concentration at the reference oxygen level \( O_R \);
- \( O_R \): reference oxygen level in vol-%;
- \( E_M \): measured emission concentration;
- \( O_M \): measured oxygen level in vol-%.

For averaging periods of BAT-AELs for emissions to air, the following definition applies.

<table>
<thead>
<tr>
<th>Averaging Period</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average over the sampling period</td>
<td>Average value of three consecutive measurements of at least 30 minutes each (').</td>
</tr>
</tbody>
</table>

(’) For any parameter where, due to sampling or analytical limitations, 30-minute measurement is inappropriate, a more suitable measurement period may be employed.

When the waste gases of two or more dryers or kilns are discharged through a common stack, the BAT-AEL applies to the combined discharge from the stack.
Emission levels associated with the best available techniques (BAT-AELs) for emissions to water

**BAT-AELs expressed as concentrations**

The BAT-AELs expressed as concentrations refer to daily averages, i.e. 24-hour flow-proportional composite samples, taken with the minimum frequency set for the relevant parameter and under normal operating conditions. Time-proportional composite samples can be used provided that sufficient flow stability can be demonstrated.

In the case of total organic carbon (TOC), chemical oxygen demand (COD) and total nitrogen (TN), the calculation of the average abatement efficiency referred to in these BAT conclusions (see Table 17.3) is based on specific loads and includes the treatment techniques described in BAT 12.

**BAT-AELs expressed as specific loads**

The BAT-AELs expressed as specific loads refer to yearly averages and are calculated using the following equation:

\[
\text{specific load} = \frac{\text{concentration} \times \text{waste water flow}}{\text{production}}
\]

where:
- concentration: yearly average concentration, expressed in mg/l, calculated as the flow-weighted average of all daily average concentrations;
- waste water flow: waste water volume discharged, expressed in m$^3$/year;
- production: total amount of all products (or all raw materials, depending on the specific sector), expressed in tonnes/year or hl/year.

The flow-weighted yearly average concentration of the parameter ($c_{w}$) is calculated using the following equation:

\[
c_{w} = \frac{\sum_{i=1}^{n} c_{i} q_{i}}{\sum_{i=1}^{n} q_{i}}
\]

where:
- \(n\): number of measurements;
- \(c_{i}\): average concentration during \(i^{th}\) measurement;
- \(q_{i}\): average flow rate during \(i^{th}\) measurement.

**Other environmental performance levels**

**Specific waste water discharge**

The environmental performance levels related to specific waste water discharge refer to yearly averages and are calculated using the following equation:

\[
\text{specific waste water discharge} = \frac{\text{waste water discharge}}{\text{production}}
\]

where:
- waste water discharge: total amount of waste water discharged (i.e. direct discharge, indirect discharge and/or landspreading) by the installation, expressed in m$^3$/year, excluding cooling water and run-off water, that is not reused and is discharged separately from process water;
- production: total amount of all products (or all raw materials, depending on the specific sector), expressed in tonnes/year or hl/year.
**Specific energy consumption**

The environmental performance levels related to specific energy consumption refer to yearly averages and are calculated using the following equation:

\[
\text{specific energy consumption} = \frac{\text{energy consumption}}{\text{production}}
\]

where:
- energy consumption: total amount of energy consumed by the installation, excluding the energy generated on site from by-products and effluents, expressed in MWh/year;
- production: total amount of all products (or all raw materials, depending on the specific sector), expressed in tonnes/year or hl/year.

**Specific hexane consumption**

The environmental performance level related to specific hexane consumption refers to a yearly average and is calculated using the following equation:

\[
\text{specific hexane consumption} = \frac{\text{hexane consumption}}{\text{raw materials}}
\]

where:
- hexane consumption: total amount of hexane consumed by the installation, expressed in kg/yr;
- raw materials: total amount of crushed seeds or beans, expressed in tonnes/year.
17.1 General BAT conclusions

17.1.1 Environmental management systems

BAT 1. In order to improve the overall environmental performance, BAT is to implement and adhere to an environmental management system (EMS) that incorporates all of the following features:

I. commitment of the management, including senior management;
II. definition, by the management, of an environmental policy that includes the continuous improvement of the environmental performance of the installation;
III. planning and establishing the necessary procedures, objectives and targets, in conjunction with financial planning and investment;
IV. implementation of procedures paying particular attention to:
   (a) structure and responsibility;
   (b) recruitment, training, awareness and competence;
   (c) communication;
   (d) employee involvement;
   (e) documentation;
   (f) effective process control;
   (g) maintenance programmes;
   (h) emergency preparedness and response;
   (i) safeguarding compliance with environmental legislation.
V. checking performance and taking corrective action, paying particular attention to:
   (a) monitoring and measurement (see also the JRC Reference Report on Monitoring of emissions to air and water from IED-installations – ROM);
   (b) corrective and preventive action;
   (c) maintenance of records;
   (d) independent (where practicable) internal or external auditing in order to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;
VI. review, by senior management, of the EMS and its continuing suitability, adequacy and effectiveness;
VII. following the development of cleaner technologies;
VIII. consideration for the environmental impacts from the eventual decommissioning of the installation at the stage of designing a new plant, and throughout its operating life;
IX. application of sectoral benchmarking (e.g. EMAS Sectoral Reference Document on Food and Beverage Manufacturing) on a regular basis;
X. establishment of inventories of waste water and waste gas streams (see BAT 2).

Specifically for the food, drink and milk sector, BAT is also to incorporate the following features in the EMS:

XI. noise management plan (see BAT 13);
XII. odour management plan (see BAT 15).

Applicability

The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

[This BAT conclusion is based on information given in Section 2.3.1.1]
BAT Conclusions

BAT 2. In order to facilitate the reduction of emissions to water and air and the reduction of water usage, BAT is to establish and to maintain an inventory of waste water and waste gas streams, as part of the environmental management system (see BAT 1), that incorporates all of the following features:

I. information about the food, drink and milk production processes, including:
   (a) simplified process flow sheets that show the origin of the emissions;
   (b) descriptions of process-integrated techniques and waste water/waste gas treatment including their performances;

II. information, as comprehensive as is reasonably possible, about the characteristics of the waste water streams, such as:
   (a) average values and variability of flow, pH, temperature, and conductivity;
   (b) average concentration and load values of relevant pollutants/parameters and their variability (e.g. TOC or COD, nitrogen species, phosphorus, chloride);

III. information, as comprehensive as is reasonably possible, about the characteristics of the waste gas streams, such as:
   (a) average values and variability of flow and temperature;
   (b) average concentration and load values of relevant pollutants/parameters and their variability (e.g. dust, TVOC, CO, NO\textsubscript{X}, SO\textsubscript{X});
   (c) presence of other substances that may affect the waste gas treatment system or plant safety (e.g. oxygen, water vapour, dust).

17.1.2 Monitoring

BAT 3. For relevant emissions to water as identified by the inventory of waste water streams (see BAT 2), BAT is to monitor key process parameters (including continuous monitoring of waste water flow, pH and temperature) at key locations (e.g. influent to pretreatment and influent to final treatment).

BAT 4. BAT is to monitor emissions to water with at least the frequency given below and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

<table>
<thead>
<tr>
<th>Substance/parameter</th>
<th>Standard(s)</th>
<th>Minimum monitoring frequency</th>
<th>Monitoring associated with</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total organic carbon (TOC)</td>
<td>EN 1484</td>
<td>Once every day</td>
<td>BAT 11</td>
</tr>
<tr>
<td>Chemical oxygen demand (COD)</td>
<td>No EN standard available</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total suspended solids (TSS)</td>
<td>EN 872</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total nitrogen (TN)</td>
<td>EN 12260</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total phosphorus (TP)</td>
<td>Various EN standards available (e.g. EN ISO 6878, EN ISO 15681-1, EN ISO 15681-2, EN ISO 11885)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biochemical oxygen demand (BOD\textsubscript{5})</td>
<td>EN 1899</td>
<td>Once every week</td>
<td></td>
</tr>
<tr>
<td>Chloride (Cl\textsuperscript{-})</td>
<td>Various EN standards available (e.g. EN ISO 10304-1, EN ISO 15682)</td>
<td>Once every month</td>
<td></td>
</tr>
</tbody>
</table>
If the emission levels are proven to be sufficiently stable, a lower monitoring frequency can be adopted but in any case at least once every month.

The sampling point is located where the emission leaves the installation.

TOC monitoring and COD monitoring are alternatives. TOC monitoring is the preferred option because it does not rely on the use of very toxic compounds.

Monitoring of chloride only applies to the dairy and the fish and shellfish sectors.

BAT 5. BAT is to monitor emissions to air with at least the frequency given below and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sector</th>
<th>Specific process</th>
<th>Standard(s)</th>
<th>Minimum monitoring frequency ((^{(1)}))</th>
<th>Monitoring associated with</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>Animal feed</td>
<td>Drying of green fodder</td>
<td></td>
<td>Once every month</td>
<td>BAT 17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Processing of grain feed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extrusion (manufacture of compound feed)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brewing</td>
<td></td>
<td>EN 13284-1</td>
<td></td>
<td>BAT 22</td>
</tr>
<tr>
<td></td>
<td>Dairies</td>
<td>Drying processes</td>
<td></td>
<td>Once every year</td>
<td>BAT 25</td>
</tr>
<tr>
<td></td>
<td>Grain milling</td>
<td></td>
<td></td>
<td>Once every four months</td>
<td>BAT 30</td>
</tr>
<tr>
<td></td>
<td>Oil seed processing and vegetable oil refining</td>
<td></td>
<td></td>
<td></td>
<td>BAT 34</td>
</tr>
<tr>
<td></td>
<td>Drying of meal</td>
<td></td>
<td></td>
<td>Once every year</td>
<td>BAT 35</td>
</tr>
<tr>
<td></td>
<td>Starch production</td>
<td>Drying of starch, protein and/or fibre</td>
<td></td>
<td></td>
<td>BAT 39</td>
</tr>
<tr>
<td></td>
<td>Sugar manufacturing</td>
<td>Drying of beet pulp</td>
<td></td>
<td>Once every month</td>
<td>BAT 42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Handling and preparation of raw materials</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{(1)}\) Parameter(s) - WORKING DRAFT IN PROGRESS
17.1.3 Energy efficiency

BAT 6. In order to increase energy efficiency, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a Heat recovery</td>
<td>Use of heat exchangers and heat pumps to recover heat.</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>b Use of the biogas generated by anaerobic digestion</td>
<td>See BAT 10a. The biogas generated by the anaerobic digester passes through a scrubber (to remove hydrogen sulphide) and then flows through a series of condensate traps before being stored. The stored biogas is preconditioned (dried), analysed and then used as a fuel, e.g. in a gas engine.</td>
<td>May not be generally applicable to installations generating less than 400 tonnes of residues per year.</td>
</tr>
<tr>
<td>c Precooling of ice-water</td>
<td>Precooling of the returning ice-water (e.g. with a plate heat exchanger), prior to final cooling in an accumulating ice-water tank with a coil evaporator.</td>
<td>Only applicable when ice-water is used.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 2.3.2]
Further sector-specific techniques to increase energy efficiency are given in Sections 17.2 to 17.13 of these BAT conclusions.

### Table 17.1: BAT-associated environmental performance levels (BAT-AEPLs) for specific energy consumption

<table>
<thead>
<tr>
<th>Sector</th>
<th>Specific process/product</th>
<th>Unit</th>
<th>BAT-AEPL (yearly average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal feed</td>
<td>Compound feed</td>
<td>MWh/tonne of raw material(s)</td>
<td>0.016–0.075</td>
</tr>
<tr>
<td></td>
<td>Dry pet food</td>
<td></td>
<td>0.39–0.45</td>
</tr>
<tr>
<td>Brewing</td>
<td></td>
<td>MWh/l of product(s)</td>
<td>0.048–0.06</td>
</tr>
<tr>
<td>Dairies</td>
<td>Market milk</td>
<td>MWh/tonne of raw material(s)</td>
<td>0.045–0.59</td>
</tr>
<tr>
<td></td>
<td>Cheese</td>
<td></td>
<td>0.10–0.21</td>
</tr>
<tr>
<td></td>
<td>Powder</td>
<td></td>
<td>0.19–0.51</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>Potato processing</td>
<td>MWh/tonne of product(s)</td>
<td>0.90–2.1</td>
</tr>
<tr>
<td></td>
<td>Tomato processing</td>
<td></td>
<td>0.55–1.95</td>
</tr>
<tr>
<td>Dairies</td>
<td>Market milk</td>
<td>MWh/tonne of raw material(s)</td>
<td>0.045–0.59</td>
</tr>
<tr>
<td></td>
<td>Cheese</td>
<td></td>
<td>0.10–0.21</td>
</tr>
<tr>
<td></td>
<td>Powder</td>
<td></td>
<td>0.19–0.51</td>
</tr>
<tr>
<td>Grain milling</td>
<td></td>
<td>MWh/tonne of product(s)</td>
<td>0.05–0.1</td>
</tr>
<tr>
<td>Meat processing</td>
<td></td>
<td>MWh/tonne of raw material(s)</td>
<td>0.27–3.6</td>
</tr>
<tr>
<td>Oilseed processing and</td>
<td>Integrated crushing and refining</td>
<td>MWh/tonne of product(s)</td>
<td>0.47–1.48</td>
</tr>
<tr>
<td>vegetable oil refining</td>
<td>Refining</td>
<td></td>
<td>0.17–0.72</td>
</tr>
<tr>
<td>Starch production</td>
<td>Potato processing</td>
<td>MWh/l of product(s)</td>
<td>0.01–0.034</td>
</tr>
<tr>
<td></td>
<td>Maize, wheat processing/native</td>
<td>MWh/tonne of raw material(s)</td>
<td>0.08–0.14</td>
</tr>
<tr>
<td></td>
<td>and modified starch</td>
<td></td>
<td>0.7–1.77</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>Raw sugar beet processing</td>
<td>MWh/tonne of beet processed(s)</td>
<td>0.03–0.32</td>
</tr>
</tbody>
</table>

### 17.1.4 Water consumption

**BAT 7.** In order to reduce water consumption and the volume of waste water discharged, BAT is to use BAT 7a and a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Water recycling</td>
<td>Recycling or reuse of water streams (preceded or not by water treatment), e.g. for cleaning, washing, cooling or for the process itself. The degree to which the water can be recycled or reused is limited by the purity requirements and the water demand of the process.</td>
</tr>
<tr>
<td>b</td>
<td>Use of control devices to optimise water flow</td>
<td>Use of control devices, e.g. photocells, flow valves, thermostatic valves, to automatically adjust the water flow.</td>
</tr>
<tr>
<td>c</td>
<td>Optimisation of water nozzles</td>
<td>Use of correct number and position of nozzles; adjustment of water pressure and flow.</td>
</tr>
<tr>
<td>d</td>
<td>Segregation of water</td>
<td>Water streams that do not need treatment</td>
</tr>
</tbody>
</table>
**BAT Conclusions**

<table>
<thead>
<tr>
<th>Techniques related to cleaning operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>e</td>
</tr>
<tr>
<td>f</td>
</tr>
<tr>
<td>g</td>
</tr>
</tbody>
</table>
| h | Optimisation of cleaning-in-place (CIP) | Ensuring that CIP is optimised, e.g. by:  
  - measuring turbidity, conductivity, temperature or pH to dose water and chemicals in optimised quantities;  
  - reuse of water and chemicals. |
| i | Low-pressure foam and/or gel cleaning | Use of low-pressure foam and/or gel instead of water to clean walls, floors and/or equipment surfaces. |
| j | Optimised design and construction to facilitate cleaning | This can be achieved by spillage collection devices, reduction of pipelines, closed loops, better design of nozzle system, etc. |
| k | Optimisation of manual cleaning | Ensuring that the water consumption of manual cleaning is reduced. This includes:  
  - monitoring of water consumption;  
  - water pressure controls and water-efficient spray nozzles for hoses;  
  - cleaning as soon as possible after use to prevent wastes hardening. |

<table>
<thead>
<tr>
<th>Techniques related to bottling</th>
</tr>
</thead>
<tbody>
<tr>
<td>l</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 2.3.3]

Further sector-specific techniques to reduce water consumption are given in Sections 17.6.1 and 17.9.1 of these BAT conclusions.
Table 17.2: BAT-associated environmental performance levels (BAT-AEPLs) for specific waste water discharge

<table>
<thead>
<tr>
<th>Sector</th>
<th>Specific process/product</th>
<th>Unit</th>
<th>BAT-AEPL (yearly average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal feed</td>
<td>Wet pet food</td>
<td>m³/tonne of raw materials</td>
<td>≤ 5.6</td>
</tr>
<tr>
<td>Brewing</td>
<td></td>
<td>m³/hl of products</td>
<td>0.10 – 0.44</td>
</tr>
<tr>
<td>Dairies</td>
<td>Market milk</td>
<td>m³/tonne of raw materials</td>
<td>0.30 – 2.10</td>
</tr>
<tr>
<td></td>
<td>Cheese</td>
<td>m³/tonne of raw materials</td>
<td>0.75 – 1.84</td>
</tr>
<tr>
<td></td>
<td>Powder</td>
<td></td>
<td>2.0 – 2.70</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>Potato processing</td>
<td>m³/tonne of products</td>
<td>4.45 – 5.55</td>
</tr>
<tr>
<td></td>
<td>Tomato processing</td>
<td></td>
<td>2.0 – 11.6</td>
</tr>
<tr>
<td>Meat processing</td>
<td>Integrated crushing and refining</td>
<td>m³/tonne of products</td>
<td>0.10 – 0.90</td>
</tr>
<tr>
<td></td>
<td>Refining</td>
<td></td>
<td>0.16 – 1.22</td>
</tr>
<tr>
<td>Soft drinks and nectar/juice</td>
<td></td>
<td>m³/hl of products</td>
<td>0.08 – 0.18</td>
</tr>
<tr>
<td>Starch production</td>
<td>Potato processing</td>
<td></td>
<td>0.43 – 1.60</td>
</tr>
<tr>
<td></td>
<td>Maize, wheat processing/native and modified starch</td>
<td>m³/tonne of raw materials</td>
<td>1.11 – 3.50</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>Raw sugar beet processing</td>
<td>m³/tonne of beet processed</td>
<td>0.05 – 0.93</td>
</tr>
</tbody>
</table>

(*) The lower end of the range is typically achieved when beet cleaning is carried out off site.

17.1.5 Avoiding the use of harmful substances

BAT 8. In order prevent or reduce the use of harmful chemicals in cleaning and disinfection, BAT is to use a combination of techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Proper selection and reduction of cleaning chemicals</td>
<td>Avoidance or minimisation of the production of harmful residues:</td>
</tr>
<tr>
<td></td>
<td>• use of less harmful cleaning chemicals (e.g. ozone);</td>
<td>• reduction of the use of cleaning chemicals (e.g. EDTA, halogenated biocides, acids).</td>
</tr>
<tr>
<td>b</td>
<td>Optimal use of cleaning-in-place (CIP) by reuse of cleaning chemicals</td>
<td>Collection and reuse of CIP detergents, such as caustic soda.</td>
</tr>
<tr>
<td>c</td>
<td>Dry cleaning</td>
<td>See BAT 7</td>
</tr>
<tr>
<td>d</td>
<td>Optimised design and construction to facilitate cleaning</td>
<td>See BAT 7</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 2.3.4]
BAT Conclusions

BAT 9. In order to prevent or reduce emissions of harmful substances in cooling and freezing, BAT is to use refrigerants without ozone depletion potential and with low global warming potential.

Description
Prevention of emissions of substances that deplete the ozone layer or have a high global warming potential by using alternative refrigerants, such as water, CO₂ or ammonia.

[This BAT conclusion is based on information given in Section 2.3.4]

17.1.6 Waste

BAT 10. In order to reduce the quantity of waste sent for disposal, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a Anaerobic digestion</td>
<td>Treatment of biodegradable residues by microorganisms in the absence of oxygen, resulting in biogas and digestate.</td>
<td>May not be generally applicable to installations generating less than 400 tonnes of residues per year.</td>
</tr>
<tr>
<td>b Use of residues as animal feed</td>
<td>Raw materials, partially processed foods and final products not suitable for human consumption are used as animal feed.</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>c Separation of residues</td>
<td>Separation of residues, e.g. using positioned splash protectors, screens, flaps, catchpots, drip trays and troughs.</td>
<td></td>
</tr>
<tr>
<td>d Recovery and reuse of residues from the pasteuriser</td>
<td>Residues from the pasteuriser are fed back to the blending unit and are thereby reused as raw materials.</td>
<td>Only applicable to liquid food products</td>
</tr>
<tr>
<td>e Recovery of spilled contents during filling and washing of cans, bottles and jars</td>
<td>Use of can, bottle and jar filling and cleaning systems with spilled contents recovery.</td>
<td>Generally applicable</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 2.3.5]

Further sector-specific techniques to reduce waste sent for disposal are given in Sections 17.3.2, 17.4.2, 17.5.1 and 17.13.2 of these BAT conclusions.

17.1.7 Emissions to water

BAT 11. In order to prevent uncontrolled emissions to water, BAT is to provide an appropriate buffer storage capacity for waste water generated during other than normal operating conditions based on a risk assessment (taking into account the nature of the pollutant, the effects on further treatment, the receiving environment, etc.), and to take appropriate further measures (e.g. control, treat, reuse).

BAT 12. In order to reduce emissions to water, BAT is to use an appropriate combination of the techniques given below.
Technique (1) | Typical pollutants abated | Applicability
--- | --- | ---
**Preliminary and primary treatment** |  |  |
a Equalisation | All pollutants |  |
b Neutralisation | Acids, alkalis |  |
c Physical separation, e.g. screens, sieves, grit separators, oil/fat separators or primary settlement tanks | Suspended solids, oil/grease | Generally applicable

**Biological treatment (secondary treatment)** |  |  |
d Activated sludge process | Biodegradable organic compounds | Generally applicable

e Aerobic lagoon |  |  |
f Upflow anaerobic sludge blanket (UASB) |  |  |
g Membrane bioreactor |  |  |

**Nitrogen removal** |  |  |
h Biological nitrification and denitrification | Total nitrogen, ammonia | Nitrification may not be applicable in the case of high chloride concentrations (i.e. around 10 g/l) and provided that the reduction of the chloride concentration prior to nitrification would not be justified by the environmental benefits.

**Phosphorus recovery and/or removal** |  |  |
i Phosphorus recovery as struvite | Phosphorus | Only applicable to waste water streams with a high phosphorus content (i.e. higher than 50 mg/l)

j Chemical precipitation |  |  |
k Enhanced biological phosphorus removal |  | Generally applicable

**Final solids removal** |  |  |
l Coagulation and flocculation |  |  |
m Sedimentation |  |  |
n Filtration (e.g. sand filtration, microfiltration, ultrafiltration) | Suspended solids | Generally applicable

o Flotation |  |  |

(1) The descriptions of the techniques are given in Section 17.14.1.

17.1.7.1 **BAT-associated emission levels for emissions to water**

The BAT-associated emission levels (BAT-AELs) for emissions to water given in Table 17.3, Table 17.4, Table 17.5, Table 17.6 and Table 17.7 apply to direct emissions to a receiving water body from:

(i) the activities specified in Sections 6.4 (b) and (c) of Annex I to Directive 2010/75/EU;

(ii) independently operated waste water treatment plants specified in Section 6.11 of Annex I to Directive 2010/75/EU provided that the main pollutant load originates from activities specified in Sections 6.4 (b) and (c) of Annex I to Directive 2010/75/EU;

(iii) the combined treatment of waste water from different origins provided that the main pollutant load originates from activities specified in Sections 6.4 (b) and (c) of Annex I to Directive 2010/75/EU.

The BAT-AELs apply at the point where the emission leaves the installation.
17.1.7.1.1 BAT-associated emission levels expressed as concentrations

Table 17.3: BAT-associated emission levels (BAT-AELs) for direct emissions to a receiving water body

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BAT-AEL (daily average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total organic carbon (TOC)</td>
<td>10–33 mg/l (1)</td>
</tr>
<tr>
<td>Chemical oxygen demand (COD)</td>
<td>30–100 mg/l (2)</td>
</tr>
<tr>
<td>Total suspended solids (TSS)</td>
<td>4–65 mg/l (2)</td>
</tr>
<tr>
<td>Total nitrogen (TN)</td>
<td>2–20 mg/l (3)</td>
</tr>
<tr>
<td>Total phosphorus (TP)</td>
<td>0.2–6 mg/l</td>
</tr>
</tbody>
</table>

(1) No BAT-AEL applies for biochemical oxygen demand (BOD). As an indication, the yearly average BOD, level in the effluent from a biological waste water treatment plant will generally be ≤ 20 mg/l.
(2) Either the BAT-AEL for TOC or the BAT-AEL for COD applies. TOC is the preferred option because its monitoring does not rely on the use of very toxic compounds.
(3) The upper end of the range may be up to 66 mg/l for TOC or up to 200 mg/l for COD, both as daily averages, if both of the following conditions are fulfilled:
- Condition A: Abatement efficiency ≥ 95 % as a daily average.
- Condition B: If a biological treatment is used, at least one of the following criteria is met:
  - A low-loaded biological treatment step is used (i.e. ≤ 0.25 kg COD/kg of organic dry matter of sludge).
  - This implies that the yearly average BOD₅ level in the effluent is ≤ 20 mg/l.
  - Nitrification is used.
(4) The lower end of the range is typically achieved when using filtration (e.g. sand filtration, microfiltration, ultrafiltration, membrane bioreactor), while the upper end of the range is typically achieved when using sedimentation only.
(5) The upper end of the range may be higher, and up to 30 mg/l as a daily average, if the abatement efficiency is ≥ 75 % as a daily average.

The associated monitoring is given in BAT 4.

17.1.7.1.2 BAT-associated emission levels expressed as average specific loads

Table 17.4: BAT-associated emission levels (BAT-AELs) for direct emissions of COD to a receiving water body

<table>
<thead>
<tr>
<th>Sector</th>
<th>Unit</th>
<th>BAT-AEL (yearly average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brewing</td>
<td>g/hl of products</td>
<td>4.4–13.4</td>
</tr>
<tr>
<td>Dairies</td>
<td>g/tonne of raw materials</td>
<td>8.5–115.5</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>g/tonne of products</td>
<td>33–221</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td>g/tonne of products</td>
<td>8–39</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>g/tonne of beet processed</td>
<td>29–81</td>
</tr>
</tbody>
</table>
Table 17.5: BAT-associated emission levels (BAT-AELs) for direct emissions of TSS to a receiving water body

<table>
<thead>
<tr>
<th>Sector</th>
<th>Unit</th>
<th>BAT-AEL (yearly average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairies</td>
<td>g/tonne of raw materials</td>
<td>3.5–29.0</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>g/tonne of products</td>
<td>18–99</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td>g/tonne of products</td>
<td>0.1–5.9</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>g/tonne of beet processed</td>
<td>0–22</td>
</tr>
</tbody>
</table>

Table 17.6: BAT-associated emission levels (BAT-AELs) for direct emissions of TN to a receiving water body

<table>
<thead>
<tr>
<th>Sector</th>
<th>Unit</th>
<th>BAT-AEL (yearly average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brewing</td>
<td>g/hl of products</td>
<td>0.30–2.15</td>
</tr>
<tr>
<td>Dairies</td>
<td>g/tonne of raw materials</td>
<td>4.6–15.5</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>g/tonne of products</td>
<td>8–67</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td>g/tonne of products</td>
<td>0.6–4.7</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>g/tonne of beet processed</td>
<td>1.5–14</td>
</tr>
</tbody>
</table>

Table 17.7: BAT-associated emission levels (BAT-AELs) for direct emissions of TP to a receiving water body

<table>
<thead>
<tr>
<th>Sector</th>
<th>Unit</th>
<th>BAT-AEL (yearly average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brewing</td>
<td>g/hl of products</td>
<td>0.19–0.55</td>
</tr>
<tr>
<td>Dairies</td>
<td>g/tonne of raw materials</td>
<td>0.2–3.5</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>g/tonne of products</td>
<td>1.5–7.5</td>
</tr>
<tr>
<td>Oilseed processing and vegetable oil refining</td>
<td>g/tonne of products</td>
<td>0.1–1.4</td>
</tr>
<tr>
<td>Sugar manufacturing</td>
<td>g/tonne of beet processed</td>
<td>0.08–0.95</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 4.
17.1.8 Techniques to reduce noise and vibrations

BAT 13. In order to prevent or, where that is not practicable, to reduce noise and vibration emissions, BAT is to set up, implement and regularly review a noise and vibration management plan, as part of the environmental management system (see BAT 1), that includes all of the following elements:

I. a protocol containing actions and timelines;
II. a protocol for conducting noise and vibration emissions monitoring;
III. a protocol for response to identified noise and vibration events;
IV. a noise and vibration reduction programme designed to identify the source(s), to measure/estimate noise and vibration exposure, to characterise the contributions of the sources and to implement prevention and/or reduction measures.

Applicability
The applicability is restricted to cases where noise or vibration nuisance can be expected or has been substantiated.

BAT 14. In order to prevent or, where that is not practicable, to reduce noise and vibration emissions, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>a Appropriate location of equipment and buildings</td>
</tr>
<tr>
<td>b Operational measures</td>
</tr>
<tr>
<td>c Low-noise equipment</td>
</tr>
<tr>
<td>d Noise and vibration control equipment</td>
</tr>
<tr>
<td>e Noise abatement</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing the distance between the emitter and the receiver, using buildings as noise screens and relocating buildings' exits or entrances.</td>
</tr>
</tbody>
</table>
| This includes:  
  i. improved inspection and maintenance of equipment;  
  ii. closing of doors and windows of enclosed areas, if possible;  
  iii. equipment operation by experienced staff;  
  iv. avoidance of noisy activities at night, if possible;  
  v. provisions for noise control during maintenance activities. |
| This includes low-noise compressors, pumps and fans. |
| This includes:  
  i. noise-reducers;  
  ii. equipment insulation;  
  iii. enclosure of noisy equipment;  
  iv. soundproofing of buildings. |
| Inserting obstacles between emitters and receivers (e.g. protection walls, embankments and buildings). |

<table>
<thead>
<tr>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>For existing plants, the relocation of equipment and buildings' exits or entrances may be restricted by a lack of space or excessive costs.</td>
</tr>
<tr>
<td>Generally applicable</td>
</tr>
<tr>
<td>For existing plants, applicability may be restricted by a lack of space.</td>
</tr>
<tr>
<td>Applicable only to existing plants, since the design of new plants should make this technique unnecessary. For existing plants, the insertion of obstacles may be restricted by a lack of space.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 2.3.8]
17.1.9 Odour

BAT 15. In order to prevent or, where that is not practicable, to reduce odour emissions, BAT is to set up, implement and regularly review an odour management plan, as part of the environmental management system (see BAT 1), that includes all of the following elements:

- A protocol containing actions and timelines.
- A protocol for conducting odour monitoring. It may be complemented by measurement/estimation of odour exposure or estimation of odour impact.
- A protocol for response to identified odour incidents.
- An odour prevention and reduction programme designed to identify the source(s); to measure/estimate odour exposure; to characterise the contributions of the sources; and to implement prevention and/or reduction measures.

Applicability
BAT 16 is only applicable to cases where an odour nuisance at sensitive receptors is expected and/or has been substantiated.
17.2  BAT conclusions for animal feed

Unless otherwise stated, the BAT conclusions presented in this section are generally applicable to animal feed. They apply in addition to the general BAT conclusions given in Section 1.1.

17.2.1  Energy efficiency

BAT 16.  In order to increase energy efficiency in green fodder processing, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Flat pre-wilting</td>
<td>Spreading the mown fodder flat on the mowing site to allow it to dry in the open air before harvesting it.</td>
</tr>
<tr>
<td>b</td>
<td>Recycling of humid air from the dryer</td>
<td>Injection of the outgoing warm air from the cyclonic separation (about 120 °C) into the burner of the dryer.</td>
</tr>
<tr>
<td>c</td>
<td>Use of waste heat for predrying</td>
<td>The outgoing steam from the high-temperature dryers is used for predrying part or all of the green fodder.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 3.4.1]

17.2.2  Emissions to air

BAT 17.  In order to reduce dust emissions to air from processing of grain-based feed, BAT is to use a bag filter.

Description
See Section 17.14.2.

Table 17.8:  BAT-associated emission level (BAT-AEL) for dust emissions to air from processing of grain-based feed

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL (average over the sampling period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>mg/Nm³</td>
<td>&lt; 2.5</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.

[This BAT conclusion is based on information given in Section 3.4.2.2]
BAT 18. In order to reduce dust emissions to air from the extrusion process in compound feed manufacture, BAT is to use one or both of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Bag filter</td>
<td>See Section 17.14.2</td>
</tr>
<tr>
<td>b</td>
<td>Bioscrubber</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>c</td>
<td>Cyclone</td>
<td></td>
</tr>
</tbody>
</table>

Table 17.9: BAT-associated emission level (BAT-AEL) for dust emissions to air from the extrusion process in compound feed manufacture

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL (average over the sampling period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>mg/Nm³</td>
<td>&lt; 2–5</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.

[This BAT conclusion is based on information given in Section 3.4.2.3]

BAT 19. In order to reduce odour emissions from compound feed and/or pet food production, BAT is to use one of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Biofilter</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>Bioscrubber</td>
<td>See Section 17.14.2</td>
</tr>
<tr>
<td>c</td>
<td>Non-thermal plasma treatment</td>
<td>Generally applicable</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 3.4.2.4]
17.3 BAT conclusions for brewing

Unless otherwise stated, the BAT conclusions presented in this section are generally applicable to brewing. They apply in addition to the general BAT conclusions given in Section 1.1.

17.3.1 Energy efficiency

BAT 20. In order to increase energy efficiency, BAT is to use a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Double malt kilning</td>
<td>The malt drying process takes place in two steps. In the first step, water on the surface of the malt is evaporated at a high rate. In the second step, the water from the core of the grains is evaporated.</td>
</tr>
<tr>
<td>b</td>
<td>Mashing-in at higher temperatures</td>
<td>The mashing-in of the grain is carried out at temperatures of approximately 60 °C, which reduces the use of cold water.</td>
</tr>
<tr>
<td>c</td>
<td>Decrease of evaporation rate during wort boiling</td>
<td>The evaporation rate can be reduced from 10% down to approximately 4% per hour (e.g. by two-phase boiling systems, dynamic low-pressure boiling).</td>
</tr>
<tr>
<td>d</td>
<td>Increase of the degree of high-gravity brewing</td>
<td>Production of concentrated wort which reduces its volume and thereby saves energy.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 4.4.1]

17.3.2 Waste

BAT 21. In order to reduce the quantity of waste sent for disposal, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Recovery and (re)use of yeast after fermentation</td>
<td>After fermentation, yeast is separated and stored in tanks and is used as an animal feed (see BAT 10) or is reused in the fermentation process. It may also be used for pharmaceutical purposes or sent to an anaerobic waste water treatment plant for biogas production.</td>
</tr>
<tr>
<td>b</td>
<td>Recovery and reuse of natural filter material</td>
<td>Natural mineral adsorbents (e.g. diatomaceous earth) are transferred to a reactor where they are dried in a stream of hot air. Then, they can be reused for filtration purposes.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 4.4.3]
17.3.3 Emissions to air

BAT 22. In order to reduce dust emissions to air from brewing, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a Bag filter</td>
<td>See Section 17.14.2</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>b Cyclone</td>
<td>See Section 17.14.2. Cyclones are commonly used as a preliminary abatement step.</td>
<td></td>
</tr>
</tbody>
</table>

Table 17.10: BAT-associated emission level (BAT-AEL) for dust emissions to air from brewing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL (average over the sampling period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>mg/Nm$^3$</td>
<td>≤ 2.5</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.

[This BAT conclusion is based on information given in Section 4.4.4.1]
17.4 BAT conclusions for dairies

Unless otherwise stated, the BAT conclusions presented in this section are generally applicable to dairies. They apply in addition to the general BAT conclusions given in Section 1.1.

17.4.1 Energy efficiency

BAT 23. In order to increase energy efficiency, BAT is to use a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Partial milk homogenisation</td>
<td>The cream is homogenised together with a small proportion of skimmed milk. The size of the homogeniser can be significantly reduced, leading to energy savings.</td>
</tr>
<tr>
<td>b</td>
<td>Energy-efficient homogeniser</td>
<td>The homogeniser's working pressure is reduced through optimised design and thus the associated electrical energy needed to drive the system is also reduced.</td>
</tr>
<tr>
<td>c</td>
<td>Use of continuous pasteurisers</td>
<td>Flow-through heat exchangers are used (e.g. tubular, plate and frame). The pasteurisation time is much shorter than that of batch systems.</td>
</tr>
<tr>
<td>d</td>
<td>Regenerative heat exchange in pasteurisation</td>
<td>The incoming milk in the countercurrent flow is preheated by the hot milk leaving the pasteurisation section.</td>
</tr>
<tr>
<td>e</td>
<td>Ultra-high-temperature (UHT) process without intermediate pasteurisation</td>
<td>UHT milk is produced in one step from raw milk, thus reducing the energy needed for pasteurisation.</td>
</tr>
<tr>
<td>f</td>
<td>Multi-stage drying in milk powder production</td>
<td>A spray-drying process is used in combination with a downstream dryer, e.g. fluidised bed dryer.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 5.4.2]

17.4.2 Waste

BAT 24. In order to reduce the quantity of waste sent for disposal, BAT is to use one or a combination of the techniques given below.
### Techniques related to the use of centrifuges

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Optimised operation of centrifuges</td>
<td>Operation of centrifuges according to their specifications to minimise the discharge of product as waste.</td>
</tr>
</tbody>
</table>

### Techniques related to butter production

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>Rinsing of the cream heater with skimmed milk or water</td>
<td>Rinsing of the cream heater with skimmed milk or water which is then recovered and reused, before the cleaning.</td>
</tr>
</tbody>
</table>

### Techniques related to ice cream production

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>Continuous freezing of ice cream</td>
<td>Continuous freezing of ice cream using optimised start-up procedures and control loops that reduce the amount of stoppages and waste.</td>
</tr>
</tbody>
</table>

### Techniques related to cheese production

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>Minimisation of the generation of acid whey</td>
<td>Whey is processed as quickly as possible to reduce the formation of lactic acid.</td>
</tr>
<tr>
<td>e</td>
<td>Recovery and use of whey</td>
<td>Whey is recovered (if needed using techniques such as evaporation or membrane filtration) and used, e.g. to produce proteins or mitzithra cheese or as a carbon source in a biogas plant.</td>
</tr>
</tbody>
</table>

---

17.4.3 Emissions to air

**BAT 25.** In order to reduce dust emissions to air from a dryer, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Bag filter</td>
<td>See Section 17.14.2</td>
</tr>
<tr>
<td>b</td>
<td>Cyclone</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>Wet scrubber</td>
<td></td>
</tr>
</tbody>
</table>

**Table 17.11: BAT-associated emission level (BAT-AEL) for dust emissions to air from a dryer**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL ((1)) (average over the sampling period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>mg/Nm(^3)</td>
<td>(&lt; 2–10)</td>
</tr>
</tbody>
</table>

\((1)\) The lower end of the range is typically achieved when using a bag filter.

The associated monitoring is given in BAT 5.

**[This BAT conclusion is based on information given in Section 5.4.6.1]**
17.5 BAT conclusions for ethanol production

Unless otherwise stated, the BAT conclusion presented in this section is generally applicable to ethanol production. It applies in addition to the general BAT conclusions given in Section 1.1.

17.5.1 Waste

BAT 26. In order to reduce the quantity of waste sent for disposal, BAT is to use one or both of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Recovery and (re)use of yeast after fermentation</td>
<td>See BAT 21a</td>
</tr>
<tr>
<td>b</td>
<td>Recovery and reuse of natural filter material</td>
<td>See BAT 21b</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 6.4.2]
17.6 BAT conclusions for fish and shellfish processing

Unless otherwise stated, the BAT conclusions presented in this section are generally applicable to fish and shellfish processing. They apply in addition to the general BAT conclusions given in Section 1.1.

17.6.1 Water consumption

BAT 27. In order to reduce water consumption and the volume of waste water discharged, BAT is to use one or both of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Removal of fat and viscera by vacuum</td>
<td>Using a vacuum, fat and viscera are removed from the fish.</td>
</tr>
<tr>
<td>b</td>
<td>Dry transport of fat, viscera, skin and fillets</td>
<td>Use of conveyors or a vacuum instead of using transport water.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 7.4.2]

17.6.2 Emissions to air

BAT 28. In order to reduce emissions of organic compounds to air from a smoke kiln, BAT is to use one of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Biofilter</td>
<td>See Section 17.14.2</td>
</tr>
<tr>
<td>b</td>
<td>Thermal oxidation</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>Non-thermal plasma treatment</td>
<td></td>
</tr>
</tbody>
</table>

Table 17.12: BAT-associated emission level (BAT-AEL) for TVOC emissions to air from a smoke kiln

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL (average over the sampling period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVOC</td>
<td>mg/Nm$^3$</td>
<td>1.2–10</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.

[This BAT conclusion is based on information given in Section 7.4.4]
17.7 BAT conclusions for fruit and vegetables

Unless otherwise stated, the BAT conclusion presented in this section is generally applicable to fruit and vegetables. It applies in addition to the general BAT conclusions given in Section 1.1.

17.7.1 Energy efficiency

BAT 29. In order to increase energy efficiency, BAT is to cool fruits and vegetables before deep freezing.

Description
The temperature of the fruit and vegetables is lowered to around 4 °C before they enter the freezing tunnel by bringing them into contact with cold water. Water is removed from the food and then collected for reuse in the cooling process.

[This BAT conclusion is based on information given in Section 8.4.1]
17.8 BAT conclusions for grain milling

Unless otherwise stated, the BAT conclusion presented in this section is generally applicable to grain milling. It applies in addition to the general BAT conclusions given in Section 1.1.

17.8.1 Emissions to air

BAT 30. In order to reduce dust emissions to air from grain milling, BAT is to use a bag filter.

Description
See Section 17.14.2.

Table 17.13: BAT-associated emission level (BAT-AEL) for dust emissions to air from grain milling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL (average over the sampling period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>mg/Nm³</td>
<td>&lt; 2–5</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.

[This BAT conclusion is based on information given in Section 9.4.1.1]
17.9  BAT conclusions for meat processing

Unless otherwise stated, the BAT conclusions presented in this section are generally applicable to meat processing. They apply in addition to the general BAT conclusions given in Section 1.1.

17.9.1 Water consumption

BAT 31. In order to reduce water consumption and the volume of waste water discharged in ground frozen meat processing, BAT is to use a suitable mixture of chilled and frozen raw materials.

Description

By using a suitable mixture of chilled and frozen raw materials, the production and use of flake ice is avoided.

[This BAT conclusion is based on information given in Section 10.4.2]

17.9.2 Emissions to air

BAT 32. In order to reduce emissions of organic compounds to air from a smoke kiln, BAT is to use one of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Adsorption</td>
<td>See Section 17.14.2</td>
</tr>
<tr>
<td>b</td>
<td>Thermal oxidation</td>
<td></td>
</tr>
</tbody>
</table>

Table 17.14: BAT-associated emission level (BAT-AEL) for TVOC emissions to air from a smoke kiln

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL (average over the sampling period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVOC</td>
<td>mg/Nm³</td>
<td>1.2–10</td>
</tr>
</tbody>
</table>
17.10 BAT conclusions for oilseed processing and vegetable oil refining

Unless otherwise stated, the BAT conclusions presented in this section are generally applicable to oilseed processing and vegetable oil refining. They apply in addition to the general BAT conclusions given in Section 1.1.

17.10.1 Energy efficiency

BAT 33. In order to increase energy efficiency, BAT is to use pumps for generating an auxiliary vacuum.

Description
The auxiliary vacuum used for oil drying, oil degassing or minimisation of oil oxidation is generated by pumps (e.g. water ring pumps). The vacuum reduces the amount of thermal energy needed for these process steps.

[This BAT conclusion is based on information given in Section 11.4.1]

17.10.2 Emissions to air

BAT 34. In order to reduce dust emissions to air from seed processing, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Bag filter</td>
<td>See Section 17.14.2</td>
</tr>
<tr>
<td>b</td>
<td>Cyclone</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>Wet scrubber</td>
<td></td>
</tr>
</tbody>
</table>

Table 17.15: BAT-associated emission level (BAT-AEL) for dust emissions to air from seed processing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL (average over the sampling period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>mg/Nm³</td>
<td>&lt; 2–5</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.

[This BAT conclusion is based on information given in Section 11.4.2.1]

BAT 35. In order to reduce dust emissions to air from the drying and cooling of meal, BAT is to use a cyclone.

Description
See Section 17.14.2.
BAT Conclusions

Table 17.16: BAT-associated emission level (BAT-AEL) for dust emissions to air from the drying and cooling of meal

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL (average over the sampling period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>mg/Nm³</td>
<td>&lt; 2–5</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.

[This BAT conclusion is based on information given in Section 11.4.2.2]

BAT 36. In order to reduce the consumption of hexane and to reduce the hexane load sent to further treatment from oilseed processing and refining, BAT is to use a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Countercurrent flow of meal and steam in the desolventiser-toaster</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>b</td>
<td>Evaporation of oil/hexane mixture</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>Condensation in combination with a mineral oil wet scrubber</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>Gravitational phase separation in combination with distillation</td>
<td></td>
</tr>
</tbody>
</table>

Table 17.17: BAT-associated performance level (BAT-AEPL) for hexane consumption from oilseed processing and refining

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEPL (Yearly average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hexane consumption</td>
<td>kg hexane/tonne of crushed seeds or beans</td>
<td>0.19–0.78</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 11.4.2.4]

BAT 37. In order to reduce emissions of organic compounds to air from oilseed processing and vegetable oil refining, BAT is to use one or a combination of the techniques given below.
<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a Wet scrubber</td>
<td>Followed by condensation. See Section 17.14.2. This technique is usually used for the waste gas from the deodoriser.</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>b Biofilter</td>
<td>See Section 17.14.2</td>
<td></td>
</tr>
<tr>
<td>c Bioscrubber</td>
<td>See Section 17.14.2</td>
<td></td>
</tr>
<tr>
<td>d Thermal oxidation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 17.18: BAT-associated emission level (BAT-AEL) for TVOC emissions to air from oilseed processing and vegetable oil refining

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL (average over the sampling period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVOC</td>
<td>mg/Nm$^3$</td>
<td>2.95</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.

[This BAT conclusion is based on information given in Section 11.4.2.3]
17.11 BAT conclusions for soft drinks and nectar/juice made from processed fruit and vegetables

Unless otherwise stated, the BAT conclusion presented in this section is generally applicable to soft drinks and nectar/juice made from processed fruit and vegetables. It applies in addition to the general BAT conclusions given in Section 1.1.

17.11.1 Energy efficiency

BAT 38. In order to increase energy efficiency, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Single pasteuriser for beverages with pulp</td>
<td>Use of one pasteuriser for both the juice and the pulp instead of using two separate pasteurisers.</td>
</tr>
<tr>
<td>b</td>
<td>Hydraulic sugar transportation</td>
<td>Sugar is transported to the production process with water. As some of the sugar is already dissolved during the transportation, less energy is needed in the process for dissolving sugar.</td>
</tr>
<tr>
<td>c</td>
<td>Energy-efficient homogeniser</td>
<td>See BAT 23b</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 13.4.1]
17.12 BAT conclusions for starch production

Unless otherwise stated, the BAT conclusion presented in this section is generally applicable to starch production. It applies in addition to the general BAT conclusions given in Section 1.1.

17.12.1 Emissions to air

BAT 39. In order to reduce dust emissions to air from a starch, protein or fibre dryer, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Bag filter</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>b</td>
<td>Cyclone</td>
<td>See Section 17.14.2</td>
</tr>
<tr>
<td>c</td>
<td>Wet scrubber</td>
<td>Generally applicable</td>
</tr>
</tbody>
</table>

Table 17.19: BAT-associated emission level (BAT-AEL) for dust emissions to air from a starch, protein or fibre dryer

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL (average over the sampling period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>mg/Nm³</td>
<td>&lt; 2–10</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.

[This BAT conclusion is based on information given in Section 14.4.4.1]
17.13 BAT conclusions for sugar manufacturing

Unless otherwise stated, the BAT conclusions presented in this section are generally applicable to sugar manufacturing. They apply in addition to the general BAT conclusions given in Section 1.1.

17.13.1 Energy efficiency

BAT 40. In order to increase the energy efficiency of beet pulp processing and to reduce the quantity of waste sent for disposal, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Pressing of beet pulp</td>
<td>The beet pulp is pressed to a dry matter content of typically 25–32%. Generally applicable</td>
</tr>
<tr>
<td>b</td>
<td>Indirect drying (steam drying) of beet pulp</td>
<td>Drying of beet pulp by the use of superheated steam.</td>
</tr>
<tr>
<td>c</td>
<td>Direct drying of beet pulp</td>
<td>A drying gas, e.g. air or waste gas, is put in direct contact with the pulp (i.e. high-temperature drying, two-stage drying). Not applicable for new plants due to the relatively high energy consumption.</td>
</tr>
<tr>
<td>d</td>
<td>Solar drying of beet pulp</td>
<td>Use of the solar energy to dry the beet pulp. Applicability may be restricted due to space availability and local climatic conditions.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 15.4.1]

17.13.2 Waste

BAT 41. In order to reduce the quantity of waste sent for disposal, BAT is to recover and reuse the filter cake in sugar refining.

Description
Filtered residue is reused, replacing calcium oxide in sugar refining.

[This BAT conclusion is based on information given in Section 15.4.3]

17.13.3 Emissions to air

BAT 42. In order to reduce dust emissions to air from a beet pulp dryer, BAT is to use one or a combination of the techniques given below.
### BAT Conclusions

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Fuel choice</td>
<td>See Section 17.14.2</td>
</tr>
<tr>
<td>b</td>
<td>Cyclone</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>c</td>
<td>Wet scrubber</td>
<td></td>
</tr>
</tbody>
</table>

#### Table 17.20: BAT-associated emission level (BAT-AEL) for dust emissions to air from a beet pulp dryer

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL (1) (average over the sampling period)</th>
<th>Reference oxygen level (O_R)</th>
<th>Reference gas condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>mg/Nm(^3)</td>
<td>10–75</td>
<td>16 vol-%</td>
<td>No correction for water content</td>
</tr>
</tbody>
</table>

(1) The lower end of the range is typically achieved with the combustion of natural gas.

The associated monitoring is given in BAT 5.

*This BAT conclusion is based on information given in Section 15.4.4.1*

#### BAT 43. In order to reduce SO\(_X\) emissions to air from a beet pulp dryer, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Fuel choice</td>
<td>See Section 17.14.2</td>
</tr>
<tr>
<td>b</td>
<td>Exhaust gas recirculation</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>c</td>
<td>Wet scrubber</td>
<td></td>
</tr>
</tbody>
</table>

#### Table 17.21: BAT-associated emission level (BAT-AEL) for SO\(_X\) emissions to air from a beet pulp dryer

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEL (average over the sampling period)</th>
<th>Reference oxygen level (O_R)</th>
<th>Reference gas condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO(_X)</td>
<td>mg/Nm(^3)</td>
<td>10–40</td>
<td>16 vol-%</td>
<td>No correction for water content</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.

*This BAT conclusion is based on information given in Section 15.4.4.4*
**17.14 Description of techniques**

**17.14.1 Waste water treatment**

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated sludge process</td>
<td>The biological oxidation of dissolved organic pollutants with oxygen using the metabolism of microorganisms. In the presence of dissolved oxygen (injected as air or pure oxygen), the organic components are transformed into carbon dioxide, water or other metabolites and biomass (i.e. the activated sludge). The microorganisms are maintained in suspension in the waste water and the whole mixture is mechanically aerated. The activated sludge mixture is sent to a separation facility from where the sludge is recycled to the aeration tank.</td>
</tr>
<tr>
<td>Aerobic lagoon</td>
<td>Shallow earthen basins for the biological treatment of waste water, the content of which is periodically mixed to allow oxygen to enter the liquid through atmospheric diffusion.</td>
</tr>
<tr>
<td>Chemical precipitation</td>
<td>The conversion of dissolved pollutants into insoluble compounds by adding chemical precipitants. The solid precipitates formed are subsequently separated by sedimentation, air flotation, or filtration. Multivalent metal ions (e.g. calcium, aluminium, iron) are used for phosphorus precipitation.</td>
</tr>
<tr>
<td>Coagulation and flocculation</td>
<td>Coagulation and flocculation are used to separate suspended solids from waste water and are often carried out in successive steps. Coagulation is carried out by adding coagulants with charges opposite to those of the suspended solids. Flocculation is carried out by adding polymers, so that collisions of microfloc particles cause them to bond to produce larger flocs.</td>
</tr>
<tr>
<td>Equalisation</td>
<td>Balancing of flows and pollutant loads at the inlet of the waste water treatment by using central tanks. Equalisation may be decentralised or carried out using other management techniques.</td>
</tr>
<tr>
<td>Enhanced biological phosphorus removal</td>
<td>A combination of aerobic and anaerobic treatment to selectively enrich polyphosphate-accumulating microorganisms in the bacterial community within the activated sludge. These microorganisms take up more phosphorus than is required for normal growth.</td>
</tr>
<tr>
<td>Filtration</td>
<td>The separation of solids from waste water by passing them through a porous medium, e.g. sand filtration, microfiltration and ultrafiltration.</td>
</tr>
<tr>
<td>Flotation</td>
<td>The separation of solid or liquid particles from waste water by attaching them to fine gas bubbles, usually air. The buoyant particles accumulate at the water surface and are collected with skimmers.</td>
</tr>
<tr>
<td>Membrane bioreactor</td>
<td>A combination of activated sludge treatment and membrane filtration. Two variants are used: - an external recirculation loop between the activated sludge tank and the membrane module; - immersion of the membrane module into the aerated activated sludge tank, where the effluent is filtered through the hollow fibre membrane, the biomass remaining in the tank (this variant is less energy-consuming and results in more compact plants).</td>
</tr>
<tr>
<td>Neutralisation</td>
<td>The adjustment of the pH of waste water to a neutral level (approximately 7) by the addition of chemicals. Sodium hydroxide (NaOH) or calcium hydroxide (Ca(OH)$_2$) is generally used to increase the pH; whereas, sulphuric acid (H$_2$SO$_4$), hydrochloric acid (HCl) or carbon dioxide (CO$_2$) is generally used to decrease the pH. The precipitation of some substances may occur during neutralisation.</td>
</tr>
</tbody>
</table>
### BAT Conclusions

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrification and denitrification</td>
<td>A two-step process that is typically incorporated into biological waste water treatment plants. The first step is the aerobic nitrification where microorganisms oxidise ammonium ($\text{NH}_4^+$) to the intermediate nitrite ($\text{NO}_2^-$), which is then further oxidised to nitrate ($\text{NO}_3^-$). In the subsequent anoxic denitrification step, microorganisms chemically reduce nitrate to nitrogen gas.</td>
</tr>
<tr>
<td>Phosphorus recovery as struvite</td>
<td>Phosphorus is recovered by chemical precipitation in the form of struvite (magnesium ammonium phosphate).</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>The separation of suspended particles and suspended material by gravitational settling.</td>
</tr>
<tr>
<td>Upflow anaerobic sludge blanket (UASB)</td>
<td>Waste water is introduced at the bottom of the reactor where it flows upward through a sludge blanket composed of biologically formed granules or particles. The waste water phase passes into a settling chamber where the solid content is separated; the gases are collected in domes in the top of the reactor.</td>
</tr>
</tbody>
</table>

### 17.14.2 Treatment of emissions to air

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adsorption</td>
<td>A technique for removing compounds from a waste gas stream by retention on a solid surface (typically activated carbon).</td>
</tr>
<tr>
<td>Bag filter</td>
<td>Bag filters, often referred to as fabric filters, are constructed from porous woven or felted fabric through which gases are passed to remove particles. The use of a bag filter requires the selection of a fabric suitable for the characteristics of the waste gas and the maximum operating temperature.</td>
</tr>
<tr>
<td>Biofilter</td>
<td>The waste gas stream is passed through a bed of organic material (such as peat, heather, compost, root, tree bark, compost, softwood and different kinds of combinations) or some inert material (such as clay, activated carbon, and polyurethane), where it is biologically oxidised by naturally occurring microorganisms into carbon dioxide, water, other metabolites and biomass.</td>
</tr>
<tr>
<td>Bioscrubber</td>
<td>A packed tower filter with inert packing material which is normally continuously moistened by sprinkling water. Air pollutants are absorbed in the liquid phase and subsequently degraded by microorganisms settling on the filter elements.</td>
</tr>
<tr>
<td>Condensation</td>
<td>A technique for removing the vapours of organic and inorganic compounds from a waste gas stream by reducing its temperature below its dew point so that the vapours liquefy.</td>
</tr>
<tr>
<td>Cyclone</td>
<td>Dust control system based on centrifugal force, whereby particles are separated from the carrier gas.</td>
</tr>
<tr>
<td>Electrostatic precipitator (ESP)</td>
<td>Electrostatic precipitators operate such that particles are charged and separated under the influence of an electrical field. Electrostatic precipitators are capable of operating under a wide range of conditions. In a dry ESP, the collected material is mechanically removed (e.g. by shaking, vibration, compressed air), while in a wet ESP it is flushed with a suitable liquid, usually water.</td>
</tr>
<tr>
<td>Exhaust gas recirculation</td>
<td>Recirculation of (part of) the waste gas to a combustion chamber to replace part of the fresh combustion air.</td>
</tr>
<tr>
<td>Fuel choice</td>
<td>Switching from the combustion of one fuel to a less harmful one in terms of emissions (low sulphur, low ash content or better ash quality).</td>
</tr>
<tr>
<td>Non-thermal plasma treatment</td>
<td>Abatement technique based on creating a plasma (i.e. an ionised gas consisting of positive ions and free electrons in proportions resulting in more or less no overall electric charge) in the waste gases in which organic and inorganic compounds are oxidised.</td>
</tr>
<tr>
<td>BAT Conclusions</td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>Thermal oxidation</td>
<td>The oxidation of combustible gases and odorants in a waste gas stream by heating the mixture of contaminants with air or oxygen to above its auto-ignition point in a combustion chamber and maintaining it at a high temperature long enough to complete its combustion to carbon dioxide and water.</td>
</tr>
<tr>
<td>Wet scrubber</td>
<td>Gaseous compounds are dissolved in a scrubbing solution (e.g. an alkaline solution containing lime, NaOH, or H2O2). Downstream of the wet scrubber, the off-gases are saturated with water and a separation of the droplets is carried out before discharging the off-gases. The resulting liquid is further treated by a waste water process and the insoluble matter is collected by sedimentation or filtration.</td>
</tr>
</tbody>
</table>
18 CONCLUDING REMARKS

This chapter will be updated at a later stage

Timing of the review process
[Author: summarise the main milestones of the review process]

Sources of information and information gaps
[Author: summarise the sources of information and information gaps]

Degree of consensus reached during the information exchange
[Author: add a sentence indicating that [high][very high] degree of consensus was reached within TWG for the whole document]
[Author: if any valid split views have been expressed and accepted, insert the following sentence and table]

Table Z.1 shows the split views expressed by TWG members.

Table Z.1: Split views

<table>
<thead>
<tr>
<th>BAT conclusion</th>
<th>View expressed by</th>
<th>Split view</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Author: insert BAT conclusion No]</td>
<td>[Author: list the organisation/delegations that support the view]</td>
<td>[Author: add description of the split view; add as many lines as necessary]</td>
</tr>
</tbody>
</table>

Consultation of the Forum and subsequent formal adoption procedure of the BAT Conclusions
[Author: insert in this short section (no more than 10 lines) the outcome of adoption procedure indicating any issues that had to be resolved at that stage; please indicate:

- the dates of:
  - Forum meeting during which the opinion on the draft BREF was delivered,
  - IED Article 75 Committee meeting during which vote on draft Commission Implementing Decision was held,
  - formal adoption by the Commission of the BAT Conclusions;
- the main outcome of the Forum and Committee in terms of resolved issues, but without specifications, nor positions of individual members.]

Recommendations for future work
[Author: insert here the Recommendations for future work]

Suggested topics for future R&D work
The Commission is launching and supporting, through its Research and Technological Development programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially, these projects could provide a useful contribution to future BREF reviews. Readers are therefore invited to inform the European IPPC Bureau of any research results which are relevant to the scope of this document (see also the fifth section of the Preface of this document.)
## 19 ANNEXES

### 19.1 ANNEX I - Reference installations that participated in the FDM data collection

Table 19.1: List of reference installations that participated in the FDM data collection

<table>
<thead>
<tr>
<th>Installation code</th>
<th>Installation name</th>
<th>Company name</th>
<th>Member state</th>
<th>Town</th>
<th>Main FDM sector</th>
<th>Raw materials</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>#001</td>
<td>Mars Austria, Bruck/Leitha</td>
<td>Mars Austria OG</td>
<td>Austria</td>
<td>2460 Bruck an der Leitha</td>
<td>Animal feed</td>
<td>Frozen meat</td>
<td>Pet food</td>
</tr>
<tr>
<td>#002</td>
<td>Stieglbrauere zu Salzburg</td>
<td>Stieglbrauerei zu Salzburg GmbH</td>
<td>Austria</td>
<td>5017 Salzburg</td>
<td>Brewing</td>
<td>Water, malt, hop and yeast</td>
<td>Beer (bottles, cans and barrels)</td>
</tr>
<tr>
<td>#003</td>
<td>Berglandmilch Wörgl</td>
<td>Berglandmilch reg.Gen.m.b.H.</td>
<td>Austria</td>
<td>6300 Wörgl</td>
<td>Dairy</td>
<td>Milk, whey, sugar, fruit preparations</td>
<td>Drinking milk, several drinks, cheese, butter</td>
</tr>
<tr>
<td>#004</td>
<td>Berglandmilch Aschbach-Markt</td>
<td>Berglandmilch reg.Gen.m.b.H.</td>
<td>Austria</td>
<td>3361 Aschbach-Markt</td>
<td>Dairy</td>
<td>Milk, cream, sugar, fruit preparations, protein powder</td>
<td>Drinking milk, sour milk drinks, yoghurt, cream, fruit yoghurt, desserts, mixed milk beverages, cheese</td>
</tr>
<tr>
<td>#005</td>
<td>Kärntnermilch, Spittal/Drau</td>
<td>Kärntnermilch reg GenmbH</td>
<td>Austria</td>
<td>9800 Spittal/Drau</td>
<td>Dairy</td>
<td>Mainly milk</td>
<td>Drinking milk, sour milk drinks, yogurt, fruit yoghurt, whey drinks, butter and different types of semi-soft and hard cheese</td>
</tr>
<tr>
<td>#006</td>
<td>Gmundner Molkerei, Gmunden</td>
<td>Gmundner Molkerei reg.Gen.m.b.H.</td>
<td>Austria</td>
<td>4810 Gmunden</td>
<td>Dairy</td>
<td>Mainly milk</td>
<td>Milk, long-lasting milk, sour cream, butter, yoghurt and cheese, etc.</td>
</tr>
<tr>
<td>#007</td>
<td>Rauch, Nüziders</td>
<td>Rauch Fruchtsäfte GmbH &amp; Co</td>
<td>Austria</td>
<td>6714 Nüziders</td>
<td>Soft drinks and juice made from concentrate</td>
<td>Water (Nüziders is a pure filling site), fruit juice concentrate</td>
<td>Fruit and other soft drinks</td>
</tr>
<tr>
<td>#008</td>
<td>Spitz, Attnang-Puchheim</td>
<td>S.Spitz GmbH</td>
<td>Austria</td>
<td>4800 Attnang-Puchheim</td>
<td>Soft drinks and juice made from concentrate</td>
<td>Water, fruit concentrates and mixtures, sugar, four, cacao,</td>
<td>Water and soft drinks waffles, cake, roulades and toast mustard, ketchup, jam and</td>
</tr>
<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
<td>Main FDM sector</td>
<td>Raw materials</td>
<td>Products</td>
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<tr>
<td>#009</td>
<td>Betriebsstätte Tann, Föderlach</td>
<td>Spar Österreichische Warenhandels AG</td>
<td>Austria</td>
<td>9241 Föderlach</td>
<td>Meat processing</td>
<td>Meat (pork, beef and veal)</td>
<td>Packaging of fresh meat. Production of sausages, smoked meat, ham, bacon and meat paste.</td>
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<tr>
<td>#010</td>
<td>Agrana Stärke Aschach</td>
<td>Agrana Stärke GmbH</td>
<td>Austria</td>
<td>4082 Aschach a.d.D.</td>
<td>Starch production</td>
<td>Maize</td>
<td>Starch, glucose syrups, derivatives</td>
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<tr>
<td>#011</td>
<td>Agrana Stärke Gmünd</td>
<td>Agrana Stärke GmbH</td>
<td>Austria</td>
<td>3950 Gmünd</td>
<td>Starch production</td>
<td>Potato and maize</td>
<td>Starch, modified starch, maltodextrins, syrup, long-life potato products, baby food</td>
</tr>
<tr>
<td>#012</td>
<td>Agrana Stärke Pischelsdorf</td>
<td>Agrana Stärke GmbH</td>
<td>Austria</td>
<td>3435 Pischelsdorf</td>
<td>Starch production</td>
<td>Wheat</td>
<td>Starch, gluten, wheat bran</td>
</tr>
<tr>
<td></td>
<td>Agrana Bioethanol Pischelsdorf</td>
<td>Agrana Stärke GmbH</td>
<td>Austria</td>
<td>3435 Pischelsdorf</td>
<td>Starch production</td>
<td>Wheat and maize</td>
<td>Bio-ethanol, animal feed</td>
</tr>
<tr>
<td>#014</td>
<td>Agrana Zucker Tulln</td>
<td>Agrana Zucker GmbH</td>
<td>Austria</td>
<td>3430 Tulln</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
<td>Sugar and animal feed</td>
</tr>
<tr>
<td>#015</td>
<td>Agrana Zucker Leopoldsdorf</td>
<td>Agrana Zucker GmbH</td>
<td>Austria</td>
<td>2285 Leopoldsdorf im Marchfeld</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
<td>Sugar and animal feed</td>
</tr>
<tr>
<td>#016</td>
<td>Bunge, Bruck an der Leitha</td>
<td>Bunge Austria GmbH</td>
<td>Austria</td>
<td>2460 Bruck an der Leitha</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Sunflower seed, rapeseed</td>
<td>Oil for human consumption and for technical purposes</td>
</tr>
<tr>
<td>#017</td>
<td>FrieslandCampina Professional</td>
<td>Frieslandcampina Professional NV</td>
<td>Belgium</td>
<td>Lummen</td>
<td>Dairy</td>
<td>Milk and others</td>
<td>Mix of dairy, bakery products, confectionery</td>
</tr>
<tr>
<td>#018</td>
<td>Belgomilk</td>
<td>Belgomilk cvba</td>
<td>Belgium</td>
<td>Beveren</td>
<td>Dairy</td>
<td>Milk, whey protein concentrate and vegetable oils</td>
<td>Milk, cream and milk powder</td>
</tr>
<tr>
<td>#019</td>
<td>Friesland Campina Belgium</td>
<td>Frieslandcampina Belgium NV</td>
<td>Belgium</td>
<td>Aalter</td>
<td>Dairy</td>
<td>Milk and others</td>
<td>Milk, drinks, chocolate and cream in bricks, multilayer PEflessen and cups, concentrated</td>
</tr>
<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
<td>Main FDM sector</td>
<td>Raw materials</td>
<td>Products</td>
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<td>#022</td>
<td>Danone Hombourg Recolte</td>
<td>Danone Hombourg Recolte NV</td>
<td>Belgium</td>
<td>Rotselaar</td>
<td>Dairy</td>
<td>Milk</td>
<td>Skimmed milk and cream</td>
</tr>
<tr>
<td>#024</td>
<td>Belgomilk</td>
<td>Milcobel cvba</td>
<td>Belgium</td>
<td>Moorslede</td>
<td>Dairy</td>
<td>Milk</td>
<td>Cheese</td>
</tr>
<tr>
<td>#025</td>
<td>Belgomilk</td>
<td>Milcobel cvba</td>
<td>Belgium</td>
<td>Schoten</td>
<td>Dairy</td>
<td>Milk</td>
<td>Drink milk, specialty products</td>
</tr>
<tr>
<td>#027</td>
<td>Tiense SuikerraFFinaderij</td>
<td>Tiense SuikerraFFinaderij NV</td>
<td>Belgium</td>
<td>Tienen</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
<td>Sugar</td>
</tr>
<tr>
<td>#029</td>
<td>Noliko</td>
<td>Scana Noliko nv</td>
<td>Belgium</td>
<td>Bree</td>
<td>Fruit and vegetables</td>
<td>Fruit and vegetables</td>
<td></td>
</tr>
<tr>
<td>#030</td>
<td>Ardo/Ardo E. Haspeslagh</td>
<td>Ardo/Ardo E. Haspeslagh</td>
<td>Belgium</td>
<td>Ardooie</td>
<td>Fruit and vegetables</td>
<td>Vegetables</td>
<td>Processed vegetables (frozen)</td>
</tr>
<tr>
<td>#031</td>
<td>Clarebout Potatoes</td>
<td>NV Clarebout Potatoes</td>
<td>Belgium</td>
<td>Heuvelland</td>
<td>Fruit and vegetables</td>
<td>Potatoes</td>
<td>Potato products</td>
</tr>
<tr>
<td>#032</td>
<td>d'Arta</td>
<td>N.V./N.V. D'Arta / D'Arta Menu</td>
<td>Belgium</td>
<td>Ardooie</td>
<td>Fruit and vegetables</td>
<td>Vegetables</td>
<td>Processed vegetables</td>
</tr>
<tr>
<td>#035</td>
<td>Unifrost</td>
<td>N.V. Unifrost</td>
<td>Belgium</td>
<td>Ardooie</td>
<td>Fruit and vegetables</td>
<td>Vegetables and potatoes</td>
<td>Processed vegetables and potatoes (frozen)</td>
</tr>
<tr>
<td>#036</td>
<td>Pluma</td>
<td>NV Pluma</td>
<td>Belgium</td>
<td>Wommelgem</td>
<td>Meat processing</td>
<td>Meat</td>
<td></td>
</tr>
<tr>
<td>#038</td>
<td>Forfarmers Belgium</td>
<td>B.V.B.A. for farmers Belgium</td>
<td>Belgium</td>
<td>Izegem</td>
<td>Animal feed</td>
<td>Animal (1–20 %) and vegetable raw materials (80–99 %)</td>
<td>Dry animal feed for pigs and broilers</td>
</tr>
<tr>
<td>#039</td>
<td>Degrave Voeders</td>
<td>N.V. Degrave Voeders</td>
<td>Belgium</td>
<td>Staden</td>
<td>Animal feed</td>
<td>Vegetable raw materials (milling and feed factory)</td>
<td>Animal feed for pigs (99 %) and cattle (1 %)</td>
</tr>
<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
<td>Main FDM sector</td>
<td>Raw materials</td>
<td>Products</td>
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</tr>
<tr>
<td>#041</td>
<td>Vanden Avenne-Ooigem</td>
<td>NV Vanden Avenne-Ooigem</td>
<td>Belgium</td>
<td>Wielsbeke</td>
<td>Animal feed</td>
<td>Animal (2 %) and vegetable (98 %) raw materials (milling and feed processing)</td>
<td>Animal feed (pigs, poultry and others)</td>
</tr>
<tr>
<td>#042</td>
<td>Aveve veevoeders</td>
<td>N.V. Aveve</td>
<td>Belgium</td>
<td>Merksem</td>
<td>Animal feed</td>
<td>Animal (&lt;1 % animal fat) and vegetable (&gt;99 %) raw materials</td>
<td>Animal feed (pigs, poultry, cattle and others) in bulk (80 %) and bags (20 %)</td>
</tr>
<tr>
<td>#043</td>
<td>Agrifirm</td>
<td>Agrifirm Belgium N.V.</td>
<td>Belgium</td>
<td>Grobbendonk</td>
<td>Animal feed</td>
<td>Animal (1.4 %) and vegetable raw materials</td>
<td>Animal feed (layers and pigs)</td>
</tr>
<tr>
<td>#044</td>
<td>Cargill</td>
<td>NV Cargill</td>
<td>Belgium</td>
<td>Antwerpen</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Crush and refinery rapeseed</td>
<td>Meal, crude and refined oil</td>
</tr>
<tr>
<td>#045</td>
<td>Cargill</td>
<td>NV Cargill</td>
<td>Belgium</td>
<td>Izegem</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Multoil refinery and bottling</td>
<td>Refined oils and fats, bottled oil</td>
</tr>
<tr>
<td>#046</td>
<td>Fuji Oil Europe</td>
<td>Fuji Oil Europe</td>
<td>Belgium</td>
<td>Gent</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Edible Oils</td>
<td>Palm oil, Palm kernel, coconut, shea and others</td>
</tr>
<tr>
<td>#047</td>
<td>Alken-Maes</td>
<td>NV Brouwerijen Alken-Maes</td>
<td>Belgium</td>
<td>Alken</td>
<td>Brewing</td>
<td>Malted barley, unmalted wheat, barley, maize grits and sugar syrup</td>
<td>Beer in bottles and barrels</td>
</tr>
<tr>
<td>#048</td>
<td>Brouwerij Haacht</td>
<td>Brouwerij Haacht NV</td>
<td>Belgium</td>
<td>Boortmeerbeek</td>
<td>Brewing</td>
<td>Malt, corn, grains</td>
<td>Beer, drinks in bottles and barrels (different beer styles and sizes of batches)</td>
</tr>
<tr>
<td>#051</td>
<td>Konings</td>
<td>NV Konings</td>
<td>Belgium</td>
<td>Zonhoven</td>
<td>Soft drinks and juice made from concentrate</td>
<td>Fruit (apples and pears)</td>
<td>Fruit juices, concentrates</td>
</tr>
<tr>
<td>#056</td>
<td>frischli Milchwerk plant</td>
<td>frischli Milchwerke GmbH</td>
<td>Germany</td>
<td>Rehburg-Lochem</td>
<td>Dairy</td>
<td>Skimmed milk or concentrate of</td>
<td>Spray dried skimmed milk powder</td>
</tr>
<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
<td>Main FDM sector</td>
<td>Raw materials</td>
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<td>#057</td>
<td>Thalfang</td>
<td>Hochwald Foods GmbH</td>
<td>Germany</td>
<td>Thalfang</td>
<td>Dairy</td>
<td>Raw milk</td>
<td>Butter, skimmed milk powder, condensed milk</td>
</tr>
<tr>
<td>#058</td>
<td>Hünfeld</td>
<td>Hochwald Foods GmbH</td>
<td>Germany</td>
<td>Hünfeld</td>
<td>Dairy</td>
<td>Raw milk</td>
<td>Mozzarella cheese, whey concentrate, permeate concentrate, demineralised whey concentrate and powder</td>
</tr>
<tr>
<td>#059</td>
<td>Heilbronn</td>
<td>FrieslandCampina Germany GmbH</td>
<td>Germany</td>
<td>Heilbronn</td>
<td>Dairy</td>
<td>Raw milk</td>
<td>Yoghurt, dessert</td>
</tr>
<tr>
<td>#061</td>
<td>DMK Nordhackstedt</td>
<td>DMK GmbH</td>
<td>Germany</td>
<td>Zeven</td>
<td>Dairy</td>
<td>Raw milk</td>
<td>Cheese production: mozzarella, gouda, edam</td>
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<tr>
<td>#062</td>
<td>wheyco Altentreptow</td>
<td>wheyco GmbH</td>
<td>Germany</td>
<td>Hamburg</td>
<td>Dairy</td>
<td>Whey</td>
<td>Lactose/whey protein concentrate production: WPC 35, 60, 80, lactose, whey powder, protein powder</td>
</tr>
<tr>
<td>#063</td>
<td>Lauben</td>
<td>Käserei Champignon Hofmeister GmbH &amp; Co. KG</td>
<td>Germany</td>
<td>Lauben</td>
<td>Dairy</td>
<td>Raw milk and whey powder</td>
<td>Soft cheese</td>
</tr>
<tr>
<td>#064</td>
<td>Upahl</td>
<td>Arla Foods Deutschland GmbH</td>
<td>Germany</td>
<td>Upahl</td>
<td>Dairy</td>
<td>Raw milk</td>
<td>Skimmed milk powder, yogurt, UHT-milk, pasteurised milk, quark, evaporated milk, whipped cream, crème fraîche, sour cream, buttermilk</td>
</tr>
<tr>
<td>#065</td>
<td>Karstädt</td>
<td>Arla Foods Deutschland GmbH</td>
<td>Germany</td>
<td>Karstädt</td>
<td>Dairy</td>
<td>Raw milk</td>
<td>Skimmed milk powder</td>
</tr>
<tr>
<td>#066</td>
<td>Pronsfeld</td>
<td>Arla Foods Deutschland GmbH</td>
<td>Germany</td>
<td>Pronsfeld</td>
<td>Dairy</td>
<td>Raw milk</td>
<td>Skimmed milk powder, UHT-milk, pasteurised milk, evaporated milk,</td>
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<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
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<td>#068</td>
<td>Neu-Ulm</td>
<td>Milchwerke Schwaben</td>
<td>Germany</td>
<td>Neu-Ulm</td>
<td>Dairy</td>
<td>NI</td>
<td>whipped cream, crème fraiche, sour cream, butter</td>
</tr>
<tr>
<td>#072</td>
<td>Augustiner-Bräu Wagner KG</td>
<td>NI</td>
<td>Germany</td>
<td>München</td>
<td>Brewing</td>
<td>NI</td>
<td>NI</td>
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<td>#073</td>
<td>Paulaner Brauerei GmbH &amp; Co. KG</td>
<td>NI</td>
<td>Germany</td>
<td>München</td>
<td>Brewing</td>
<td>NI</td>
<td>NI</td>
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<td>Betriebstätte 1</td>
<td>Kulmbacher Brauerei AG</td>
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<td>Kulmbach</td>
<td>Brewing</td>
<td>NI</td>
<td>NI</td>
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<td>#075</td>
<td>Anheuser-Busch InBev Germany Holding GmbH Brauerei Beck &amp; Co.</td>
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<td>Bremen</td>
<td>Brewing</td>
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<tr>
<td>#076</td>
<td>Bitburger Brauerei Th. Simon GmbH</td>
<td>NI</td>
<td>Germany</td>
<td>Bitburg</td>
<td>Brewing</td>
<td>NI</td>
<td>NI</td>
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<tr>
<td>#077</td>
<td>Badische Staatsbrauerei Rothaus AG</td>
<td>NI</td>
<td>Germany</td>
<td>Grafenhausen-Rothaus</td>
<td>Brewing</td>
<td>NI</td>
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<tr>
<td>#078</td>
<td>König-Brauerei GmbH</td>
<td>NI</td>
<td>Germany</td>
<td>Duisburg</td>
<td>Brewing</td>
<td>NI</td>
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<td>#079</td>
<td>Brauerei C. &amp; A. Veltins GmbH &amp; Co. KG</td>
<td>NI</td>
<td>Germany</td>
<td>Meschede</td>
<td>Brewing</td>
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<td>#080</td>
<td>Krombacher Brauerei Bernhard Schadeberg GmbH &amp; Co KG</td>
<td>Germany</td>
<td>Kreuztal-Krombach</td>
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<td>#081</td>
<td>Karlsberg Brauerei GmbH</td>
<td>NI</td>
<td>Germany</td>
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<td>Brewing</td>
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<td>#082</td>
<td>Mecklenburgische Brauerei Lübz GmbH</td>
<td>NI</td>
<td>Germany</td>
<td>Lübz</td>
<td>Brewing</td>
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<td>#084</td>
<td>Holsten Brauerei AG</td>
<td>Holsten Brauerei AG</td>
<td>Germany</td>
<td>Hamburg</td>
<td>Brewing</td>
<td>NI</td>
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<td>#085</td>
<td>Werk Sünching</td>
<td>Südstärke GmbH</td>
<td>Germany</td>
<td>Sünching</td>
<td>Starch production</td>
<td>Potatoes</td>
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<td>#086</td>
<td>ADM Hamburg AG, Werk Hamburg</td>
<td>ADM</td>
<td>Germany</td>
<td>Hamburg</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Rapeseed and Soybeans</td>
<td>Rapeseed meal, soybean meal, refined rapeseed oil and refined soybean oil</td>
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<td>#087</td>
<td>ADM Hamburg AG, Werk Noble &amp; Thörll</td>
<td>ADM</td>
<td>Germany</td>
<td>Hamburg</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Crude vegetable oils</td>
<td>Refined, hydrogenated, winterized and interesterified vegetable oils</td>
</tr>
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<td>#088</td>
<td>ADM Soya Mainz</td>
<td>ADM</td>
<td>Germany</td>
<td>Mainz</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Soybeans</td>
<td>Soybean meal and once-refined soybean oil</td>
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<td>#089</td>
<td>ADM Spyck GmbH</td>
<td>ADM</td>
<td>Germany</td>
<td>Spyck</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Rapeseed and sunflower seed</td>
<td>Rapeseed meal, sunflower meal, once-refined rapeseed oil and once-refined sunflower oil</td>
</tr>
<tr>
<td>#090</td>
<td>ADM Spyck GmbH, Werk Straubing</td>
<td>ADM</td>
<td>Germany</td>
<td>Straubing</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Rapeseed</td>
<td>Rapeseed meal and once-refined rapeseed oil</td>
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<tr>
<td>#091</td>
<td>Mannheim</td>
<td>Bunge</td>
<td>Germany</td>
<td>Mannheim</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Rapeseed</td>
<td>Rapeseed meal and Rapeseed refined oil</td>
</tr>
<tr>
<td>#092</td>
<td>Mainz</td>
<td>Carell</td>
<td>Germany</td>
<td>Mainz</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Crush and refinery rapeseed</td>
<td>Meal, crude and refined oil</td>
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<tr>
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<td>Company name</td>
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<td>#093</td>
<td>Riesa</td>
<td>Cargill</td>
<td>Germany</td>
<td>Riesa</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Crush, refinery and bottling rape/sun sunflower</td>
<td>Meal, crude and refined oil, bottled oil</td>
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<td>#094</td>
<td>Salzgitter</td>
<td>Cargill</td>
<td>Germany</td>
<td>Salzgitter</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Crush and refinery</td>
<td>Rapeseed, malt</td>
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<td>#095</td>
<td>Protein- und Oelwerk Neuss GmbH &amp; Co. KG</td>
<td>C. Thywissen GmbH</td>
<td>Germany</td>
<td>Neuss</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Rapeseed, sunflower seed, linseed</td>
<td>Vegetable oils crude, semi-refined, refined, winterized, Oilseed meals, Lecithin</td>
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<td>#096</td>
<td>Wilmar Edible Oils GmbH</td>
<td>Wilmar</td>
<td>Germany</td>
<td>Brake</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Crude palm oil, crude coconut oil, crude palm kernel oil</td>
<td>RPKO/RPO/POL56/POL64/PST</td>
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<tr>
<td>#097</td>
<td>Kaufland Fleischwerk Handelshof GmbH</td>
<td>NI</td>
<td>Germany</td>
<td>Haibronn</td>
<td>Meat processing</td>
<td>NI</td>
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<td>#098</td>
<td>Bauerngut</td>
<td>NI</td>
<td>Germany</td>
<td>Buckeburg</td>
<td>Meat processing</td>
<td>NI</td>
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<td>#102</td>
<td>Tulip Fleischwaren Oldenburg GmbH</td>
<td>Danish Crown</td>
<td>Germany</td>
<td>Oldenburg</td>
<td>Meat Processing</td>
<td>NI</td>
<td>NI</td>
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<td>#105</td>
<td>Gerolsteiner Brunnen GmbH &amp; Co.</td>
<td>NI</td>
<td>Germany</td>
<td>Gerolstein</td>
<td>Soft drinks and juice made from concentrate</td>
<td>NI</td>
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<td>#108</td>
<td>Könönnen</td>
<td>Pfeier &amp; Langen GmbH &amp; Co. KG</td>
<td>Germany</td>
<td>Könönnen</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
<td>Sugar</td>
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<tr>
<td>#109</td>
<td>Offenau</td>
<td>Südzucker AG</td>
<td>Germany</td>
<td>Offenau</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
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<td>#111</td>
<td>Nordstemmen</td>
<td>Nordzucker AG</td>
<td>Germany</td>
<td>Nordstemmen</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
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<td>Rain</td>
<td>Südzucker AG</td>
<td>Germany</td>
<td>Rain</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
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<td>#113</td>
<td>Klein Wanzleben</td>
<td>Nordzucker AG</td>
<td>Germany</td>
<td>Klein Wanzleben</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
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<tr>
<td>#114</td>
<td>Zeitz</td>
<td>CropEnergies AG (Südzucker Group)</td>
<td>Germany</td>
<td>Zeitz</td>
<td>Ethanol production</td>
<td>Cereals, sugar beet, syrups</td>
<td>Ethanol and feed (DDGS)</td>
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<td>#115</td>
<td>Werk Aldrup</td>
<td>Agrarfrost GmbH &amp; Co. KG</td>
<td>Germany</td>
<td>Wildeshausen</td>
<td>Fruit and vegetables</td>
<td>Potatoes</td>
<td>Potato products, deep frozen; potato flakes</td>
</tr>
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<td>#116</td>
<td>Werk Oschersleben</td>
<td>Agrarfrost GmbH &amp; Co. KG</td>
<td>Germany</td>
<td>Oschersleben</td>
<td>Fruit and vegetables</td>
<td>Potatoes</td>
<td>Potato products, deep frozen; potato crisps</td>
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<tr>
<td>#118</td>
<td>Mars</td>
<td>PetCom Tierernährung GmbH &amp; Co. KG</td>
<td>Germany</td>
<td>Minden</td>
<td>Animal feed</td>
<td>NI</td>
<td>Pet food</td>
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<td>#119</td>
<td>Zweigniederlassung Apolda</td>
<td>Ospelt Petfood Anstalt</td>
<td>Germany</td>
<td>Apolda</td>
<td>Animal feed</td>
<td>NI</td>
<td>Pet food</td>
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<td>#121</td>
<td>Landshuter Kunstmühle C.A. Meyers Nachfolger AG</td>
<td>NI</td>
<td>Germany</td>
<td>Landshut</td>
<td>Grain milling</td>
<td>NI</td>
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<td>#123</td>
<td>Rosenmühle Ergolding</td>
<td>Kampffmeyer Mühlen GmbH</td>
<td>Germany</td>
<td>84030 Ergolding</td>
<td>Grain milling</td>
<td>NI</td>
<td>NI</td>
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<td>#124</td>
<td>Rødkærørsbro Dairy</td>
<td>Arla Foods amba</td>
<td>Denmark</td>
<td>Rødkærørsbro</td>
<td>Dairy</td>
<td>Mainly milk but also cheese, salt and other ingredients</td>
<td>Mozzarella in blocks and shredded e.g. mixed with other kind of cheese</td>
</tr>
<tr>
<td>#125</td>
<td>Taulov Dairy</td>
<td>Arla Foods amba</td>
<td>Denmark</td>
<td>Fredericia</td>
<td>Dairy</td>
<td>Mainly milk but also salt and other ingredients</td>
<td>Different types of yellow cheese</td>
</tr>
<tr>
<td>#126</td>
<td>Nr. Vium Dairy</td>
<td>Arla Foods amba</td>
<td>Denmark</td>
<td>Videbæk</td>
<td>Dairy</td>
<td>Mainly milk but also cheese, salt and other ingredients</td>
<td>Yellow cheese (Havarti), slicing and packaging of cheese</td>
</tr>
<tr>
<td>Installation code</td>
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<td>Company name</td>
<td>Member state</td>
<td>Town</td>
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<td>#127</td>
<td>Holstebro Cream cheese</td>
<td>Arla Foods amba</td>
<td>Denmark</td>
<td>Holstebro</td>
<td>Dairy</td>
<td>Processed milk</td>
<td>Cream cheese plain and mixed with spices</td>
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<tr>
<td>#128</td>
<td>Holstebro Dairy</td>
<td>Arla Foods amba</td>
<td>Denmark</td>
<td>Holstebro</td>
<td>Dairy</td>
<td>Mainly milk, cream, salt, vegetable oil</td>
<td>Butter and spreadable</td>
</tr>
<tr>
<td>#129</td>
<td>Kruså Dairy</td>
<td>Arla Foods amba</td>
<td>Denmark</td>
<td>Kruså</td>
<td>Dairy</td>
<td>Mainly milk, salt and other ingredients</td>
<td>White cheese packed in e.g. in vegetable oil with olive etc.</td>
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<tr>
<td>#130</td>
<td>Danmark Protein Ingredients</td>
<td>Arla Foods amba</td>
<td>Denmark</td>
<td>Videbæk</td>
<td>Dairy</td>
<td>Mainly whey</td>
<td>Whey powder, lactose and other products from whey</td>
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<tr>
<td>#131</td>
<td>Arinco</td>
<td>Arla Foods amba</td>
<td>Denmark</td>
<td>Videbæk</td>
<td>Dairy</td>
<td>Mainly milk</td>
<td>Milk powder, child nutrition</td>
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<tr>
<td>#132</td>
<td>Esbjerg Dairy</td>
<td>Arla Foods amba</td>
<td>Denmark</td>
<td>Esbjerg</td>
<td>Dairy</td>
<td>Mainly milk and also many different ingredients</td>
<td>Cocoa beverages, soups and other products based on animal and vegetable raw materials, UHT and ESL</td>
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<tr>
<td>#133</td>
<td>Slagelse Dairy</td>
<td>Arla Foods amba</td>
<td>Denmark</td>
<td>Slagelse</td>
<td>Dairy</td>
<td>Mainly milk</td>
<td>Fresh milk (different variants), cream, dessert</td>
</tr>
<tr>
<td>#134</td>
<td>Thise Dairy</td>
<td>Thise Dairy</td>
<td>Denmark</td>
<td>Roslev</td>
<td>Dairy</td>
<td>Mainly milk</td>
<td>Fresh milk (different variants), yoghurt, cream, cheese, butter</td>
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<tr>
<td>#135</td>
<td>Tulip Esbjerg</td>
<td>Tulip Food Company</td>
<td>Denmark</td>
<td>Esbjerg</td>
<td>Meat processing</td>
<td>Primarily red meat</td>
<td>Soups, ducklings and ready meals</td>
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<tr>
<td>#136</td>
<td>Tulip Aalborg</td>
<td>Tulip Food Company</td>
<td>Denmark</td>
<td>Aalborg</td>
<td>Meat processing</td>
<td>Primarily red meat</td>
<td>Meatballs, toppings and meat for burgers</td>
</tr>
<tr>
<td>#137</td>
<td>Tulip Svenstrup</td>
<td>Tulip Food Company</td>
<td>Denmark</td>
<td>Svenstrup</td>
<td>Meat processing</td>
<td>Primarily red meat</td>
<td>Sausages and salami</td>
</tr>
<tr>
<td>#138</td>
<td>Tulip Vejle</td>
<td>Tulip Food Company</td>
<td>Denmark</td>
<td>Vejle</td>
<td>Meat processing</td>
<td>Primarily red meat</td>
<td>Sausages, canned meat and liver pâté</td>
</tr>
<tr>
<td>#140</td>
<td>Danish Crown Skjern</td>
<td>Danish Crown</td>
<td>Denmark</td>
<td>Skjern</td>
<td>Meat processing</td>
<td>Beef and veal</td>
<td>Cut beef</td>
</tr>
<tr>
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<td>Company name</td>
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<td>#144</td>
<td>Skagerac Pelagic, Tobiskaj</td>
<td>Skagerac Pelagic</td>
<td>Denmark</td>
<td>Skagen</td>
<td>Fish and shellfish processing</td>
<td>Fresh herring and mackerel</td>
<td>Filleted and salted herring</td>
</tr>
<tr>
<td>#146</td>
<td>DLG Fabrik Tjele, Vingevej 70</td>
<td>DLG, Axelborg, Vesterborgade 4A, 1503 København V</td>
<td>Denmark</td>
<td>Tjele</td>
<td>Animal feed</td>
<td>Grain, soya, protein raw material, minerals premix</td>
<td>Mainly pelleted feed for pigs and poultry</td>
</tr>
<tr>
<td>#147</td>
<td>DLG Fabrik Bårse, Kornrevet 4</td>
<td>DLG, Axelborg, Vesterborgade 4A, 1503 København V</td>
<td>Denmark</td>
<td>Præstø</td>
<td>Animal feed</td>
<td>Grain, soya, protein raw material, minerals premix</td>
<td>Mainly pelleted feed for pigs and poultry</td>
</tr>
<tr>
<td>#148</td>
<td>DLG Skærøbek, Industrivej 36</td>
<td>DLG, Axelborg, Vesterborgade 4A, 1503 København V</td>
<td>Denmark</td>
<td>Skærøbek</td>
<td>Animal feed</td>
<td>Grain, soya, protein raw material, minerals premix</td>
<td>Mainly pelleted feed for cattle and pigs</td>
</tr>
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<td>#149</td>
<td>AKV Langholt</td>
<td>AKV Langholt</td>
<td>Denmark</td>
<td>Langholt</td>
<td>Starch production</td>
<td>Potatoes</td>
<td>Potato starch, potato protein</td>
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<tr>
<td>#150</td>
<td>AKK</td>
<td>AKK</td>
<td>Denmark</td>
<td>Karup</td>
<td>Starch production</td>
<td>Potatoes</td>
<td>Potato starch, potato protein</td>
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<td>#151</td>
<td>AKM</td>
<td>AKM</td>
<td>Denmark</td>
<td>Brønde</td>
<td>Starch production</td>
<td>Potatoes</td>
<td>Potato starch, potato protein</td>
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<tr>
<td>#152</td>
<td>AKS</td>
<td>AKS</td>
<td>Denmark</td>
<td>Toftlund</td>
<td>Starch production</td>
<td>Potatoes</td>
<td>Potato starch, potato protein</td>
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<tr>
<td>#153</td>
<td>Rynkeby</td>
<td>Arla Foods amba</td>
<td>Denmark</td>
<td>Ringe</td>
<td>Soft drinks and juice made from concentrate</td>
<td>Mainly juices from fruit and vegetables, as single strength and concentrate but also fruit purées and dry frozen berries</td>
<td>Fruit juice, nectar, fruit drinks, fruit sups</td>
</tr>
<tr>
<td>#154</td>
<td>Carlsberg Danmark A/S</td>
<td>Carlsberg Danmark A/S</td>
<td>Denmark</td>
<td>Fredericia</td>
<td>Brewing</td>
<td>Malt, hops, water, sugar, concentrates</td>
<td>Finished beer, soft drink, cider</td>
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<tr>
<td>#155</td>
<td>Scanola</td>
<td>Scanola A/S</td>
<td>Denmark</td>
<td>Aarhus</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Rapeseed</td>
<td>Rapeseed oil and rape pellets</td>
</tr>
<tr>
<td>#156</td>
<td>AAK Denmark A/S</td>
<td>AAK Denmark A/S</td>
<td>Denmark</td>
<td>Aarhus</td>
<td>Oilseed processing and vegetable oil</td>
<td>Shea, rape, cocoa</td>
<td>Vegetable oil and fats</td>
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<td>Company name</td>
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<tr>
<td>#157</td>
<td>Mahou Fca. Cerveza</td>
<td>Mahou San Miguel</td>
<td>Spain</td>
<td>Alovera (Guadalajara)</td>
<td>Brewing</td>
<td>Malt</td>
<td>Beer and non-alcoholic beer (up to 1% abv)</td>
</tr>
<tr>
<td>#158</td>
<td>San Miguel Fca. Cerveza</td>
<td>Mahou San Miguel</td>
<td>Spain</td>
<td>Lérida</td>
<td>Brewing</td>
<td>Malt</td>
<td>Beer and non-alcoholic beer (up to 1% abv)</td>
</tr>
<tr>
<td>#159</td>
<td>San Miguel Fca. Cerveza</td>
<td>Mahou San Miguel</td>
<td>Spain</td>
<td>Málaga</td>
<td>Brewing</td>
<td>Malt</td>
<td>Beer and non-alcoholic beer (up to 1% abv)</td>
</tr>
<tr>
<td>#160</td>
<td>San Miguel Fca. Cerveza</td>
<td>Mahou San Miguel</td>
<td>Spain</td>
<td>Burgos</td>
<td>Brewing</td>
<td>Malt</td>
<td>Beer and non-alcoholic beer (up to 1% abv)</td>
</tr>
<tr>
<td>#161</td>
<td>La Coruña</td>
<td>Hijos de Rivera SAU</td>
<td>Spain</td>
<td>La Coruña</td>
<td>Brewing</td>
<td>Malt</td>
<td>Beer and non-alcoholic beer (up to 1% abv)</td>
</tr>
<tr>
<td>#165</td>
<td>Jaén</td>
<td>Heineken España, S.A.</td>
<td>Spain</td>
<td>Jaén</td>
<td>Brewing</td>
<td>Malt</td>
<td>Beer and non-alcoholic beer (up to 1% abv)</td>
</tr>
<tr>
<td>#166</td>
<td>El Prat</td>
<td>Compañía Cervecerina Damm</td>
<td>Spain</td>
<td>El Prat de Llobregat</td>
<td>Brewing</td>
<td>Malt</td>
<td>Beer and non-alcoholic beer (up to 1% abv)</td>
</tr>
<tr>
<td>#167</td>
<td>Espinardo</td>
<td>Estrella de Levante</td>
<td>Spain</td>
<td>Espinardo</td>
<td>Brewing</td>
<td>Malt</td>
<td>Beer and non-alcoholic beer (up to 1% abv)</td>
</tr>
<tr>
<td>#169</td>
<td>Carnes Selectas</td>
<td>Carnes Selectas 2000, S. A.</td>
<td>Spain</td>
<td>Burgos</td>
<td>Meat processing</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>#170</td>
<td>Tarancón</td>
<td>Incarlopsa</td>
<td>Spain</td>
<td>Tarancón</td>
<td>Meat processing</td>
<td>Pork carcasses, fresh pork meat, frozen meat, deboned cured hams</td>
<td></td>
</tr>
<tr>
<td>#171</td>
<td>Cartama Estacion</td>
<td>Mataderos Industriales Soler, S.A. y Frigoríficos Andaluces de Conservas de Carne, S.A.</td>
<td>Spain</td>
<td>Cartama estacion</td>
<td>Meat processing</td>
<td>Pigs</td>
<td>Deboned meats, dried meat, dried sausages, frozen meat</td>
</tr>
<tr>
<td>#172</td>
<td>Tarancón</td>
<td>Incarlopsa- Fábrica de elaborados</td>
<td>Spain</td>
<td>Tarancón</td>
<td>Meat processing</td>
<td>Fresh meat (pig, turkey, chicken)</td>
<td>Processed meat (cooked, fresh, and cured)</td>
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<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
<td>Main FDM sector</td>
<td>Raw materials</td>
<td>Products</td>
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<tr>
<td>#173</td>
<td>Binéfar</td>
<td>Fribin</td>
<td>Spain</td>
<td>Binéfar</td>
<td>Meat processing</td>
<td>Pork and beef</td>
<td>Bovine and pork meat quartering and packing (chilled and frozen)</td>
</tr>
<tr>
<td>#174</td>
<td>Matadero frigorífico de Begíjar, S.A.</td>
<td>Matadero frigorífico de Begíjar, S.A.</td>
<td>Spain</td>
<td>Begíjar (Jaén)</td>
<td>Meat processing</td>
<td>Pigs</td>
<td>Pigs carcasses, pork viscera and lean pork</td>
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<tr>
<td>#175</td>
<td>Campofrio Torrent</td>
<td>Campofrio Food Group, S.A.</td>
<td>Spain</td>
<td>Torrent (Valencia)</td>
<td>Meat processing</td>
<td>Beef, pork, poultry</td>
<td>Cooked sausages, sliced bacon, pieces of cooked meat (fiambre), sliced cooked meat</td>
</tr>
<tr>
<td>#176</td>
<td>Campofrio Villaverde</td>
<td>Campofrio Food Group, S.A.</td>
<td>Spain</td>
<td>Villaverde (Madrid)</td>
<td>Meat processing</td>
<td>Pork, poultry</td>
<td>Sausages, dried ham</td>
</tr>
<tr>
<td>#177</td>
<td>Alcolea</td>
<td>Deoleo</td>
<td>Spain</td>
<td>Alcolea (Córdoba)</td>
<td>Fruit and vegetables</td>
<td>Oil, sauces, vinegar</td>
<td>Refinery and packaging of olive oil. Production and packaging of sauces (mayonnaise, ketchup and mustard). Production and packaging of vinegar</td>
</tr>
<tr>
<td>#178</td>
<td>Conservas Vegetales de Extremadura</td>
<td>Conesa</td>
<td>Spain</td>
<td>Badajoz</td>
<td>Fruit and vegetables</td>
<td>Fresh tomato</td>
<td>Tomato dices and powder, concentrated tomato pulp</td>
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<td>#179</td>
<td>Alimentos españoles alsat, S.L.</td>
<td>Alsat</td>
<td>Spain</td>
<td>Don benito (Badajoz)</td>
<td>Fruit and vegetables</td>
<td>Tomato</td>
<td>Tomato industrial products: concentrated pulp and tomato dices</td>
</tr>
<tr>
<td>#181</td>
<td>Azucarera La Bañeza</td>
<td>AB Azucarera Iberia</td>
<td>Spain</td>
<td>La Bañeza (León)</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
<td>Sugar, pulp and molasses</td>
</tr>
<tr>
<td>#182</td>
<td>Azucarera Guadalete</td>
<td>AB Azucarera Iberia</td>
<td>Spain</td>
<td>Jerez de la Frontera (Cádiz)</td>
<td>Sugar manufacturing</td>
<td>Sugar beet and raw sugar</td>
<td>Sugar, pulp and molasses</td>
</tr>
<tr>
<td>#183</td>
<td>Toledo</td>
<td>Orangina - Schweppes</td>
<td>Spain</td>
<td>Toledo</td>
<td>Soft drinks and juice made from concentrate</td>
<td>Water, sugar, juices, compounds fruits and wine</td>
<td>Lines with multiproduct. Still and carbonated beverages. Soft drinks with juices fruits, soft drinks flavoured, juices, nectars</td>
</tr>
</tbody>
</table>
## Annexes

<table>
<thead>
<tr>
<th>Installation code</th>
<th>Installation name</th>
<th>Company name</th>
<th>Member state</th>
<th>Town</th>
<th>Main FDM sector</th>
<th>Raw materials</th>
<th>Products</th>
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<tbody>
<tr>
<td>#184</td>
<td>Málaga</td>
<td>Coca-Cola Iberian Partners</td>
<td>Spain</td>
<td>Málaga</td>
<td>Soft drinks and juice made from concentrate</td>
<td>Water, sugar, juices, and compounds fruits</td>
<td>NI</td>
</tr>
<tr>
<td>#185</td>
<td>Bilbao</td>
<td>Coca-Cola Iberian Partners</td>
<td>Spain</td>
<td>Bilbao</td>
<td>Soft drinks and juice made from concentrate</td>
<td>Water, sugar, juices, and compounds fruits</td>
<td>NI</td>
</tr>
<tr>
<td>#186</td>
<td>Echevarri</td>
<td>Pepsico</td>
<td>Spain</td>
<td>Alava</td>
<td>Soft drinks and juice made from concentrate</td>
<td>Water, sugar, juices, and compounds fruits</td>
<td>NI</td>
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<tr>
<td>#187</td>
<td>Roquette Laisa España S.A.</td>
<td>Roquette Laisa España S.A.</td>
<td>Spain</td>
<td>Benillobio</td>
<td>Starch production</td>
<td>Corn</td>
<td>Corn-starches (native and modified) and its derivatives (glucose syrups, glucose and fructose syrups and dextrose). Maize gluten, maize gluten feed, maize germ expeller, corn oil.</td>
</tr>
<tr>
<td>#189</td>
<td>Aldaia Plant</td>
<td>Danone</td>
<td>Spain</td>
<td>Aldaia</td>
<td>Dairy</td>
<td>Milk</td>
<td>Fermented milk, yoghourt, and milk desserts</td>
</tr>
<tr>
<td>#190</td>
<td>Salas Plant</td>
<td>Danone</td>
<td>Spain</td>
<td>Salas</td>
<td>Dairy</td>
<td>Milk</td>
<td>Milk desserts and fresh cheese</td>
</tr>
<tr>
<td>#191</td>
<td>Parets Plant</td>
<td>Danone</td>
<td>Spain</td>
<td>Parets del Vallès</td>
<td>Dairy</td>
<td>Milk</td>
<td>Yoghurt, milk desserts and fermented soya products.</td>
</tr>
<tr>
<td>#193</td>
<td>Granada</td>
<td>Puleva Food, S.L.</td>
<td>Spain</td>
<td>Granada</td>
<td>Dairy</td>
<td>Milk, orgeat and cream</td>
<td>Drinking milk, functional milk, flavoured milk, orgeat</td>
</tr>
<tr>
<td>#194</td>
<td>Mollerussa</td>
<td>Puleva Food, S.L.</td>
<td>Spain</td>
<td>Mollerussa</td>
<td>Dairy</td>
<td>Milk</td>
<td>Functional and drinking milk</td>
</tr>
<tr>
<td>#195</td>
<td>Lugo</td>
<td>Puleva Food, S.L.</td>
<td>Spain</td>
<td>Lugo</td>
<td>Dairy</td>
<td>Milk</td>
<td>Functional and drinking milk, milk powder and concentrated milk</td>
</tr>
<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
<td>Main FDM sector</td>
<td>Raw materials</td>
<td>Products</td>
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<tr>
<td>#196</td>
<td>Valladolid</td>
<td>Industrias Lacteas Vallisoletanas, S.L.U.</td>
<td>Spain</td>
<td>Valladolid</td>
<td>Dairy</td>
<td>Milk</td>
<td>Functional and drinking milk</td>
</tr>
<tr>
<td>#197</td>
<td>Villalba</td>
<td>Leche de Galicia, S.L.</td>
<td>Spain</td>
<td>Villalba (Lugo)</td>
<td>Dairy</td>
<td>Milk</td>
<td>Drinking milk</td>
</tr>
<tr>
<td>#198</td>
<td>Villarrobledo</td>
<td>Lactalis Villarrobledo, S.L.U.</td>
<td>Spain</td>
<td>Villarrobledo</td>
<td>Dairy</td>
<td>Cow and goat's milk</td>
<td>Cheese and whey powder</td>
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<tr>
<td>#199</td>
<td>Guadalajara</td>
<td>L.N.P.L.R. Guadalajara S.L.</td>
<td>Spain</td>
<td>Guadalajara</td>
<td>Dairy</td>
<td>Milk, concentrated milk and cream</td>
<td>Yogurt and dairy desserts</td>
</tr>
<tr>
<td>#203</td>
<td>Valladolid</td>
<td>Queserías entrepinares</td>
<td>Spain</td>
<td>Valladolid</td>
<td>Dairy</td>
<td>Milk and cheese</td>
<td>Pressed cheese</td>
</tr>
<tr>
<td>#209</td>
<td>Granda</td>
<td>Corporación Alimentaria Peñasanta, S.A.</td>
<td>Spain</td>
<td>Granda</td>
<td>Dairy</td>
<td>Milk</td>
<td>UHT milk, powder milk, butter, yogurt</td>
</tr>
<tr>
<td>#210</td>
<td>Lugo</td>
<td>Corporación Alimentaria Peñasanta, S.A.</td>
<td>Spain</td>
<td>Lugo</td>
<td>Dairy</td>
<td>Milk</td>
<td>UHT milk, powder milk</td>
</tr>
<tr>
<td>#211</td>
<td>Zarzalejo</td>
<td>Corporación Alimentaria Peñasanta, S.A.</td>
<td>Spain</td>
<td>Zarzalejo</td>
<td>Dairy</td>
<td>Milk</td>
<td>UHT milk</td>
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<tr>
<td>#212</td>
<td>Vidreres</td>
<td>Vidreres Llet, S.L</td>
<td>Spain</td>
<td>Vidreres</td>
<td>Dairy</td>
<td>Milk</td>
<td>UHT milk</td>
</tr>
<tr>
<td>#214</td>
<td>Aranda</td>
<td>Calidad Pascual, S.A.U.</td>
<td>Spain</td>
<td>Aranda de Duero</td>
<td>Dairy</td>
<td>Milk, soya seeds and fruit juices concentrate</td>
<td>Milk, dairy drinks, soya drinks, yogurts and dairy desserts, butter</td>
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<tr>
<td>#215</td>
<td>Gurb</td>
<td>Calidad pascual, s.a.u.</td>
<td>Spain</td>
<td>Gurb (Barcelona)</td>
<td>Dairy</td>
<td>Milk</td>
<td>Milk</td>
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<tr>
<td>#216</td>
<td>Alcázar de San Juan</td>
<td>Lácteas García Baquero, S.A.</td>
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<td>Jumilla</td>
<td>Dairy</td>
<td>Cow, goat and sheep milk</td>
<td>Cheese</td>
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<tr>
<td>#217</td>
<td>Zaragoza</td>
<td>Cuarte, S.L.</td>
<td>Spain</td>
<td>Zaragoza</td>
<td>Animal feed</td>
<td>Cereals, minerals, oleagins, fat</td>
<td>Compound feed</td>
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</table>
### Installation code | Installation name | Company name | Member state | Town | Main FDM sector | Raw materials | Products |
---|---|---|---|---|---|---|---|
#218 | Plasencia del Monte | Harineras Villamayor, S.A. | Spain | Plasencia del Monte | Grain milling | NI | Flour |
#220 | La Rambla - Córdoba | San Lorenzo, S.A | Spain | La Rambla - Córdoba | Grain milling | Wheat | Flour |
#222 | Torija - Guadalajara | Harinas Torija, S.L. | Spain | Torija - Guadalajara | Grain milling | Wheat | Flour |
#223 | Barcelona | Cargill | Spain | Barcelona | Oilseed processing and vegetable oil refining | Soya | Crude soya oil, soya hulls, low pro meal and high pro meal |
#224 | Reus | Cargill | Spain | Reus | Oilseed processing and vegetable oil refining | Sunflower, maize, soya | Crude sunflower oil, low pro and high pro meal, refined sunflower oil, refined maize oil |
#225 | Barcelona | Bunge | Spain | Barcelona | Oilseed processing and vegetable oil refining | Soybeans | Soybean meal and Soybean refined oil |
#226 | Zierbena | Bunge | Spain | Bilbao | Oilseed processing and vegetable oil refining | Soybeans and sunflower crude oil | Soybean meal, soybean refined oil and sunflower refined oil |
#227 | Escombreras | Bunge | Spain | Cartagena | Oilseed processing and vegetable oil refining | Soybeans and sunflower crude oil | Soybean meal, soybean refined oil and sunflower refined oil |
#228 | Valio Riihimaki | Valio Ltd | Finland | Riihimäki | Dairy | Milk | Liquid milks, yoghurts, desserts |
#229 | Valio Jyväskyla | Valio Ltd | Finland | Jyväskylä | Dairy | Milk | Liquid milk, special milk drinks |
#230 | Valio Tampere | Valio Ltd | Finland | Tampere | Dairy | Milk | Liquid milk, soft cheese |
#231 | Valio Oulu | Valio Ltd | Finland | Oulu | Dairy | Milk | Liquid milks, yoghurts, desserts, sour creams |

*Annexes*
<table>
<thead>
<tr>
<th>Installation code</th>
<th>Installation name</th>
<th>Company name</th>
<th>Member state</th>
<th>Town</th>
<th>Main FDM sector</th>
<th>Raw materials</th>
<th>Products</th>
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<tbody>
<tr>
<td>#232</td>
<td>Valio Haapavesi</td>
<td>Valio Ltd</td>
<td>Finland</td>
<td>Haapavesi</td>
<td>Dairy</td>
<td>Milk</td>
<td>Semi-hard cheese, demineralised whey powders</td>
</tr>
<tr>
<td>#233</td>
<td>Valio Joensuu</td>
<td>Valio Ltd</td>
<td>Finland</td>
<td>Joensuu</td>
<td>Dairy</td>
<td>Milk</td>
<td>Semi-hard and soft cheese, milk and whey powders, milk drink components</td>
</tr>
<tr>
<td>#234</td>
<td>Valio Lapinlahti</td>
<td>Valio Ltd</td>
<td>Finland</td>
<td>Lapinlahti</td>
<td>Dairy</td>
<td>Milk</td>
<td>Hard and semi-hard cheese, demineralised whey powders</td>
</tr>
<tr>
<td>#235</td>
<td>Valio Seinajoki</td>
<td>Valio Ltd</td>
<td>Finland</td>
<td>Seinäjoki</td>
<td>Dairy</td>
<td>Milk</td>
<td>Butter, spreads, cottage cheese, quark, milk powders</td>
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<tr>
<td>#236</td>
<td>Apetit Oyj Säkylä WWTP (serving IED 6.4.ii activities also from other companies)</td>
<td>Apetit Suomi Oy</td>
<td>Finland</td>
<td>Säkylä</td>
<td>Fruit and vegetables</td>
<td>Apetit Oyj: pea, carrot, potato, spinach, yellow turnip, red beet, celery, leek. Sucros Ltd: sugar beet. Hankkija Oyj: hard pressed sugar beet pulp.</td>
<td>Frozen vegetables, sugar, animal feed from sugar manufacturing</td>
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<tr>
<td>#237</td>
<td>Finnamyl Oy</td>
<td>Finnamyl Oy</td>
<td>Finland</td>
<td>Kokemäki</td>
<td>Starch production</td>
<td>Potato</td>
<td>Potato starch and feed</td>
</tr>
<tr>
<td>#238</td>
<td>Finnsugar Ltd. Porrkala factory (WWTP serving also other companies and the community)</td>
<td>Finnsugar Ltd.</td>
<td>Finland</td>
<td>Kirkkonummi</td>
<td>Sugar manufacturing</td>
<td>Finnsugar Ltd: raw cane sugar, raw beet sugar Mildola Oy: oil plant seeds (e.g. rape, soybean)</td>
<td>Finnsugar Ltd: Dry sugar products, liquid sugar products, syrups, food molasses, side products Mildola Oy: vegetable oils, protein feed</td>
</tr>
<tr>
<td>#239</td>
<td>Sinebrychoff Kerava</td>
<td>Sinebrychoff Supply Company</td>
<td>Finland</td>
<td>Kerava</td>
<td>Brewing</td>
<td>Water, malt, sugar, juice concentrates, flavours, carbon dioxide</td>
<td>Beer, ciders, flavoured alcoholic beverages, soft drinks, carbonated water</td>
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<tr>
<td>#242</td>
<td>Hankkija Oy / Säkylä factory</td>
<td>Hankkija Oy</td>
<td>Finland</td>
<td>Säkylä</td>
<td>Sugar manufacturing</td>
<td>Sugar beet pulp</td>
<td>Dried sugar beet pulp</td>
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<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
<td>Main FDM sector</td>
<td>Raw materials</td>
<td>Products</td>
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<tr>
<td>#243</td>
<td>Iisalmi brewery</td>
<td>Olvi Oyj</td>
<td>Finland</td>
<td>Iisalmi</td>
<td>Brewing</td>
<td>Malt, water, hops, sugar, sweeteners, apple and peach base, compounds,</td>
<td>Beer, cider, RTD, soft drink, mineral water, sports drink</td>
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<td>#245</td>
<td>Biomar - Nersac</td>
<td>BioMar</td>
<td>France</td>
<td>16440 Nersac</td>
<td>Animal feed</td>
<td>Cereals, oilseeds, vegetable proteins, fishmeal, fish oil, vegetable oils, additives</td>
<td>Compound feed for marine and fresh water fishes, various sizes, with and without Land animal products. Only fish feed.</td>
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<tr>
<td>#246</td>
<td>Huttepain Aliments - La Chapelle Saint Aubin</td>
<td>Huttepain Aliments</td>
<td>France</td>
<td>La Chapelle Saint Aubin</td>
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<td>Vegetable raw materials</td>
<td>animal feed (poultry)</td>
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<td>#247</td>
<td>Brasserie de l'Espérance _ Schiltigheim</td>
<td>Heineken</td>
<td>France</td>
<td>Schiltigheim</td>
<td>Brewing</td>
<td>NI</td>
<td>NI</td>
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<tr>
<td>#248</td>
<td>Brasserie Kronenbourg Obernai</td>
<td>Kronenbourg</td>
<td>France</td>
<td>Obernai</td>
<td>Brewing</td>
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<td>NI</td>
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<td>#249</td>
<td>Brasserie Licorne SAS</td>
<td>Brasserie Licorne SAS</td>
<td>France</td>
<td>Saverne</td>
<td>Brewing</td>
<td>NI</td>
<td>Beer, shandy, energy drink</td>
</tr>
<tr>
<td>#250</td>
<td>Candia - Awoingt</td>
<td>Candia (Groupe Sodiaal)</td>
<td>France</td>
<td>Awoingt</td>
<td>Dairy</td>
<td>Milk (95%), milk powder, vegetal oils, cacao</td>
<td>UHT white milk, flavoured milk, liquid cream, milk powder, infant formula</td>
</tr>
<tr>
<td>#251</td>
<td>Celia-laiterie de craon</td>
<td>Lactalis</td>
<td>France</td>
<td>53400 craon</td>
<td>Dairy</td>
<td>Milk, powder, cream, permeate,</td>
<td>Hard cheese, milk powder, infant formula, retentate, concentrated whey, cream</td>
</tr>
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<td>#252</td>
<td>Entremont - Guingamp</td>
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<td>Guingamp</td>
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<td>Milk, vegetal oils, cream, concentrated milk and whey, whey</td>
<td>Cheese, powder, concentrated whey, cream</td>
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<td>Entremont - Malestroit</td>
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<td>France</td>
<td>Malestroit</td>
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<td>Milk, concentrated milk and whey</td>
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<td>Entremont - Quimper</td>
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<td>France</td>
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<td>Dairy</td>
<td>Milk, buttermilk, concentrated whey, permeate</td>
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<td>#255</td>
<td>Eurosérum, Saint-Martin</td>
<td>Euroserum</td>
<td>France</td>
<td>Saint-Martin-Belle-Roche</td>
<td>Dairy</td>
<td>Milk, concentrated whey</td>
<td>Cream, milk powder, whey powder, milk powder, infant formula, retentate, concentrated whey</td>
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<td>#256</td>
<td>Fromagerie BEL - Dole</td>
<td>Groupe BEL</td>
<td>France</td>
<td>Dole</td>
<td>Dairy</td>
<td>Cheese, butter, cream</td>
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<td>#257</td>
<td>Fromagerie BEL - Sablé sur Sarthe</td>
<td>Groupe BEL</td>
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<td>Sablé sur Sarthe</td>
<td>Dairy</td>
<td>Milk, cream, powder milk &amp; whey</td>
<td>Cheddar, powder, retentate, cream</td>
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<td>Usine de Vallet</td>
<td>Lactalis</td>
<td>France</td>
<td>Vallet</td>
<td>Dairy</td>
<td>Milk, sugar, chocolate, fruits, rice</td>
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<td>#259</td>
<td>Laiterie d'Ancenis</td>
<td>Laita</td>
<td>France</td>
<td>Ancenis</td>
<td>Dairy</td>
<td>Milk, cream</td>
<td>Powder, cheese, butter</td>
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<td>Societe Beurriere de Retiers</td>
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<td>#261</td>
<td>Societe Fromagerie du Massegros</td>
<td>Lactalis</td>
<td>France</td>
<td>Le Massegros</td>
<td>Dairy</td>
<td>Sheep milk</td>
<td>Cheese: sheep's milk (feta), concentrated whey, liquid serum</td>
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<td>Danone - Le Molay Littry</td>
<td>Danone</td>
<td>France</td>
<td>Le Molay Littry</td>
<td>Dairy</td>
<td>Mainly milk, but also cereals, milk powder, sugar, fruits preparation, chocolate, starch</td>
<td>Fresh cheese, yoghurt, dessert, liquid whey</td>
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<td>Grands Moulins de Paris Site de Verneuil-l'Etang</td>
<td>Grands moulins de Paris</td>
<td>France</td>
<td>Verneuil-l' Etang</td>
<td>Grain milling</td>
<td>Wheat</td>
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<td>APM Pleurs</td>
<td>APM Deshy</td>
<td>France</td>
<td>Pleurs</td>
<td>Animal feed</td>
<td>Alfalfa (field culture) and sugar beet pulp (sugar manufacturing)</td>
<td>Dehydrated alfalfa (pellets, bales), dehydrated sugar beet pulp (pellets), other</td>
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<td>Luzeal</td>
<td>France</td>
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<td>Animal feed</td>
<td>Alfalfa (field culture) and sugar beet pulp (sugar manufacturing coproduct)</td>
<td>Dehydrated alfalfa (pellets, bales), dehydrated sugar beet pulp (pellets), other dehydrated products (pellets)</td>
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<td>Charal</td>
<td>Charal</td>
<td>France</td>
<td>Flers</td>
<td>Meat processing</td>
<td>2nd and 3rd level of beef meat processing</td>
<td>NI</td>
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<tr>
<td>#267</td>
<td>Duc</td>
<td>Duc</td>
<td>France</td>
<td>Riec-sur-Bélon</td>
<td>Meat processing</td>
<td>Cutting of turkey and production of breaded turkey</td>
<td>NI</td>
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<td>#268</td>
<td>Madrange</td>
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<td>France</td>
<td>Limoges</td>
<td>Meat processing</td>
<td>Pork meat, salt, seasoning</td>
<td>Cooked ham</td>
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<td>#269</td>
<td>Saviel France Etablissement de Tain l'Hermitage</td>
<td>Saviel France</td>
<td>France</td>
<td>Tain L'Hermitage</td>
<td>Meat processing</td>
<td>3rd and 4rd level of meat processing: -3rd : cutting of beef, lamb, pork and veal meat and offal</td>
<td>Brochettes (3rd) and sausages (4rd), chilled minced meat (3rd and 4rd)</td>
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<td>Site Aoste</td>
<td>Groupe Aoste</td>
<td>France</td>
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<td>Meat processing</td>
<td>Pork meat</td>
<td>Production of dry sausage, dry ham, slicing of delicatessen products</td>
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<td>Raynal et Roquelaure zi les Taillades</td>
<td>Raynal et Roquelaure</td>
<td>France</td>
<td>Capdenac Gare</td>
<td>Meat processing</td>
<td>Meat, cooked vegetables</td>
<td>Traditional and exotic dishes made with cooked meat and vegetables</td>
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<td>#272</td>
<td>Cargill St Nazaire Boulevard Leferne</td>
<td>Cargill</td>
<td>France</td>
<td>St Nazaire</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Crush and refinery sunflower</td>
<td>Meal, crude and refined oil</td>
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<td>Lesieur Coudekerque</td>
<td>Lesieur</td>
<td>France</td>
<td>Coudekerque</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Crude oil (rape, sunflower, soya, corn)</td>
<td>Refined oil, acid oils, refined-oil bottling</td>
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<td>Saipol Bassens</td>
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<td>France</td>
<td>Bassens</td>
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<td>Refined oil, neutral oil, meal</td>
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<td>Saipol Sète</td>
<td>Saipol</td>
<td>France</td>
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<td>#276</td>
<td>MARS Petcare &amp; Food France - Boulevard des Chenêts</td>
<td>Mars Inc</td>
<td>France</td>
<td>Saint-Denis-de-l'Hôtel</td>
<td>Animal feed</td>
<td>Frozen and fresh meats, cereals and vegetables</td>
<td>Wet pet food for cats and dogs</td>
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<td>Royal Canin SAS</td>
<td>Royal Canin subsidiary of Mars Inc</td>
<td>France</td>
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<td>Specific raw materials depending to the receipt</td>
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<td>Pepsico / Tropicana</td>
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<td>France</td>
<td>Hermes</td>
<td>Soft drinks and juice made from concentrate</td>
<td>Fruit or vegetable juice</td>
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<td>#279</td>
<td>Refresco France- Site de Délifruits</td>
<td>Refresco France</td>
<td>France</td>
<td>Marges</td>
<td>Soft drinks and juice made from concentrate</td>
<td>Fruit or vegetable juice, fruit or vegetable juice made from concentrate, fruit or vegetable nectar, soft drinks, fruit drinks</td>
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<td>Chamtor Bazancourt</td>
<td>Chamtor</td>
<td>France</td>
<td>Bazancourt</td>
<td>Starch production</td>
<td>Wheat native starch and their derivatives (glucose syrups, glucose and fructose syrups) and their coproducts (wheat gluten, wheat hydrolysed gluten, wheat soluble feed, wheat germ, wheat</td>
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<td>#281</td>
<td>Roquette Beinheim</td>
<td>Roquette Freres</td>
<td>France</td>
<td>Beinheim</td>
<td>Starch production</td>
<td>Maize and wheat</td>
<td>Maize and wheat starches (native and modified) and their derivatives (glucose syrups, glucose and fructose syrups) and their coproducts (maize gluten, wheat gluten, maize gluten feed, wheat feed, maize soluble, maize germ expeller, corn oil) and bioethanol production and other derivatives such as fermentation products</td>
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<td>#282</td>
<td>Roquette Lestrem</td>
<td>Roquette Freres</td>
<td>France</td>
<td>Lestrem</td>
<td>Starch production</td>
<td>Maize and wheat</td>
<td>Maize and wheat starches (native and modified) and their derivatives (glucose syrups, glucose and fructose syrups and dextrose, maltodextrins) and their coproducts (maize gluten, wheat gluten, maize gluten feed, wheat feed, maize soluble, maize germ expeller, corn oil) and other derivatives such as polyols and fermentation products and isosorbide</td>
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<td>#283</td>
<td>Roquette Vecquemont</td>
<td>Roquette Freres</td>
<td>France</td>
<td>Vecquemont</td>
<td>Starch production</td>
<td>Starch potato</td>
<td>Potato starches (native and modified) and their coproducts (potato protein, fibres (pulps))</td>
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<td>Roquette Vic</td>
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<td>Vic sur Aisne</td>
<td>Starch production</td>
<td>Starch pea</td>
<td>Pea starches (native and modified) and their coproducts (protein, fibres)</td>
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<td>SAS Lesaffre Frères</td>
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<td>Sugar beets only</td>
<td>Sugar production, animal feed from sugar beet pulp</td>
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<td>#286</td>
<td>Tereos France site d'Origny Sainte Benoîte</td>
<td>Tereos</td>
<td>France</td>
<td>Origny Sainte Benoîte</td>
<td>Sugar manufacturing</td>
<td>Sugar beets (sugar and ethanol), wheat (ethanol)</td>
<td>Sugar and ethanol production, animal feed from sugar beet pulp and DDGS</td>
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<td>Cristal Union + Cristanol</td>
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<td>France</td>
<td>Bazancourt</td>
<td>Sugar manufacturing</td>
<td>Sugar beets (sugar and ethanol), wheat (ethanol)</td>
<td>Sugar and ethanol production, animal feed from sugar beet pulp and DDGS</td>
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<td>#288</td>
<td>Tereos France site de Bucy le long</td>
<td>Tereos</td>
<td>France</td>
<td>Bucy le long</td>
<td>Sugar manufacturing</td>
<td>Sugar beets only</td>
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<td>ARDO Gourin</td>
<td>ARDO</td>
<td>France</td>
<td>Gourin</td>
<td>Fruit and vegetables</td>
<td>Spinach, green beans, cauliflower, broccoli, carrots, potatoes, peas</td>
<td>Production, packaging and storage of frozen vegetable</td>
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<td>#290</td>
<td>Borderes et Lamensans</td>
<td>Société Sud Ouest Legumes S.A.</td>
<td>France</td>
<td>Borderes et Lamensans</td>
<td>Fruit and vegetables</td>
<td>Sweet corn, peas, bean</td>
<td>Canned and frozen vegetables</td>
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<td>#291</td>
<td>Conserves France</td>
<td>Saint Mamet SAS</td>
<td>France</td>
<td>Vauvert</td>
<td>Fruit and vegetables</td>
<td>Fruits</td>
<td>Fruits in syrup, compotes, jams</td>
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<td>Alfalfa Manufacturing</td>
<td>Cristal Union</td>
<td>France</td>
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<td>Animal feed</td>
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<td>Coothehill, Co Cavan</td>
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<td>Glanbia Ingredients (Ballyragget) Limited</td>
<td>Glanbia Ingredients (Ballyragget) Limited</td>
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<td>Ballyragget, Co Kilkenny</td>
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<td>Carbery Milk Products Limited</td>
<td>Carbery Milk Products Limited</td>
<td>Ireland</td>
<td>Ballineen, Co. Cork</td>
<td>Dairy</td>
<td>Milk and whey</td>
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<td>Kerry Ingredients (Ireland) Limited</td>
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<td>Ireland</td>
<td>Listowel, Co. Kerry</td>
<td>Dairy</td>
<td>Milk, oils, cheese</td>
<td>Cheese, whey protein powders, whey protein isolates, sports food, creams, skimmed milk powder, alcohol, yeast extract powder</td>
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<td>Oleificio Zucchi</td>
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<td>Oilsed processing and vegetable oil refining</td>
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<td>Refined seed oils: groundnut oil, corn oil, sunflower oil, soybean oil, rapeseed oil</td>
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<td>Carapelli Firenze S.p.A.</td>
<td>Inveruno Plant</td>
<td>Deoleo S.A.</td>
<td>Italy</td>
<td>Inveruno (MI)</td>
<td>Olive oil processing and refining</td>
<td>Crude olive-oil and seeds oil</td>
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<td>Unigra' Srl</td>
<td>Italy</td>
<td>Conselice (RA)</td>
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<td>Palm oil, oilseed</td>
<td>Margarine, refined oil</td>
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<td>Salov Refinery</td>
<td>Salov S.P.A.</td>
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<td>Olive oil</td>
<td>Refined olive oil</td>
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<td>Italcol Spa</td>
<td>Italcol Spa</td>
<td>Italy</td>
<td>Castelfiorentino (FI)</td>
<td>Oilseeds processing and vegetable oil refining</td>
<td>Sunflower, Rapeseed, Olive Husk, Grape-seed</td>
<td>Crude oil, extraction meal and biomass for combustion</td>
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<td>Tampieri S.P.A.</td>
<td>Tampieri S.P.A.</td>
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<td>Faenza (RA)</td>
<td>Oilseeds processing and vegetable oil refining</td>
<td>Sunflower seed, corn germ, pomace, grapeseed</td>
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<td>Ital Green Oil S.r.l. (Veneto)</td>
<td>Ital Green Oil SRL</td>
<td>Italy</td>
<td>San Pietro di Morubio (VR)</td>
<td>Oilseeds processing and vegetable oil refining</td>
<td>Soybeans</td>
<td>Soybeans crude oil, soymeal high and low protein, lecithin, soybeans refining oil</td>
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<td>#306</td>
<td>Mangimificio di Quinto di Valpantena</td>
<td>Agricola Tre Valli Soc. Coop</td>
<td>Italy</td>
<td>Verona</td>
<td>Animal feed</td>
<td>Cereals grains and derived products, oil seeds and derived products, legume seeds and derived products, minerals, feed additives, land animals products, fish, other aquatic animals</td>
<td>Fish feed</td>
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<td>#307</td>
<td>Via Nazionale Sannitica, 60</td>
<td>Mangimi Liverini Spa</td>
<td>Italy</td>
<td>Telese Terme (BN)</td>
<td>Animal feed</td>
<td>Cereal grains and derived products, oil seeds, forages, milk products, animal by-products, minerals, fermentation by-products, fatty acids, feed</td>
<td>Compound feed for cattle, dairy and laying hens</td>
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## Annexes

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<td>Cargill Spessa</td>
<td>Cargill srl - Feed Nutrition</td>
<td>Italy</td>
<td>Spessa (PV)</td>
<td>Animal feed</td>
<td>Grains and by-products, oilseed and oilseed meals, roughages like hay, and dehydrated alfalfa, sugar beet pulp, oils, minerals, vitamins and oligo premix, medicated and additives premixes,</td>
<td>Compound and concentrate feed for dairy, beef, sheep, rabbits, horses</td>
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<td>#309</td>
<td>Purina Petcare</td>
<td>Nestlè Italiana S.p.A.</td>
<td>Italy</td>
<td>Portogruaro</td>
<td>Animal feed</td>
<td>Others</td>
<td>Dry pet food for dogs and cats</td>
</tr>
<tr>
<td>#310</td>
<td>Bologna</td>
<td>Granarolo Spa</td>
<td>Italy</td>
<td>Bologna</td>
<td>Dairy</td>
<td>Fresh pasteurised and extended shelf life milk. Fresh dairy product, cheese</td>
<td>Milk</td>
</tr>
<tr>
<td>#311</td>
<td>Gioia del Colle (Bari)</td>
<td>Granarolo Spa</td>
<td>Italy</td>
<td>Gioia del Colle (Bari)</td>
<td>Dairy</td>
<td>Fresh pasteurised and UHT milk, cream pasteurised</td>
<td>Milk</td>
</tr>
<tr>
<td>#312</td>
<td>Igor srl</td>
<td>Igor srl</td>
<td>Italy</td>
<td>Cameri (NO)</td>
<td>Dairy</td>
<td>Milk</td>
<td>Gorgonzola cheese</td>
</tr>
<tr>
<td>#313</td>
<td>Zanetti spa-marmirolo</td>
<td>Zanetti spa</td>
<td>Italy</td>
<td>Marmirolo (MN)</td>
<td>Dairy</td>
<td>Grana Padano cheese</td>
<td>Grana Padano cheese</td>
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<tr>
<td>#314</td>
<td>Collecchio Parma</td>
<td>Parmalat</td>
<td>Italy</td>
<td>Collecchio</td>
<td>Dairy</td>
<td>Milk, juices, sugar, flavour, aroma, fruits</td>
<td>UHT Milk, UHT cream, bechamel, fruit juices, yogurt, dessert</td>
</tr>
<tr>
<td>#315</td>
<td>Zevio Verona</td>
<td>Parmalat</td>
<td>Italy</td>
<td>Zevio</td>
<td>Dairy</td>
<td>Milk</td>
<td>UHT milk</td>
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<td>#316</td>
<td>Barbiano</td>
<td>Conserve Italia soc coop agricolo</td>
<td>Italy</td>
<td>Cotignola (RA)</td>
<td>Fruit and vegetables</td>
<td>Apricot, peach, pear and apple</td>
<td>Fruit juice and nectars</td>
</tr>
<tr>
<td>Installation code</td>
<td>Installation name</td>
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<td>Member state</td>
<td>Town</td>
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<tr>
<td>#317</td>
<td>Solana SpA</td>
<td>Solana SpA</td>
<td>Italy</td>
<td>Maccastorna (LO)</td>
<td>Fruit and vegetables</td>
<td>Processing tomatoes and fruits and vegetables semifinished</td>
<td>Diced, crushed, Passata, tomato paste and others tomato-based products, vegetables juices, pulps and concentrates for semi-finished products</td>
</tr>
<tr>
<td>#318</td>
<td>Mutti Spa</td>
<td>Mutti SpA</td>
<td>Italy</td>
<td>Montechiarugolo (PR)</td>
<td>Fruit and vegetables</td>
<td>Processing tomatoes</td>
<td>Diced, crushed, Passata, tomato paste, tomato sauces and others tomato-based products</td>
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<tr>
<td>#319</td>
<td>Ferrara Food SpA</td>
<td>Ferrara Food</td>
<td>Italy</td>
<td>Argenta (FE)</td>
<td>Fruit and vegetables</td>
<td>Processing tomatoes and fruits and vegetables semifinished</td>
<td>Diced, crushed, Passata, tomato paste and others tomato-based products, vegetables and fruits juices, pulps and concentrates for semi-finished products</td>
</tr>
<tr>
<td>#320</td>
<td>Rodolfi Mansueto SpA</td>
<td>Rodolfi Mansueto SpA</td>
<td>Italy</td>
<td>Conecchio (PR)</td>
<td>Fruit and vegetables</td>
<td>Processing tomatoes and vegetables semifinished</td>
<td>Diced, crushed, Passata, tomato paste, tomato sauces and others tomato-based products, vegetables juices, pulps and concentrates for semi-finished products</td>
</tr>
<tr>
<td>#321</td>
<td>Columbus Srl</td>
<td>Columbus Srl</td>
<td>Italy</td>
<td>Parma (PR)</td>
<td>Fruit and vegetables</td>
<td>Processing tomatoes</td>
<td>Diced, crushed, Passata, tomato paste, tomato sauces and others tomato-based products</td>
</tr>
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<td>#322</td>
<td>Hans Zipperle spa</td>
<td>Hans Zipperle spa</td>
<td>Italy</td>
<td>Merano (BZ)</td>
<td>Fruit and vegetables</td>
<td>Fruit and vegetables</td>
<td>Fruit juices, pulps and concentrates for semi-finished</td>
</tr>
<tr>
<td>#323</td>
<td>SICA SRL</td>
<td>SICA SRL</td>
<td>Italy</td>
<td>Pagani (SA)</td>
<td>Fruit and vegetables</td>
<td>Canned tomatoes</td>
<td>Whole peeled tomatoes, crushed/diced tomatoes</td>
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<tr>
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<td>Town</td>
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<td>#326</td>
<td>La Doria spa</td>
<td>La Doria spa</td>
<td>Italy</td>
<td>Fisciano (SA)</td>
<td>Fruit and vegetables</td>
<td>Canned tomatoes</td>
<td>Chopped and peeled</td>
</tr>
<tr>
<td>#327</td>
<td>Greci Industria Alimentare spa</td>
<td>Greci Industria Alimentare spa</td>
<td>Italy</td>
<td>Parma</td>
<td>Fruit and vegetables</td>
<td>fruit and vegetables</td>
<td>Diced, crushed, Passata, tomato paste, tomato sauces and others tomato-based products, canned vegetables (artichokes, mushrooms, etc.)</td>
</tr>
<tr>
<td>#329</td>
<td>Zuccherificio di Minerbio</td>
<td>Co.Pro.B. SCA</td>
<td>Italy</td>
<td>Minerbio (BO)</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
<td>White sugar, molasses, dried and pressed beet pulp</td>
</tr>
<tr>
<td>#330</td>
<td>Cesare Fiorucci SpA</td>
<td>Campofrio foodholding</td>
<td>Italy</td>
<td>Pomezia (RM)</td>
<td>Meat processing</td>
<td>Raw pork</td>
<td>Salami, mortadelle, wurstel, prosciutti cott/arrosti, pancette, coppe</td>
</tr>
<tr>
<td>#331</td>
<td>Cesena Production plant (Avi.Coop s.c.a)</td>
<td>Avi.Coop s.c.a.</td>
<td>Italy</td>
<td>Cesena (FC)</td>
<td>Meat processing</td>
<td>Poultry</td>
<td>Processed meat products</td>
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<tr>
<td>#336</td>
<td>FrieslandCampina Workum</td>
<td>FrieslandCampina</td>
<td>Netherlands</td>
<td>Workum</td>
<td>Dairy</td>
<td>Milk and whey</td>
<td>Cheese and whey powder</td>
</tr>
<tr>
<td>#338</td>
<td>FrieslandCampina Beilen</td>
<td>FrieslandCampina</td>
<td>Netherlands</td>
<td>Beilen</td>
<td>Dairy</td>
<td>Milk and whey</td>
<td>Milk and whey powder</td>
</tr>
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<tr>
<td>#339</td>
<td>FrieslandCampina na Lochem</td>
<td>FrieslandCampina</td>
<td>Netherlands</td>
<td>Lochem</td>
<td>Dairy</td>
<td>Milk</td>
<td>Milk powder</td>
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<tr>
<td>#340</td>
<td>FrieslandCampina na Borculo</td>
<td>FrieslandCampina</td>
<td>Netherlands</td>
<td>Borculo</td>
<td>Dairy</td>
<td>Whey</td>
<td>Whey related powders and concentrates</td>
</tr>
<tr>
<td>#341</td>
<td>FrieslandCampina na Lutjewinkel</td>
<td>FrieslandCampina</td>
<td>Netherlands</td>
<td>Lutjewinkel</td>
<td>Dairy</td>
<td>Milk</td>
<td>Cheese</td>
</tr>
<tr>
<td>#342</td>
<td>FrieslandCampina na Maasdam</td>
<td>FrieslandCampina</td>
<td>Netherlands</td>
<td>Maasdam</td>
<td>Dairy</td>
<td>Milk</td>
<td>Consumer products like milk, yoghurt, dairy deserts</td>
</tr>
<tr>
<td>#344</td>
<td>FrieslandCampina na Den Bosch</td>
<td>FrieslandCampina</td>
<td>Netherlands</td>
<td>Den Bosch</td>
<td>Dairy</td>
<td>Cream</td>
<td>Butter and butter related products</td>
</tr>
<tr>
<td>#345</td>
<td>FrieslandCampina na Veghel</td>
<td>FrieslandCampina</td>
<td>Netherlands</td>
<td>Veghel</td>
<td>Dairy</td>
<td>Milk and whey</td>
<td>Processed whey powders, cream, skimmed milk, milk powders</td>
</tr>
<tr>
<td>#351</td>
<td>Sugar production line/ Plant Chełmża</td>
<td>Nordzucker Polska S.A.</td>
<td>Poland</td>
<td>Chełmża</td>
<td>Sugar manufacturing</td>
<td>Sugar beet, raw cane sugar</td>
<td>Sugar, molasses, pulp</td>
</tr>
<tr>
<td>#352</td>
<td>Sugar production line/ Sugar Factory Glinojeck</td>
<td>Pfeifer &amp; Langen Glinojeck S.A.</td>
<td>Poland</td>
<td>Glinojeck</td>
<td>Sugar manufacturing</td>
<td>Sugar beet, raw cane sugar</td>
<td>Sugar, molasses, pulp</td>
</tr>
<tr>
<td>#353</td>
<td>Sugar production line/ Sugar Factory Miejska Górka</td>
<td>Pfeifer &amp; Langen Polska S.A.</td>
<td>Poland</td>
<td>Miejska Górka</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
<td>Sugar, molasses, pulp</td>
</tr>
<tr>
<td>#354</td>
<td>Sugar production line/ Sugar Factory Cerekiew</td>
<td>Suedzucker Polska S.A.</td>
<td>Poland</td>
<td>Ciężkowice</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
<td>Sugar, molasses, pulp</td>
</tr>
<tr>
<td>#355</td>
<td>Sugar production line/ Sugar Factory Ropczyce</td>
<td>Suedzucker Polska S.A.</td>
<td>Poland</td>
<td>Ropczyce</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
<td>Sugar, molasses, pulp</td>
</tr>
<tr>
<td>#356</td>
<td>Gerber Factory</td>
<td>Nestle Polska S.A.</td>
<td>Poland</td>
<td>Rzeszów</td>
<td>Fruit and vegetables</td>
<td>Processed vegetable and fruits</td>
<td>Baby food</td>
</tr>
<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
<td>Main FDM sector</td>
<td>Raw materials</td>
<td>Products</td>
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<tr>
<td>#357</td>
<td>OSI Food Solutions Poland Sp. z o.o. Production Plant</td>
<td>OSI Food Solutions Poland Sp. z o.o.</td>
<td>Poland</td>
<td>Ostróda</td>
<td>Meat processing</td>
<td>Meat</td>
<td>Meat patties</td>
</tr>
<tr>
<td>#360</td>
<td>Tyski Browar Książęcy</td>
<td>Kompania Piwowarska S.A.</td>
<td>Poland</td>
<td>Tychy</td>
<td>Brewing</td>
<td>Malt, sugar syrup, bitterness extract, granulated bitterness and aroma</td>
<td>Beer</td>
</tr>
<tr>
<td>#361</td>
<td>Bosman Browar w Szczecinie</td>
<td>Carlsberg Supply Company Polska S.A.</td>
<td>Poland</td>
<td>Szczecin</td>
<td>Brewing</td>
<td>Malt, barley, hops, water</td>
<td>Beer</td>
</tr>
<tr>
<td>#363</td>
<td>De Heus</td>
<td>De Heus</td>
<td>Poland</td>
<td>Łęczyca</td>
<td>Animal feed</td>
<td>Edible roots and tubers, oilseeds, cereal grains, feed with greens</td>
<td>Animal food</td>
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<tr>
<td>#365</td>
<td>ADM Szamotuly</td>
<td>ADM</td>
<td>Poland</td>
<td>Szamotuly</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Rapeseed meal and refined rapeseed oil</td>
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</tr>
<tr>
<td>#366</td>
<td>Warsaw plant</td>
<td>Danone Sp. z.o.o</td>
<td>Poland</td>
<td>Warsaw</td>
<td>Dairy</td>
<td>Milk</td>
<td>Yoghurt, flavoured milk</td>
</tr>
<tr>
<td>#367</td>
<td>Bieruń plant</td>
<td>Danone Sp. z.o.o</td>
<td>Poland</td>
<td>Bieruń</td>
<td>Dairy</td>
<td>Milk</td>
<td>Drink yoghurt, cottage cheese, yoghurt</td>
</tr>
<tr>
<td>#368</td>
<td>Ice Cream Factory</td>
<td>Nestle Polska S.A.</td>
<td>Poland</td>
<td>Namysłów</td>
<td>Dairy</td>
<td>Sugar, milk powder, liquid milk, whey powder, glucose syrup, coconut oil</td>
<td>Ice cream</td>
</tr>
<tr>
<td>#373</td>
<td>Sidul Açúcares, Unipessoal Lda.</td>
<td>Sidul Açúcares, Unipessoal Lda.</td>
<td>Portugal</td>
<td>Loures</td>
<td>Sugar manufacturing</td>
<td>Raw cane sugar</td>
<td>Dry sugar products</td>
</tr>
<tr>
<td>#374</td>
<td>Refrig, Sociedade Industrial de Refrigerantes, S.A</td>
<td>Refrig, Sociedade Industrial de Refrigerantes, S.A</td>
<td>Portugal</td>
<td>Palmela</td>
<td>Soft drinks and juice made from concentrate</td>
<td>Water, sugar, juice concentrates, flavours, carbon dioxide</td>
<td>Soft drinks</td>
</tr>
<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
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<td>#375</td>
<td>Sovena Oilseeds Portugal, S.A</td>
<td>Sovena Oilseeds Portugal, S.A</td>
<td>Portugal</td>
<td>Almada</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Soybean, sunflower and rapeseed</td>
<td>Raw vegetable oil and soybean, sunflower and rapeseed flours, biodiesel</td>
</tr>
<tr>
<td>#378</td>
<td>Parmalat Portugal - Produtos Alimentares, Lda.</td>
<td>Parmalat Portugal - Produtos Alimentares, S.A.</td>
<td>Portugal</td>
<td>Palmela</td>
<td>Dairy</td>
<td>raw milk</td>
<td>Pasteurised milk, butter and cream</td>
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<tr>
<td>#379</td>
<td>SCC - Fábrica de Vialonga</td>
<td>SCC–Sociedade Central de Cervejas e Bebidas, S.A.</td>
<td>Portugal</td>
<td>Vila Franca de Xira</td>
<td>Brewing</td>
<td>Water, barley, malt, sugar, carbon dioxide, yeast</td>
<td>Beer and soft drinks</td>
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<tr>
<td>#385</td>
<td>Brewery (Fabrica de bere)</td>
<td>SC European Food SA</td>
<td>Romania</td>
<td>Bihor</td>
<td>Brewing</td>
<td>Hops, corn, water, malt</td>
<td>Beer</td>
</tr>
<tr>
<td>#386</td>
<td>SC Agrana Romania SA</td>
<td>SC Agrana Romania SA</td>
<td>Romania</td>
<td>Neama</td>
<td>Sugar manufacturing</td>
<td>Beet, raw sugar from cane</td>
<td>White sugar</td>
</tr>
<tr>
<td>#387</td>
<td>Kallhåll</td>
<td>Arla Foods</td>
<td>Sweden</td>
<td>Stockholm</td>
<td>Dairy</td>
<td>Mainly milk</td>
<td>Fresh milk and cream, fermented milk</td>
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<tr>
<td>#388</td>
<td>Götene</td>
<td>Arla Foods</td>
<td>Sweden</td>
<td>Göteborg</td>
<td>Dairy</td>
<td>Mainly milk and cream, vegetable oil, cereals and other ingredients</td>
<td>Cheese, butter products, milk powder and cereal based baby food</td>
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<tr>
<td>#389</td>
<td>Visby</td>
<td>Arla Foods</td>
<td>Sweden</td>
<td>Visby</td>
<td>Dairy</td>
<td>Milk</td>
<td>Milk powder and fresh milk</td>
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<tr>
<td>#390</td>
<td>Linköping</td>
<td>Arla Foods</td>
<td>Sweden</td>
<td>Linköping</td>
<td>Dairy</td>
<td>Mainly milk but also other ingredients</td>
<td>Yoghurt and other fermented products, milk with long shelf life</td>
</tr>
<tr>
<td>#393</td>
<td>Malmö Mejeri AB</td>
<td>Skånemejerier AB</td>
<td>Sweden</td>
<td>Malmö</td>
<td>Dairy</td>
<td>Mainly milk and other ingredients</td>
<td>ESL milk, sour milk, yoghurt</td>
</tr>
<tr>
<td>#394</td>
<td>Örtofta</td>
<td>Nordic Sugar AB</td>
<td>Sweden</td>
<td>Eslöv</td>
<td>Sugar manufacturing</td>
<td>Sugar Beets</td>
<td>Sugar, raw sugar and feed products based on sugar beet</td>
</tr>
<tr>
<td>#395</td>
<td>Kristianstads Stärkelsefabrik</td>
<td>Lyckeby Starch AB</td>
<td>Sweden</td>
<td>Kristianstad</td>
<td>Starch production</td>
<td>Potato</td>
<td>Potato starch, potato fibre, potato protein,</td>
</tr>
<tr>
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<td>Company name</td>
<td>Member state</td>
<td>Town</td>
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<td>#397</td>
<td>Danish Crown</td>
<td>Danish Crown K-Pack AB</td>
<td>Sweden</td>
<td>Jönköping</td>
<td>Meat processing</td>
<td>Beef and swine</td>
<td>Beef and swine products</td>
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<td></td>
<td>K-Pack AB</td>
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<td>#399</td>
<td>Pivovarna Laško, D.D., PLG</td>
<td>Pivovarna Laško, D.D., PLG</td>
<td>Slovenia</td>
<td>Laško</td>
<td>Brewing</td>
<td>Malt, cereals</td>
<td>Beer, radler, malt drinks, still water in glass, can, keg, PET</td>
</tr>
<tr>
<td>#400</td>
<td>Pivovarna Union, D.D., PLG</td>
<td>Pivovarna Union, D.D., PLG</td>
<td>Slovenia</td>
<td>Ljubljana</td>
<td>Brewing</td>
<td>Malt, cereals</td>
<td>Beer, radler, non-alcoholic drinks, still water in glass, can, keg, PET</td>
</tr>
<tr>
<td>#401</td>
<td>Bridgwater Dairy (South West England)</td>
<td>Muller Wiseman Dairies</td>
<td>United Kingdom</td>
<td>Bridgwater</td>
<td>Dairy</td>
<td>Raw milk</td>
<td>Liquid milk</td>
</tr>
<tr>
<td>#402</td>
<td>Droitwich Dairy (Midlands England)</td>
<td>Muller Wiseman Dairies</td>
<td>United Kingdom</td>
<td>Droitwich Spa</td>
<td>Dairy</td>
<td>Raw milk</td>
<td>Liquid milk</td>
</tr>
<tr>
<td>#405</td>
<td>Westbury Dairy (South West England)</td>
<td>Arla Foods</td>
<td>United Kingdom</td>
<td>Westbury</td>
<td>Dairy</td>
<td>Mainly milk</td>
<td>Skimmed milk powder and retail butter</td>
</tr>
<tr>
<td>#406</td>
<td>Davidstow Creamery (South West England)</td>
<td>Dairy Crest</td>
<td>United Kingdom</td>
<td>Davidstow</td>
<td>Dairy</td>
<td>Raw milk</td>
<td>Cheese, whey powder</td>
</tr>
<tr>
<td>#408</td>
<td>Llandyrnog Dairy (North Wales)</td>
<td>Arla Foods</td>
<td>United Kingdom</td>
<td>Ruthin</td>
<td>Dairy</td>
<td>Mainly milk</td>
<td>Cheese, whey concentrate</td>
</tr>
<tr>
<td>#409</td>
<td>Wyke Farms Dairy (South West England)</td>
<td>Wyke Farms</td>
<td>United Kingdom</td>
<td>Bruton</td>
<td>Dairy</td>
<td>Raw milk</td>
<td>Cheese</td>
</tr>
<tr>
<td>#412</td>
<td>Bury St Edmunds Sugar Factory (South East England)</td>
<td>British Sugar</td>
<td>United Kingdom</td>
<td>Bury St Edmunds</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
<td>Sugar, animal feed</td>
</tr>
<tr>
<td>#413</td>
<td>Cantley Sugar Factory (South East England)</td>
<td>British Sugar</td>
<td>United Kingdom</td>
<td>Norwich</td>
<td>Sugar manufacturing</td>
<td>Sugar beet</td>
<td>Sugar, animal feed</td>
</tr>
<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
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<td>Raw materials</td>
<td>Products</td>
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</tr>
<tr>
<td>#414</td>
<td>Newark Sugar Factory (Midlands England)</td>
<td>British Sugar</td>
<td>United Kingdom</td>
<td>Newark</td>
<td>Sugar manufacturing</td>
<td>Sugar beet, raw sugar</td>
<td>Sugar, animal feed</td>
</tr>
<tr>
<td>#415</td>
<td>Wissington Sugar Factory (South East England)</td>
<td>British Sugar</td>
<td>United Kingdom</td>
<td>Kings Lynn</td>
<td>Sugar manufacturing</td>
<td>Sugar beet, sugar juice and syrup</td>
<td>Sugar, animal feed, ethanol, betaine</td>
</tr>
<tr>
<td>#416</td>
<td>South Brink factory (South East England)</td>
<td>Nestle Purina Petcare</td>
<td>United Kingdom</td>
<td>Wisbech</td>
<td>Animal feed</td>
<td>Cereals, animal by-products (wet and dry)</td>
<td>Pet food, cans, foil, pouch shelf stable product</td>
</tr>
<tr>
<td>#417</td>
<td>Heineken Manchester, Royal Brewery (North West England)</td>
<td>Heineken UK</td>
<td>United Kingdom</td>
<td>Manchester</td>
<td>Brewing</td>
<td>Malted barley</td>
<td>Beer</td>
</tr>
<tr>
<td>#418</td>
<td>Heineken Hereford (Bulmers Cider Mills) (Midlands England)</td>
<td>Heineken UK</td>
<td>United Kingdom</td>
<td>Hereford</td>
<td>Brewing</td>
<td>Apple concentrate</td>
<td>Cider</td>
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<td>#419</td>
<td>Trafford Park Starch Refining facility (North West England)</td>
<td>Cargill Plc</td>
<td>United Kingdom</td>
<td>Manchester</td>
<td>Starch production</td>
<td>Wheat</td>
<td>Glucose syrup, vital wheat gluten, starch, bran, ethanol and animal feed products</td>
</tr>
<tr>
<td>#422</td>
<td>Carmarthen Feed Mill (South West Wales)</td>
<td>ForFarmers UK Ltd</td>
<td>United Kingdom</td>
<td>Carmarthen</td>
<td>Animal feed</td>
<td>Vegetable based raw materials (cereals, oil seeds and vegetable by-products from human food industry)</td>
<td>Ruminant feeds</td>
</tr>
<tr>
<td>#423</td>
<td>Dungannon Mill (Northern Ireland)</td>
<td>United Feeds Ltd</td>
<td>United Kingdom</td>
<td>Dungannon</td>
<td>Animal feed</td>
<td>Only vegetable origin products. Cereal grains and by-products, oil seeds and by products, sugar by-</td>
<td>Ruminant only feeds in pelleted and blended meal forms</td>
</tr>
<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
<td>Main FDM sector</td>
<td>Raw materials</td>
<td>Products</td>
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<td>#424</td>
<td>Lancaster Mill (North West England)</td>
<td>Carrs Billington Agriculture (Operations) Ltd</td>
<td>United Kingdom</td>
<td>Lancaster</td>
<td>Animal feed</td>
<td>Cereals, vegetable products, fruit by-products, vitamins and minerals</td>
<td>Ruminant and equine animal feed</td>
</tr>
<tr>
<td>#425</td>
<td>Flixborough Mill (North East England)</td>
<td>AB Agri Ltd</td>
<td>United Kingdom</td>
<td>Flixborough</td>
<td>Animal feed</td>
<td>Cereals, vegetable proteins, vegetable oils, fish meal (&lt;5 %), minerals, premixtures of additives and trace elements</td>
<td>Bulk poultry feeds</td>
</tr>
<tr>
<td>#431</td>
<td>Northampton brewery</td>
<td>Carlsberg UK Ltd</td>
<td>United Kingdom</td>
<td>Northampton</td>
<td>Brewing</td>
<td>Malted barley</td>
<td>Beer</td>
</tr>
<tr>
<td>#432</td>
<td>Coronet Mills Manchester</td>
<td>Allied Mills</td>
<td>United Kingdom</td>
<td>Manchester</td>
<td>Grain milling</td>
<td>Wheat</td>
<td>Flour</td>
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<tr>
<td>#433</td>
<td>Chancelot Mill Edinburgh</td>
<td>ADM</td>
<td>United Kingdom</td>
<td>Edinburgh</td>
<td>Grain milling</td>
<td>Wheat</td>
<td>Flour and animal feed pellets</td>
</tr>
<tr>
<td>#436</td>
<td>Indulleida S.A.</td>
<td>Indulleida S.A.</td>
<td>Spain</td>
<td>Aiguara (Lleida)</td>
<td>Fruit and vegetables</td>
<td>Fruit and vegetables</td>
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<td></td>
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<td>Juices, fruit fibres, fruit purees and aromas</td>
</tr>
<tr>
<td>#438</td>
<td>Ruskington</td>
<td>Tulip Ltd</td>
<td>United Kingdom</td>
<td>Sleaford</td>
<td>Meat processing</td>
<td>Primarily pork</td>
<td>Fried products (mini sausages, scotch eggs)</td>
</tr>
<tr>
<td>#439</td>
<td>Kings Lynn</td>
<td>Tulip Ltd</td>
<td>United Kingdom</td>
<td>Kings Lynn</td>
<td>Meat processing</td>
<td>Primarily pork</td>
<td>Sliced cooked meats</td>
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<tr>
<td>#440</td>
<td>Bromborough</td>
<td>Tulip Ltd</td>
<td>United Kingdom</td>
<td>Bromborough</td>
<td>Meat processing</td>
<td>Primarily pork</td>
<td>Sausages</td>
</tr>
<tr>
<td>#442</td>
<td>Belgomilk - Ysco</td>
<td>Milcobel cvba</td>
<td>Belgium</td>
<td>Langemark</td>
<td>Dairy</td>
<td>Milk</td>
<td>Cheese, butter, milk powder, whey products, ice cream</td>
</tr>
<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
<td>Main FDM sector</td>
<td>Raw materials</td>
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<td>#450</td>
<td>Aviko Oostrum</td>
<td>Royal Cosun</td>
<td>Netherlands</td>
<td>Venray</td>
<td>Fruit and vegetables</td>
<td>Potatoes</td>
<td>Pre-fried deep frozen and dried potato products</td>
</tr>
<tr>
<td>#453</td>
<td>LWM Kruiningen</td>
<td>Lamb Weston/Meijer</td>
<td>Netherlands</td>
<td>Kruiningen</td>
<td>Fruit and vegetables</td>
<td>Potatoes</td>
<td>Pre-fried deep frozen potato products and dried flakes</td>
</tr>
<tr>
<td>#458</td>
<td>Lelystad</td>
<td>McCain</td>
<td>Netherlands</td>
<td>Lelystad</td>
<td>Fruit and vegetables</td>
<td>Potatoes</td>
<td>Pre-fried deep frozen potato products</td>
</tr>
<tr>
<td>#459</td>
<td>Oerlemans Broekhuizenvorst</td>
<td>Oerlemans Foods</td>
<td>Netherlands</td>
<td>Broekhuizenvorst</td>
<td>Fruit and vegetables</td>
<td>Potatoes, vegetables and fruit</td>
<td>Frozen products</td>
</tr>
<tr>
<td>#461</td>
<td>Peka Kroef B.V.</td>
<td></td>
<td>Netherlands</td>
<td>Odiliapeel</td>
<td>Fruit and vegetables</td>
<td>Potatoes</td>
<td>Boiled potatoes</td>
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<tr>
<td>#463</td>
<td>Dry pet food plant - Hill’s</td>
<td>Hill’s pet Nutrition Mfg. BV</td>
<td>Netherlands</td>
<td>Ettent-Leur</td>
<td>Animal feed</td>
<td>Processed animal proteins, cereals, oils and fats, vitamins &amp; trace elements</td>
<td>Dry pet food for cats and dogs</td>
</tr>
<tr>
<td>#464</td>
<td>Jonker Petfood BV</td>
<td>Jonker Petfood BV</td>
<td>Netherlands</td>
<td>Waalwijk</td>
<td>Animal feed</td>
<td>Meat and meat derivatives, cereals, oils and fats, fish and fish derivatives, derivatives of vegetable origin, milk and milk derivate, vitamin and minerals</td>
<td>Milling, extrusion, drying, coating, cooling</td>
</tr>
<tr>
<td>#466</td>
<td>ADM Europoort</td>
<td>ADM</td>
<td>Netherlands</td>
<td>Europoort</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Rapeseed meal, soybean meal, refined rapeseed oil and soybean oil</td>
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</tr>
<tr>
<td>#468</td>
<td>Kruszwica</td>
<td>Bunge</td>
<td>Poland</td>
<td>Kruszwica</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Rapeseed meal, rapeseed refined oil, bottled oil and margarines</td>
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<tr>
<td>#469</td>
<td>Brzeg</td>
<td>Bunge</td>
<td>Poland</td>
<td>Brzeg</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Rapeseed meal, rapeseed refined oil, bottled oil and margarines</td>
<td></td>
</tr>
<tr>
<td>Installation code</td>
<td>Installation name</td>
<td>Company name</td>
<td>Member state</td>
<td>Town</td>
<td>Main FDM sector</td>
<td>Raw materials</td>
<td>Products</td>
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<td>#471</td>
<td>Amerikahaven</td>
<td>Cargill</td>
<td>Netherlands</td>
<td>Amsterdam</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Crush and refinery sunflower</td>
<td>Margarines</td>
</tr>
<tr>
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<tr>
<td>#473</td>
<td>WEO BV</td>
<td>Wilmar</td>
<td>Netherlands</td>
<td>Rotterdam</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Crude palm oil, crude coconut oil, crude palm kernel oil</td>
<td>Meal, crude and refined oil</td>
</tr>
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<td>#474</td>
<td>Rotterdam</td>
<td>IOI Loders Croklaan</td>
<td>Netherlands</td>
<td>Rotterdam</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Edible Oils</td>
<td>Palm oil, palm kernel, coconut and others</td>
</tr>
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</tr>
<tr>
<td>#475</td>
<td>Wormerveer</td>
<td>IOI Loders Croklaan</td>
<td>Netherlands</td>
<td>Rotterdam</td>
<td>Oilseed processing and vegetable oil refining</td>
<td>Edible Oils</td>
<td>Palm oil, palm kernel, coconut, shea and others</td>
</tr>
<tr>
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</tr>
<tr>
<td>#484</td>
<td>Gain Feeds</td>
<td>Glanbia Plc</td>
<td>Ireland</td>
<td>Portlaoise</td>
<td>Animal feed</td>
<td>Vegetable feed material</td>
<td>Compound feed for pigs and ruminants</td>
</tr>
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<td>#486</td>
<td>Aalst</td>
<td>Tereos-Syral</td>
<td>Belgium</td>
<td>Aalst</td>
<td>Starch production</td>
<td>Wheat</td>
<td>NI</td>
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</tr>
<tr>
<td>#495</td>
<td>Zoeterwoude</td>
<td>Heineken Nederland Supply</td>
<td>Netherlands</td>
<td>Zoeterwoude</td>
<td>Brewing</td>
<td>Brewery, raw material is malt</td>
<td>Beer</td>
</tr>
</tbody>
</table>

NB: NI = no information provided
Source: [193, TWG 2015]
19.2 ANNEX II - Processing techniques and unit operations

19.2.1 Materials reception and preparation

19.2.1.1 Materials handling and storage

Materials handling applies to the receipt, unpacking, storage and internal conveying of raw materials, intermediate products, final products and other outputs, including waste. It is applied in all FDM premises.

Solid materials are commonly delivered in bags stacked on pallets or in containers. They may also be delivered frozen, packed in standardised blocks with carton linings. They are typically transported by forklift trucks and stored in warehouses. Larger amounts of solid raw materials and powders are mostly delivered in bulk. These are offloaded directly for processing or stored in silos for future use. Solid raw materials can be conveyed by water, e.g. as is often the case for vegetables, roots and tubers, by air, e.g. as is the case for solid particles and powder, or by conveyor belts, elevators, screw conveyors and pumps.

Liquid materials are usually delivered in bulk tankers and then pumped into storage tanks. The internal transport of liquid is achieved by pumping the liquid through pipework systems, which can be extensive and complex. Smaller quantities of liquids are also delivered in mini-bulk containers or in drums. These are then transported to storage areas by forklift trucks.

Gases like N₂, CO₂ and SO₂ are delivered and stored in special pressurised containers. When they are required they are connected to the system concerned and transported through the pipework system by pressure differences. For example, SO₂ is used in the processing of sugar and wine, and N₂ and CO₂ in packing and chilling.

Environmental issues

Water

The main release into water is caused by leakages. During the transport by water of solid raw materials, such as vegetables, roots and tubers, both organic and inorganic TSS and soluble compounds are released to water. Cleaning of the various pipes and storage tanks also contributes to water usage and waste water load. The waste water may also contain acid/alkali solutions, FOG, nitrate, nitrite, ammonia and phosphate.

Emissions to air

Emissions to air can occur from vessel vents during filling, and/or conveying by air. These emissions may include dust, VOCs and odours, which are usually minor in quantity and local in effect.

Solid output

Some solid residues can result from vessels or other material handling equipment and from packaging. They can be, e.g. reused in the installation or elsewhere, sold as animal feed or may be disposed of as waste.

Energy

Materials handling is almost exclusively electrically driven. No significant heat is involved. The environmental issues are minor and relate to electrical consumption.
Noise

Short periods of noise may occur from certain types of vehicle-mounted blowers used to discharge solids and liquids from road vehicles into silos and other vessels.

Accidental release

Accidental releases can occur, e.g. during unloading when connecting or disconnecting hoses and during storage if valves are not fully closed or maintained.

19.2.1.2 Sorting/screening, grading, dehulling, destemming/destalking and trimming

Most raw materials contain some components which are inedible or have variable physical characteristics. Processing techniques such as sorting or screening, grading, dehulling, destemming or destalking and trimming are necessary to obtain the required uniformity of the raw material for further processing. A metal detector may also be used to ensure any metal particles in the raw material are removed. These processing techniques are used as a first step in the processing of fruit and vegetables. They are also used for meat, egg and fish processing.

Dry and wet sorting or screening is the separation of raw materials and/or slurries into categories on the basis of shape, size, weight, image and colour. Dry sorting is applied in the malting industry to select even sized grains. Wet sorting is used for slurries, to separate components.

Size sorting and dry cleaning of agricultural raw materials separates solids into two or more fractions. Size sorting is especially important for FDM products which have to be heated or cooled, as large differences in size can lead to an over or under-processing of the product. For size sorting, various types of screens and sieves, with fixed or variable apertures, can be used. The screens may be stationary, rotating or vibrating. Shape sorting can be carried out manually or mechanically with, e.g. a belt- or roller-sorter. Weight sorting is a very accurate method and is, therefore, used for more valuable foods, e.g. for cut meats, eggs, tropical fruits and certain vegetables. Image processing is used to sort foods on the basis of length, diameter and appearance, i.e. surface defects and orientation of food on a conveyor. Finally, colour sorting of defective discoloured items, can be applied at high rates using microprocessor controlled colour sorters.

Sorting also allows the separation of some additional undesirable material at first sight, e.g. leaves and stones, or inappropriate raw material such as immature or rotten berries, and is aimed at ensuring that only good quality food is preserved and passed on for further processing.

Grading is the assessment of a number of food characteristics to obtain an indication of their overall quality. The technique is normally carried out by trained operators. Meats, e.g. are examined by inspectors for disease, fat distribution, carcase size and shape. Other graded products include cheese and tea. In some cases, grading is based on laboratory analysis results.

In the wine industry, grading covers the necessary classification of the grapes harvested according to their degree of maturity, e.g. sugar content. Many characteristics cannot be examined automatically and trained operators are employed to simultaneously assess several characteristics to produce a uniform high quality product. Grading is more expensive than sorting due to the high costs of the skilled personnel required.

Dehulling is the removal of hulls from vegetables and shells from cocoa beans. To remove the shells from cocoa beans, the beans are first broken between adjustable toothed rollers. The broken pieces are subsequently separated in fractions by sieving. Each fraction is treated with a
A stream of air that carries the light shell pieces away. This breaking and fanning process is often referred to as winnowing.

Dehulling is also used in soybean crushing processes. The dehulling of soybeans is always preceded by a heating step, which enhances the removal of the hulls. The ease of dehulling vegetables depends on the thickness of the seed coat and can be achieved via wet or dry methods. The wet method involves soaking the vegetables in water for a few hours, draining, drying, milling and then blowing them with air to remove the seed coat. In the dry method, oil is mixed with the seeds by passing them through emery-coated rollers to abrade the surface. This is common practice for vegetables with particularly tough seed coats.

Destemming or destalking is the removal of fruit and vegetable stems, e.g., grapes. It is used for winemaking.

Trimming is used for the removal of either inedible parts or parts with defects, or for cutting the raw material to a size that is suitable for further processing. Trimming can be carried out manually or by rotating knives.

Environmental issues

Water

Wet screening may result in a waste water stream containing soluble organic matter and TSS.

Emissions to air

When dry cleaning food/agricultural raw materials, dust may be produced. Odour may also be a problem. These emissions are minor in quantity and local in effect.

Solid output

Material that is sorted out, or removed, is usually recovered as far as possible and then often used as animal feed. If the material cannot be used, it is disposed of as waste.

Energy

Although sorting generally needs little energy, there are large variations in electrical energy consumption. For example, in vegetable processing, the sorting operation has an electrical energy consumption of 0–20 kWh/t frozen vegetable. [32. Van Bael J., 1998]

Washing (A.4)

Objective

This section applies to washing the FDM materials only and not cleaning the equipment or the process installation. The objective of washing is to remove and separate unwanted components to ensure that the surface of the food is in a suitable condition for further processing. Unwanted components can include dirt or residual peel, brine used for preservation, soil, microorganisms, pesticide residues and salts.

Field of application
Washing is widely applied as a first processing step for root crops, potatoes, cereals, fruit and vegetables.

Description of techniques, methods and equipment

There are many types of machines and systems that have been adapted for washing material. Washing can be carried out by vigorous spraying with water, or by immersion with the aid of brushes, or by shaking and stirring. Sometimes cleaning substances are added. Warm water may be used but this can accelerate chemical and microbiological spoilage unless careful control of the washing time and process is carried out.

The dirt, once loosened, usually differs so greatly from the product that the actual separation of dirt and product is normally straightforward, e.g. by sedimentation. Semi-processed vegetables may arrive at the installation in strong brines, if so, the excess salt needs to be removed by rinsing with running water.

Environmental issues for washing (A.4) and thawing (A.5)

Water

Water is required and the waste water typically contains dissolved organic matter, TSS and salts.

Solid output

The dirt and vegetable matter removed during the washing of, e.g. sugar beets and potatoes, is sent for landspreading or for landfilling.

Energy

The electricity consumption for washing operations heavily depends on the vegetable concerned. Washing spinach, for instance, is energy intensive.

During washing operations, hot water can be used to increase the speed and efficiency of the washing. Most companies do not heat the water. Sometimes hot residual water from the blanching system is used for washing [15, Van Bael J. 1998].

Thawing using hot air consumes energy.

19.2.2  Size reduction, mixing and forming

19.2.2.1 Cutting, slicing, chopping, mincing, pulping and pressing

The objective of cutting, slicing, chopping, mincing, pulping and pressing is to reduce the size of material either for further processing or to improve the eating quality or suitability for direct consumption. These operations are widely applied in the FDM sector. For example, they are used in the processing of meat, fish, cheese, vegetables, fruit, potatoes, and various crops, e.g. sugar beets. A large variety of equipment is available, normally adapted to the product to be processed. Equipment can be power or hand-operated, depending on the size of the operations.

Cutting is used for size reduction of large to medium sized materials. Knives, blades, cleavers or saws are usually used for cutting. Cutting is an important operation in meat and fish processing.
The cutting of meat is used post slaughtering to dress and split carcases, to remove offal and to remove appendages and is covered in the Slaughterhouse and animal by-products BREF [93, COM 2005]. At meat installations, carcases are further reduced into retail cuts of joints by the removal of bone, skin and fat. Meat prepared for further processing into, e.g. ham, bacon or sausage, is initially treated in a similar manner to fresh meat, and will then be subject to further processing operations. These may include deboning, derinding, defatting, slicing, chopping, mincing and emulsifying. The cutting equipment used in meat processing includes power operated cleavers, circular or straight saws for splitting carcases, and band saws for the further reduction of the carcases. These are all electrically operated. Special derinding machines are used for separating rind and fat from pork. The cutting of potatoes for the production of potato chips often involves the use of hydro cutters where the potatoes are conveyed by water at high speed over fixed blades.

Slicing produces pieces of material of equal thickness. Slicing equipment consists of rotating or reciprocating blades which cut the food when it passes beneath. Sometimes the material is pressed against the blades by centrifugal force. In other cases, e.g. for slicing meat products, the material is held on a carriage as it travels across the blade. Hard fruit, such as apples, are simultaneously sliced and de-cored as they are forced over stationary knives inside a tube. In the sugar industry, sugar beets are cut into thin slices, called “cossettes”.

A variant of slicing is dicing and is applied to meat, fruits and vegetables. In dicing, the food is first sliced and then cut into strips by rotating blades. The strips are passed on to a second set of rotating knives, which operate at right angles to the first set, and cut the strips into cubes.

Chopping breaks down raw materials into small particles. Chopping into a coarse pulp is applied to meat, fruits and vegetables. In chopping, the material is placed in a slowly rotating bowl and subjected to a set of blades rotating at high speed. This technique, also called bowl chopping, is widely used in the production of sausages and similar products. The degree of size reduction can be varied depending on the knife-speed and cutting time, and in extreme cases, the material can be reduced to an emulsion if required.

Mincing is mainly used for the size reduction and homogenisation of meat. A meat grinder is used to mince the meat. This is a lightly constructed screw press with a cutting plate or rotating knives at its outlet. The process is a combination of cutting and extrusion, where the meat is passed through a plate with orifices.

Pulping is mainly used for the size reduction and homogenisation of fruit and vegetables. A moving rough surface ruptures the fruit or vegetables and squeezes the material through a gap producing an homogenised mass. The most common pulpers are drum pulpers and disc pulpers. Sometimes the pulping process is used for juice extraction.

Pressing is applied to extract the liquid part of grapes, other raw materials or marc after maceration. Pressing is used in wine production, for some other alcoholic drinks and for fruit and vegetable juices.

There are two main types of press. The horizontal pneumatic press comprises an inflated pneumatic membrane located in the centre of the press. Berries are slowly pressed releasing the juice, usually known as must in wine, cider and perry making, in a tank, while the solid parts remain in the press. In a hydraulic compression vertical press, grapes are placed in a cage which contains them during the pressing. A horizontal tray presses the grapes vertically and the must which flows through the cage is collected in a tank for further processing. The grapes remain in the cage. There are also other types of presses, e.g. belt presses and horizontal presses.

Environmental issues (B.1)

Water
Annexes

Waste water results mainly from the cleaning of equipment. It usually contains soluble organic material, such as small particles of meat, fruit and vegetables. In meat processing, the waste water may also contain soluble proteins, FOG and other solids, such as curing salts.

Solid output

The by-products generated depend on the raw material and process, e.g. in meat cutting, typical by-products are bones, fat and skin. These are usually used for other manufacturing processes, which might even be outside the FDM sector, such as soap manufacture. Other typical outputs include fruit and vegetable peelings.

Energy

Electrical energy is used for various equipment.

Noise

Some high-speed, power operated equipment is used which can generate high noise emission levels, e.g. circular saws used to cut through bones and bowl cutters. However, this is usually not an issue, as the noise typically does not carry off-site receptors.

19.2.2.2 Mixing/blending, homogenisation and conching

The aim of this group of operations is to obtain a uniform mixture of two or more components or to obtain an even particle size distribution in a food material. This can also result in improved characteristics and eating quality. These operations are widely applied in almost all FDM sectors.

Mixing or blending is the combination of different materials. The spatial distribution of the separate components is reduced to obtain a certain degree of homogeneity. Various mixing operations can be distinguished in the FDM sector.

Mixing solids with solids is carried out, e.g. during the production of animal feed, blends of tea and coffee, dried soup, cake mixes, custard, ice-cream mixes and malt blends. Mixing equipment commonly used includes rotating drums, rotary mixers, paddle and ribbon mixers and mixing screws in cylindrical or cone-shaped vessels and variable speed drive screws. Generally, cyclones are used as an integral part of the process to recover dust from the extracted air. The recovered material is then reprocessed.

Mixing solid with liquid is carried out, e.g. during the production of canned foods and dairy products. This type of mixing is also used in, e.g. the production of chocolates and sweets, where the ingredients are mixed in a more or less liquid state and solidify on cooling. For viscous mixtures, kneading machines are used. For low viscosity mixtures various types of stirrers, impellers and agitators are used.

Mixing liquid with liquid is carried out, e.g. during the production of emulsions like mayonnaise, margarine and mixtures of solutions. This type of mixing is also used to blend different wines or mineral water with each other or with additives or extra ingredients. Various types of stirrers, impellers and agitators are used.

Mixing liquid with gas is carried out, e.g. when making ice cream, whipped cream and some sweets. During spray drying, the liquid phase is mixed in a stream of gas. Atomisers are used to produce small liquid droplets, which are brought into contact with a stream of gas. When making ice cream, whipped cream or a foam, small gas bubbles are fed into a liquid.
The aim of homogenisation is to attain a more even particle size or a more homogeneous blend of materials. It is, e.g. applied to whole milk to reduce the size of fat globules so that they stay evenly divided in the milk, thereby preventing the fat separating and the cream rising. The liquid, i.e. whole milk, is pressed under high pressure, 200 to 300 bar, through a small orifice.

Conching is a special method of kneading used in the chocolate industry. The molten chocolate mass is placed in a special trough-shaped vessel and is kneaded by a granite roller moving slowly back and forth. The aim of conching is to reduce the viscosity of the mass and to improve the flavour and the texture.

Environmental issues (B.2)

Water

The use of water in this group of operations is normally restricted to cleaning the equipment. The amount used depends on the type of equipment. The resulting waste water contains soluble organic material, TSS, FOG and may also contain nitrate, nitrite, ammonia and phosphate.

Emissions to air

In operations where solid and volatile materials are treated, emissions to air can occur. Odour may be produced by operations which involve VOCs. Dust is emitted in operations involving solids such as solid/solid mixing.

Solid output

In operations where solid materials are processed, solid organic output may be generated when equipment is emptied for the next batch or for cleaning. Normally some losses occur during such operations. This solid waste can consist of raw materials or waste products. By careful operation and good housekeeping, the amount of solid output can often be reduced and any output resulting may be reused or sold as animal feed.

Energy

These unit operations require mainly electrical energy input.

Noise

Homogenisation may be a source of noise.

19.2.2.3 Grinding/milling and crushing

Grinding or milling is used for the size reduction of solid dry material. It may also improve the eating quality and/or suitability of the material for further processing. It is the main process in the cereal and animal feed industry and is also used to crush cane sugar and to facilitate the extraction of sugar in sugar and rum factories. Crushing covers, for instance, breaking the skin of berries and grapes to liberate the must.

Grinding or milling is applied where dry solid materials are processed, e.g. in the flour milling, animal feed, semolina, brewing, sugar and dairy sectors. Crushing is necessary to facilitate the yeasts’ multiplication and also to conduct traditional macerations before pressing, e.g. in winemaking.
A whole range of grinding or milling techniques and equipment are available for application with different types of food. It can be carried out dry or wet. In wet grinding or milling, smaller particle sizes can be attained. Often the dry technique is combined with sieving or air classification, which results in particle size fractions. Generally abatement systems, e.g. cyclones, are used as an integral part of the process, to recover dust from the extracted air. The recovered material is then reprocessed.

The common types of mills used in the FDM sector are hammer mills, ball mills, roller mills and disc mills. A hammer mill consists of a horizontal or vertical cylindrical chamber lined with a steel breaker plate and contains a high speed rotor fitted with hammers along its length. The material is broken apart by impact forces as the hammers drive it against the breaker plate. A ball mill consists of a slowly rotating horizontal steel cylinder, half filled with steel balls of 2.5 to 15 cm diameter. The final particle size depends on the speed of rotation and on the size of the balls. A roller mill consists of two or more steel rollers which revolve towards each other and pull particles of the food material through the space between the rollers, the space is known as the nip. The size of the nip can be adjusted for different food materials. A disc mill consists of either a single rotating disc in a stationary casing or two discs rotating in opposite directions. The food material passes through the adjustable gap between the disc and the casing or between the discs. Disc mills have intermeshing pins fixed onto the discs and casing. This improves the effectiveness of the milling.

Environmental issues (B.3)

Water

Wet grinding consumes large quantities of water.

Emissions to air

Dust is emitted in operations involving solids. VOCs may also be emitted.

Solid output

Solid organic output is generated when equipment is emptied for the next batch or for cleaning. Some losses occur during such operations. This solid output can consist of raw materials or waste products and can be reprocessed or sold as animal feed.

Energy

Grinding requires a significant energy input.

Noise

Grinding is a source of noise.

Forming/moulding and extruding

Objective

Forming or moulding and extruding are operations used to achieve a specified shape for solid materials.
Field of application

Forming or moulding is an operation widely applied in the production of chocolate, bread, biscuits, confectionery and pies. It is also an important process step in cheesemaking. Extruding is widely used in the production of meat sausages, confectionery products and starch-based snack foods.

Description of techniques, methods and equipment

In forming or moulding, the material is in a viscous form and is fed into the appropriate mould. As the moulding process progresses, the material becomes firmer and solidifies up to the point that it becomes a fixed shape.

Extruding is a continuous process of shaping. The material is kneaded under high pressure and pressed continuously through openings of the required shape. In cooking extruders, the material is also heat-treated or cooked, to solubilise starches. Extruders can contain one or two screws. The rotation of the screws transports and mixes the material and produces pressure build-up.

Environmental issues (B.4)

Water

Waste water is generated during the cleaning of equipment and contains primarily soluble organic material and TSS and may also contain nitrate, nitrite, ammonia and phosphate.

Emissions to air

Extrusion at high temperatures may result in some emissions to air of VOCs and odour.

Solid output

Some solid waste may be generated due to the loss of product at the beginning and end of the production process.

Energy

Typically, extruders are major users of electrical energy.

19.2.3 Separation techniques

19.2.3.1 Extraction

The objective of extraction is to recover valuable soluble components from raw materials by primarily dissolving them in a liquid solvent, so that the components can be separated and recovered later from the liquid. It is not always the objective to recover one particular compound in pure form from a raw material, i.e. sometimes extraction is intended to separate all of the soluble compounds from the residue; an example of this is the extraction of coffee.

Extraction is widely applied in the FDM sector. For example, in the extraction of sugar from sugar beets or sugar cane, oil from oilseeds and from virgin pomace, coffee extract from coffee beans, caffeine from coffee beans and various other compounds such as proteins, pectins,
vitamins, pigments, essential oils, aroma compounds and flavour compounds from many different materials.

Extraction works according to the principle that soluble components can be separated from insoluble or less soluble components by dissolving them in a suitable solvent. Raw materials that are suitable for extraction may contain either solids only, solids and a solution, or solids and a liquid. Solid/liquid extraction is sometimes called leaching. When the soluble component is incorporated in a liquid, the extraction may be applied to recover the valuable soluble component. Commonly, the extract is the product or intermediate product and the residue is a waste or by-product. The efficiency of the extraction process depends on the selectivity of the solvent. Common solvents include water, organic solvents such as hexane, methylene chloride, ethyl acetate and alcohol. Supercritical CO\textsubscript{2} is used in coffee extraction.

Raw materials are usually pretreated to ensure efficient extraction of the desired compounds. For example, sugar beets and sugar cane are cut into thin slices, nuts and seeds are ground or flaked, coffee beans are roasted and ground, and tea leaves are dried and ground.

The simplest extraction method is a repeated extraction with fresh solvent called lateral flow extraction. However, this is rarely used because of the costs of the solvent and because it results in a very low concentration extract. The most common method used is countercurrent extraction, either in a batch or continuous process. Batch wise countercurrent extraction is normally only used for the processing of small amounts of material. In continuously operating extractors, the solid material and the solvent flow countercurrently. One difficulty with extraction is the recovery of the extracted material from the solvent. This can be carried out by evaporation, crystallisation, distillation or steam stripping.

In principle, many different methods of transport are possible for material and liquid flows. Some examples of transport systems commonly used include perforated trays connected to an unbroken conveyor or loop, moving horizontally or vertically; screw conveyors which transport the solid material in a countercurrent flow vertically or upwards under an incline slope, the screws are perforated to obtain a uniform flow of liquid and finally, an unbroken perforated belt where the solvent is circulated under pump action and sprayed on top of the solid material.

Environmental issues (C.1)

Water

Water usage is an issue when water is used as a solvent in the extraction process. Also, extraction equipment is cleaned periodically to ensure efficient and optimum operating conditions. The frequency of cleaning depends on the product and extractor design. This cleaning will generate waste water containing soluble and insoluble organic material and TSS.

Emissions to air

Extraction with organic volatile solvents may cause emissions of VOCs. Council Directive 1999/13/EC [157, EC, 1999] includes provision for oilseed extraction, including VOC emission limit values for vegetable oil and animal fat extraction, and vegetable oil refining activities.

Extraction plants may also cause odour, due to the emission of H\textsubscript{2}S and organic compounds. When extraction with water takes place, water vapour containing non-condensable VOCs may be released to the air.

Solid output
The solid output may be reused as a product or co-product, or be disposed of. For example, after the removal of the adhering water, spent coffee grounds can be burned as fuel in steam boilers or used as raw material for further processing. The solid output may contain solvents.

Energy

Electrical energy and steam are required; the consumption levels depend on the type of application. For example,

Noise

Possible sources of noise are cooling towers, fans and steam safety valves.

Deionisation

Objective

Deionisation or ion exchange is used to remove unwanted organic and/or inorganic constituents from water and food products. See also electrodialysis in Section 0.

Field of application

In the dairy industry, deionisation is applied in whey processing. For the application of whey solides in human food and in baby food, low levels of mineral constituents are required. Deionisation is also widely used in the FDM sector for the treatment of boiler feed-water for power and steam generation and for the production of deionised process water. Deionisation is also applied to remove minor ionised organic substances.

Description of techniques, methods and equipment

Deionisation is normally carried out by passing the product through a column containing ion exchange resin beads. The beads contain a large number of active sites which are capable of holding a wide variety of metals, non-metal inorganic molecules and ionised organic constituents. The columns are operated batch wise and need to be regenerated when the beads are exhausted or saturated. This is normally carried out by treatment of the columns and beads with a variety of chemicals which remove the impurities and regenerate the active sites.

Environmental issues (C.2)

Water

The regeneration of ion exchange columns produces water containing the chemicals used for regeneration, usually acids or alkalis and brine; ions removed from the product, minerals and impurities extracted from the used column. The pH of the waste water fluctuates. Regeneration starts with rinsing the ion exchange columns with water. This produces waste water containing soluble organic material and product residues, which depending upon their dilution, may be reprocessed.

Solid output
The only solid output is the ion exchange resin at the end of its useful life. This can be anything from 6 months to 10 years depending on the operation and product, and the type of ion exchange resin used.

19.2.3.2 Centrifugation

Centrifugation is used to separate immiscible liquids and solids from liquids. Separation is carried out by the application of either centrifugal forces or natural gravity.

Typically used in the dairy industry in the clarification of milk, the skimming of milk and whey, the concentration of cream, the production and recovery of casein, in the cheese industry and in lactose and whey protein processing. It is also used in drink technology, vegetable and fruit juices, coffee, tea, beer, wine, soya milk, oil and fat processing/recovery, cocoa butter manufacturing, sugar manufacturing and waste water treatment.

Centrifugation is used to separate mixtures of two or more phases, one of which is a continuous phase. There are two general ways to operate centrifuges. Continuous systems and systems with breaks for cleaning. In continuous systems, the sludge can be discharged during the process. The driving force behind the separation is the difference in density between the phases. By using centrifugal forces, the separation process is accelerated. The necessary centrifugal forces are generated by rotating the materials. The force generated depends on the speed and radius of rotation. In raw milk, e.g. the skimmed milk is the continuous phase, the fat phase is a discontinuous phase formed of fat globules with diameters of some microns, and a third phase consists of solid particles. In beer production, clarification of the hot wort is carried out to remove hot trub particles to get a clear wort. The commonly used equipment for wort clarification is the hydrocyclone, where wort trub particles are separated in tangential flow.

Centrifuges are classified into four groups:

- tubular and disc bowl centrifuges
- solid bowl and nozzle or valve discharge centrifuges
- conveyor bowl, reciprocating conveyor and basket centrifuges
- hydrocyclones or whirlpools.

A tubular bowl centrifuge consists of a vertical cylinder, which rotates at 15000 to 50000 rpm, inside a stationary casing. It is used to separate immiscible liquids, e.g. vegetable oil and water or solids from liquid. The two components are separated into annular layers, with the denser liquid or solid setting nearer to the bowl wall. The two layers are then discharged separately. Typically, the disc bowl centrifuge is more widely used in the FDM sector as it can achieve a better separation due to the thinner layers of liquid formed. The cylindrical bowl contains inverted cones or discs and the liquids only have to travel a short distance to achieve separation. These centrifuges operate at 2000 to 7000 rpm and have capacities of up to 150000 l/h. Disc bowl centrifuges are used to separate cream from milk; to clarify oils, coffee extracts and juices or to separate starch from slurry.

A solid bowl centrifuge is the simplest solids/liquid centrifuge and is useful when small amounts of solids are removed from large volumes of liquid. It consists of a rotating cylindrical bowl. Liquor is fed into the bowl; the solids settle out against the bowl wall whilst the liquid spills over the top of the bowl. Cakes can also be removed without stopping the centrifuge. Liquors containing higher levels of solids, i.e. >3 wt-%, can be separated using nozzle or valve discharge centrifuges. These centrifuges are a modified disc bowl centrifuge with a double conical bowl which enables the automatic discharge of solids. These types of centrifuges are used to treat oils, juices, beers and starches to recover solid parts, e.g. yeast cells. They have capacities of up to 300000 l/h. A special type is the bactofuge, which is a high speed centrifugal process which separates bacterial cells and spores from milk.
The conveyor bowl or decanter, reciprocating conveyor and basket centrifuges are used when the feed contains high levels of solids or sludges. They are used to recover animal protein, e.g. precipitated casein from skimmed milk, vegetable proteins, to separate coffee, cocoa and tea slurries and to remove sludge from oils. In the conveyor bowl centrifuge, the solid bowl rotates at 25 rpm faster than the screw conveyor. This causes the solids to be conveyed to one end of the centrifuge whereas the liquid fraction moves to the other larger diameter end. The reciprocating conveyor centrifuge is used to separate fragile solids, e.g. crystals from liquor.

The feed enters a rotating basket through a funnel, which rotates at the same speed. This gradually accelerates the liquid to the bowl speed and thus minimises shear forces. Liquid passes through perforations in the bowl wall. When the layer of solids has built up, it is pushed forward by a reciprocating arm. The basket centrifuge has a perforated basket lined with a filtering medium, which rotates at 2000 rpm. Separation occurs in cycles, which last from 5 to 30 minutes. In the three stages of the cycle, the feed liquor first enters the slowly rotating bowl, the speed is then increased and separation takes place, finally the speed of the bowl is reduced and the cake is discharged through the base. Capacities are up to 90000 l/h.

A typical hydrocyclone comprises a conical section terminating in a cylindrical section. The hydrocyclone is fitted with a tangential inlet and closed with an end plate, with an axially mounted overflow pipe or vortex finder. The end of the conical portion terminates in a circular apex opening. During operation, the slurry is forced, under pump pressure, through the tangential inlet and this produces a strong swirling motion. The fraction of the slurry contains the lighter particles discharged through the overflow, and the remaining slurry and solids are discharged through the underflow opening.

Environmental issues (C.4)

Water

Water is used periodically to clean the separation equipment. The frequency of cleaning and the volumes of water used vary depending on the product and the equipment. Sometimes the water can be reprocessed. Waste water is produced from cleaning the equipment, as well as in the form of separated waste products from the operational process, which will contain dissolved organic material and TSS.

Solid output

Centrifugal separator sludges may sometimes be reused in the process or may otherwise have to be disposed of. The sludges produced contain organic and inorganic material.

Energy

Centrifugation uses significant amounts of energy. When sedimentation is used, electrical energy is required for pumping operations.

Noise

The operation of centrifuges may involve relatively high noise emission levels in close proximity to the machines and, therefore, suitable control measures need to be put in place.
19.2.3.3 Filtration

Filtration is the separation of solids from a suspension in a liquid by means of a porous medium, screen or filter cloth, which retains the solids and allows the liquid to pass through. Air filtration is discussed in Sections 2.3.7.2.2 and 2.3.7.2.5.

Filtration is used in the FDM sector to clarify liquid products by the removal of small amounts of solid particles with the subsequent recovery of the filtrate, e.g. for wine, beer, oils and syrups, and to separate a liquid from a significant quantity of solid material to obtain the filtrate or cake, or both, e.g. for fruit juices or beer.

The technique operates either by pressure filtration, i.e. applying pressure to the feed side, or by vacuum filtration, i.e. applying a vacuum to the filtrate side.

The two main types of pressure filtration are the plate and frame filter press and the leaf filter.

The plate and frame filter press consists of plates and frames arranged alternately and supported on a pair of rails. The hollow frame is separated from the plate by the filter cloth. The slurry is pumped through a port in each frame and the filtrate passes through the cloth and flows down the grooved surfaces of the plates and is drained through an outlet channel in the base of each plate. The filter operates at a pressure of between 250 to 800 kPa. The filter press is operated batch wise; the optimum cycle time depends on the resistance offered by the filter cake and the time taken to dismantle and refit the press. This press can be used when the dismantling, emptying and refitting of the presses are carried out in a semi-automatic manner. Sometimes, filter aids such as perlite or diatomaceous earth are used as a pre-coat or body feed to improve the filtration. The equipment is reliable and easily maintained, and is widely used, particularly for the production of apple juice and cider and in edible oil refining. A special type of plate and frame filter press is the membrane filter press. A membrane is mounted onto the plate which can be pressurised with air or water. Due to the higher pressure on the filter cake, up to 20 bar, more liquid is recovered resulting in a dryer filter cake.

Vacuum filters are normally operated continuously. Liquor is sucked through the filter plate or cloth and the solids are deposited on the cloth. The pressure difference on the downstream side of the filter plate is normally limited to 100 kPa due the cost of vacuum generation. Sometimes, filter aids are used as a pre-coat or body feed to improve filtration. In these cases, a knife is used to scrape off the solid residue. Two common types of vacuum filter are the rotary drum filter and the rotary vacuum disc filter.

Rotary drum filters consist of a slowly rotating cylinder, which is divided into compartments, which are themselves covered with a filter cloth and connected to a central vacuum pump. As the drum rotates, it dips into a bath of liquor. The filtrate flows through the filter cloth of the immersed compartment. When the compartment leaves the bath, the filter cake is sucked free of liquor and washed. As the drum rotates further, the vacuum is released for the compartment in question and the cake is loosened from the cloth by the application of compressed air, and then removed by means of a scraper. The same procedure occurs for each compartment in turn as the cycle is repeated.

Rotary vacuum disc filters consist of a series of vertical discs which rotate slowly in a bath of liquor in a similar cycle to drum filters. Each disc is divided into segments and each segment has an outlet to a central shaft. The discs are fitted with scrapers to continuously remove the solid residue.
Environmental issues (C.5)

Water

Depending on the end purpose of the filtration operation, the process may result in waste water containing dissolved organic material, TSS and FOG.

Emissions to air

The air discharge from the vacuum pump during vacuum filtration may contain dust. These emissions are minor in quantity.

Solid output

Filter residues arise and require a suitable method of recovery or disposal, e.g. bleaching earth in edible oil refining or diatomaceous earth in a brewery.

Energy

Pumping requires electrical energy.

Membrane separation

Objective

Membrane separation is aimed at the selective removal of water, solutes and/or suspended material from a solution by using semi-permeable membranes. It is considered to be a fractionation technique.

Field of application

Membrane separation is applied for the concentration of liquids, e.g. with cheese whey, the removal of salts from whey or water, whey fractionation, and water purification.

Description of techniques, methods and equipment

There are two membrane separation techniques used in the FDM sector, i.e. membrane separation and electrodialysis.

Membrane separation is a pressure driven filtration technique in which a solution is forced through a porous membrane. Some of the dissolved solids are held back because their molecular size is too large to allow them to pass through. The size range depends upon the type of membranes used. Fractionation of the feed stream occurs, with some molecules being concentrated on the upstream side of the membrane, which is known as the concentrate or retentate. The smaller molecules pass through the membrane into the permeate stream.

The various membrane separation techniques can be characterised by their membrane pore size. Cross-flow microfiltration can be used to remove bacteria from skimmed milk, or for fractionation of the skimmed milk into a casein rich retentate and a milk serum devoid of casein;
the membrane pore size ranges from about 0.1 to 5 μm. Ultrafiltration (UF) is applied to both skimmed milk and whey, to concentrate the respective protein components; the membrane pore size ranges from about 10 to 100 nm. Nanofiltration (NF) membranes have selective permeability for minerals and some small organic and inorganic molecules and NF is used predominantly for concentration and pre-deminalisation (removal of salt) of whey; the pore sizes of the NF membrane range from about 1 to 10 nm. Reverse osmosis filtration (RO) membranes are permeable to water but not minerals and are, therefore, used for dewatering, concentration of whey or skimmed milk; or for polishing NF permeates or evaporator condensate and in water treatment, e.g. softening and salt removal; the membrane pore size ranges from about 0.1 to 1 nm.

Electrodialysis is a membrane separation process undertaken in the presence of an applied electro potential. Low molecular weight ions migrate to an electrical field across cationic or anionic membranes. These membranes are alternately arranged between the cathode and anode within a stack. It is principally applied in the dairy industry for the removal of salt from whey.

Environmental issues (C.6)

Water

Water is used periodically to clean the separation equipment. The frequency of cleaning and the volumes of water used vary depending on the product and equipment. Waste water is produced from washing as well as in the form of separated waste products from the process, and contains dissolved organic material and TSS.

Energy

Membrane separation is a pressure driven process, so electrical energy is required. In electrodialysis, electrical energy is required for the transport of ions.

Crystallisation

Objective

The objective of crystallisation is to separate a solute from a solvent.

Field of application

Crystallisation is applied in the dairy industry, where lactose is produced from cheese whey or casein whey, and the sugar industry. It is also used in the edible oil industry to modify the properties of edible oils and fats; in this case it is also called fractionation.

Description of the technique, methods and equipment

Crystallisation is the formation of solid crystals from a solution. Crystals solidify in a definite geometric form. They are usually grown by the introduction of nuclei into a supersaturated solution. Any impurities in the liquid are usually not incorporated into the lattice structure of the desired crystal. Accordingly, crystallisation is also a purification process.

Environmental issues (C.7)
Water

In crystallisation operations, water is used for cooling and is normally recirculated. Depending on the cooling requirements, water is recirculated via chilling units, cooling towers or cooling ponds. Waste water containing soluble organic material is generated after the removal of crystals.

Solid output

In the refinery process, active carbon is used if required. Spent active carbon is either regenerated or disposed of as waste.

Energy

Electricity is needed to power the pumps and drives. Energy is required for the cooling system.

Product processing technology

Soaking

Objective

The objective of soaking, e.g. of vegetable seeds such as lentils, is to moisten and soften the seeds to reduce the cooking time or to aid in seed coat removal. In the malting process, the objective of soaking is the uptake of water to activate the germination process in the kernel.

Field of application

Soaking is predominantly applied in the processing of vegetable seeds. It is also applied with grain, where the grain is soaked in the malting process prior to germination. This is often called steeping.

Description of techniques, methods and equipment

Soaking is performed by putting the vegetable seeds in water for a specified time. The time needed varies depending on the seed variety and species and with the length of storage and storage conditions. Traditionally, dry beans are soaked for 8 to 16 hours in cold water with appropriate hardness. High temperature soaking accelerates hydration. To steep the grain, the grain is immersed in water at about 16 ºC, ranging from 10 to 25 ºC, depending on the equipment, the process parameters, the raw material and the finished malt to be obtained. During steeping, the moisture content increases from 12 to 15% to anywhere between 30 to 50%, depending again on the above conditions. During steeping, the water in the steep tank is changed one to three times. Alternate wet and dry stages are applied. During the wet stage, the grain is aerated continuously or at intervals. During the dry stage, the grain can be aerated or the CO₂ can be extracted. The steeping process takes one to three days.

Figure: shows an example of a steeping procedure.
Annexes

Water

For soaking, water is required and consequently some waste water containing dissolved organic material and TSS is produced.

Solid output

Some dirt can be produced, although this is usually removed during soaking. Organic solid output may also be produced.

Dissolving

Objective

Dissolving is the addition of powder to liquid to produce solutions or suspensions for further processing.

Field of application

This process is used in a variety of products to recombine and reformulate them. For example, dissolving is used for recombining or reformulating milks in the dairy industry.

Description of techniques, methods and equipment

A variety of processes and equipment are used for this purpose. Different mixing systems may be used for the same task, ranging from simple batch dissolving tanks with efficient mixing devices, to continuous mixing processes which involve either drawing solid materials into the liquid phase or mechanical powder injection into the liquids. Depending on the product, the liquids may be at ambient or elevated temperatures.

The main types of dissolving systems are:

- a blending pump that sucks the powder into the solvent. Used for total solids of up to 25%
jet dissolving which uses the venturi principle to suck powder into the solvent. Used for total solids of up to 30%.

a dissolving tank with high shear mixing impeller. Used for total solids of up to 70%.

a dissolving tank under vacuum with high shear impeller. Used for total solids of up to 30%.

Environmental issues (D.2)

Water

Waste water is generated during cleaning. This waste water may contain product residues, e.g. powder and oil from rinsing, resulting in dissolved organic material, dissolved solids and TSS in the waste water.

Emissions to air

Dust emissions may occur during bag tipping. These emissions are typically minor and generally remain inside buildings.

Energy

During the dissolving process, steam and electricity are used.

Solubilisation/alkalising

Objective

Solubilisation or alkalising is the neutralisation of cocoa nibs or cocoa liquor with an alkaline solution, resulting in a darker colour and a milder taste. The milder taste is mainly the result of the neutralisation of the light acidity of fermented beans. Considerable experience and skill is required to obtain end-products with a constant colour and hue.

Field of application

Solubilisation is primarily used in cocoa processing.

Description of techniques, methods and equipment

The process is carried out by adding an alkali solution, usually potassium carbonate (K$_2$CO$_3$), to the cocoa. Two different methods can be applied, i.e. liquid process or nibs alkalising.

In the liquid process, the liquid cocoa liquor is processed. This allows the flavour to be modified. Potash solution is added to the liquor until a pH value of 7 to 8 is achieved. The desired solubility is obtained by increasing the temperature from 45°C up to 130°C. Water vapour and undesirable volatile components are released to the air during the heating phase.

During nibs alkalising, green or pre-dried nibs are processed. This has the advantage of combining the drying with the nibs roasting and the disadvantage of the presence of the cocoa butter in the nibs, which may result in slight damage to the fat. Batch and continuous processes are available. Batch processes consist of a solubilisation tank at atmospheric pressure with a high shear impeller. Continuous processes take place in a reactor followed by a mixing tank,
usually under vacuum. A typical batch alkalising process involves two steps. First, the nibs are neutralised by adding the alkaline solution in a reactive vessel at atmospheric pressure. The reaction takes place within a temperature range of 80 to 105 °C. In the second step, water evaporation and nibs roasting are carried out in a FBD.

Environmental issues

Water

Waste water is generated from the cleaning of equipment and typically contains soluble organic material, TSS and FOG.

Emissions to air

Emissions to air typically consist of water vapour containing low concentrations of VOCs and dust. Odour may also be a problem.

Energy

An example of the typical energy requirements per tonne of cocoa is shown in Table.

Table: Typical energy requirement per tonne of cocoa

<table>
<thead>
<tr>
<th>Process</th>
<th>Electrical power (kJ/kg)</th>
<th>Electrical power (kWh/kg)</th>
<th>Steam (kg/t)</th>
<th>Steam (kWh/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid process</td>
<td>35–70</td>
<td>0.010–0.019</td>
<td>300–500</td>
<td>233–389</td>
</tr>
<tr>
<td>Nibs alkalising</td>
<td>35–550</td>
<td>0.010–0.153</td>
<td>700–1000</td>
<td>548–778</td>
</tr>
</tbody>
</table>

Sources: [1, CIAA 2002]

Germination

Objective

The objective of germination is to activate and develop the enzyme system in the grain kernel. This activated enzyme system is necessary to activate the starch and protein breakdown at the mashing stage before the later brewing process.

Field of application

Germination is an important processing step within the malting process of cereals. Malted cereals, mainly barley, are used for beer production and the production of distilled drinks, e.g. whisky. Malt is also used in food flavouring.

Description of processing techniques, methods and equipment

To start germination, the grain is steeped to obtain the necessary moisture content (see soaking, Section 0). The steeped grain is then transferred into germination vessels with perforated steel plate floors for pneumatic malting, or onto germination floors for floor malting. The grain is layered from about 70 to 150 cm thick for pneumatic malting and from about 5 to 15 cm for floor malting. The germination step generally lasts between 96 and 200 hours. Depending on the equipment, the process parameters, the raw material and the finished malt to be obtained, the germination process can be shorter or longer. Conditioned air, i.e. cooled or heated and
humidified, is blown through the grain layer in pneumatic malting, or over it, in floor malting, to control the temperature and the moisture content during germination. To prevent the grain kernels from matting or felting, the layer of grain is turned from time to time, during which water spraying can also be applied. The germination process is stopped by drying.

Environmental issues

Some water is required for the humidification of air.

Emissions to air

The air from the germination process is loaded with water vapour and minor amounts of VOCs, which may emit odour.

Energy

Energy is needed for conditioning and circulating the air.

Brining/curing

Objective

Brining or curing is a process whereby a product is treated with common salt (NaCl) and curing salts which aims for the preservation of products by lowering the \( a_w \) below microbial tolerance limits.

The objectives of these techniques are the long-life preservation of the control of the growth of spore forming microorganisms, a decrease in the energy needed for heat treatment, and adding taste to the product.

Field of application

Brining or curing is applied in the production of certain types of cheese, meat, fish, vegetables and mushrooms. Salt levels in the product can range from 1 to 5 %.

Description of techniques, methods and equipment

In the brining or curing of meat products, the meat is treated with common salt (NaCl) and with one or more of the following curing salts: sodium nitrate (NaNO\(_3\)), sodium nitrite (NaNO\(_2\)), potassium nitrate (KNO\(_3\)) or potassium nitrite (KNO\(_2\)). The process is designed to produce an acceptable salt level in the product of about 1 – 3 %, or a level of curing salt sufficient to produce an acceptable cured meat colour, which is produced by reaction of the meat pigment myoglobin with nitrite. Nitrite may be used or it may be derived from nitrate, which is converted to nitrite in the curing system. The presence of salt and nitrite in the product inhibit microbial growth and enhance the durability and safety of the product. Thus, salt and nitrite are essential to the curing process.

Whereas the salt content is determined by consumer acceptability, the curing salt content is controlled by law. At present, a maximum of 100 mg/kg of nitrite and 250 mg/kg of nitrate, can be contained in the finished product. Other ingredients may be added to cured meats for a number of reasons, including taste. These include polyphosphates, sugars, spices, non-meat
proteins and starches. Also certain types of cheese are brined for reasons of taste and preservation.

Several methods are applied for brining or curing, i.e. dry brining/curing, injection brining/curing, immersion brining/curing and tumble/massage brining/curing.

Dry brining/curing is applied to meat and cheese. In making cured meat products, salt and other curing ingredients are deposited on the surface of the meat and are absorbed by diffusion over a period of days or even weeks. At the same time liquor diffuses out of the meat, equivalent to about 10% of the initial meat weight. In the production of certain types of cheese, e.g. cheddar, dry salt is added to the curd.

Injection brining/curing is used in meat processing, e.g. bacon and ham. A prepared solution, i.e. brine, containing the ingredients, is injected by needle(s) into the meat, either manually or by machine, to achieve a rapid deposition of curing salts and common salt throughout the mass. After injection, the meat may be further processed or sealed in a plastic vacuum bag for a number of days, or immersed in a brine that is identical or similar in composition to the injected brine.

Immersion brining/curing is applied to cheese, meat and vegetables. During immersion, salt gradually penetrates into the product while water containing soluble product components are extracted from the product. The immersion brine may be discarded after each usage or it may be continually restrengthened and reused with only a bleed being discharged. Water extraction by brining can range from 5 to 15% of the product weight. The salt content of the brine ranges from 5 to 20%.

Tumble/massage brining/curing is especially applied to meat. In this process, the movement of brine into the meat is accelerated by mechanical action. The meat may be injected with the brine before treatment or it can rely on the mechanical action, possibly assisted by vacuum, to accelerate absorption of the brine. This process is normally used when the meat is to be subsequently cooked or canned.

Environmental issues

Water

Brine that is discarded after use, or excess brine from immersion baths, is discharged as waste water. The quantity discharged depends on the method of brining or curing used. This waste water contains salt, curing salts and other ingredients, and also soluble product components, such as protein which is exuded from the product during brining. The cleaning of premises and equipment also generates waste water containing residual curing ingredients, product residues, dissolved organic material, dissolved solids and TSS.

Sulphitation

Objective

The aim of sulphitation is to prevent either microbiological degradation, unwanted colour formation or to adjust pH.

Field of application

Sulphitation is applied in winemaking, potato processing and shellfish processing. It is also sometimes applied in sugar production to adjust the pH.
Description of techniques, methods and equipment

Sulphitation is the introduction of sulphur dioxide (SO\textsubscript{2}) into liquids; the quantity of SO\textsubscript{2} which can be added is regulated. It can be introduced in various forms. First, in gaseous form, generated either by burning sulphur or from liquefied gas and direct expansion. The SO\textsubscript{2} is drawn by a fan into an absorption column in which the liquid flows. Second, in liquid form, from liquefied gas or in sodium or potassium bisulphite solution. The SO\textsubscript{2} may also be stored as a liquid, under approximately 5 bar, in horizontal cylindrical tanks of 25 to 50 m\textsuperscript{3} capacity, from which it can then be introduced into the desired process stream. Third, in solid form, as sodium or potassium metabisulphite dissolved in the liquid to be treated.

An alternative sulphite source is ammonium bisulphite. Sodium bisulphite can also be used.

Environmental issues (D.10)

Emissions to air

A substance of environmental concern is SO\textsubscript{2}; however, it is readily absorbed by the liquid to be treated, e.g. wine, and actual residual emissions are extremely low.

Coating/spraying/enrobing/agglomeration/encapsulation

Objective

The aim of this group of operations is to cover a food product with a layer of material to improve the eating quality, to provide a barrier to the movement of moisture and gases, or as protection against mechanical damage.

Field of application

Coating, by one of the above-mentioned techniques, is applied to confectionery, ice cream, baked goods, snack foods, fish, poultry and potato products.

Description of techniques, methods and equipment

Confectionery, ice cream and baked goods are often coated with chocolate or compound coatings containing chocolate. The principal ingredients in such coatings are fat and sugar. The fat is tempered and held at a temperature of 31 to 32 °C, resulting in a liquid coating mass. This coating is applied to the food products in the form of a single or double curtain through which the food is passed on a stainless steel wire conveyor. A pan beneath the conveyor collects the excess coating, which is then recirculated through a heater to the enrobing curtain. Products like fish, poultry and potato products are often coated with batters. A suspension of flour in water to which sugar, salt, thickening agents, flavourings and colourings are added to achieve the required characteristics of the batter. The product is passed through the batter between two submerged mesh conveyors. Coating with breadcrumbs can take place by depositing food products onto a moving bed of breadcrumbs and then passing the bed through a curtain of breadcrumbs. Other methods for coating are spraying the coating material onto the product, agglomeration of products and encapsulation of the food particles.

Environmental issues

Water
Annexes

Waste water is produced from the cleaning of the equipment. This will contain product residues consisting of dissolved organic material, TSS and FOG.

Emissions to air

Odour is produced.

Solid output

Solid output is produced which contains organic and inorganic material.

Ageing

Objective

The aim of this process is to mature the product, especially for products aged in wooden casks that allow some gas exchange between the product contained in the cask and the environment. It is also part of the legal requirements when manufacturing some products.

Field of application

Ageing is commonly applied to wine and brown spirits.

Description of techniques, methods and equipment

Ageing consists of filling wooden vessels, usually oak barrels, and then storing these vessels at a moderate temperature during a period of time according to the product needs and the regulatory requirements for this product. The capacity of oak barrels is between 200 and 600 litres.

Environmental issues

Water

Water is used for cleaning and this generates waste water which contains soluble organic material and TSS.

Emissions to air

Emissions to air include odour and VOCs.

Solid output

Solid output is produced which contains organic material. Waste from packaging may also be produced.

19.2.4 Heat processing

Melting

Objective
The objective of melting is to obtain a phase change from solid to liquid, to prepare the material for further processing, e.g. for fats and processed cheese, or to recover the melted fraction, i.e. in fat recovery.

Field of application

The main applications of melting in the FDM sector are in chocolate moulding, the production of processed cheese, the processing of oils and fats and the recovery of animal fat from meat residues.

Description of techniques, methods and equipment

For melting, processing kettles are used. These can be operated either batch wise or continuously. Heating may be carried out by direct steam injection or indirectly by steam jackets. Processing kettles are available in various sizes and shapes. In continuous processing, scraped surface heat-exchangers are applied.

Environmental issues

Water

Waste water is generated during cleaning. This waste water generally has high BOD emission levels and may also contain TSS and FOG.

Emissions to air

Odour emissions may occur in the dry melting process of meat residues, for example.

Solid output

In some melting processes, a solid phase remains. This is considered to be a by-product.

Energy

In the melting process, the use of steam is the main energy component.

19.2.4.1 Cooking and boiling

Several processing techniques are available for cooking within the FDM sector; these are described in Section 19.2.4.1. These techniques are also used for cooking, e.g. meat and fish, before preservation in cans, bottles and jars (see Section).

Cooking and boiling are heat processing techniques applied to foodstuffs, principally to make the food edible. They also alter the texture, colour and moisture content of the food and may facilitate other later processes.

Cooking and boiling are applied on an industrial scale for the preparation of ready-to-eat meals, in the preparation of complete meals and for meal components, such as in various meat products. They are also applied to heat foodstuffs prior to final processing.
Cooking is carried out in ovens. There are several different types of ovens; water bath, shower, steam, hot air and microwave.

Water bath ovens allow the best homogeneity of heating to be obtained. The immersion into hot water causes weight loss, and results in proteins and greases being released into the water. Boiling is cooking in a water bath oven at boiling temperature.

Shower ovens allow a good uniformity of heating. They include the simultaneous action of water sent through the showers and the saturated steam which rises from the collecting basin, at the bottom of the oven, which is heated, in turn, by coils.

In steam ovens, the water shower is eliminated and any heating is only due to the steam produced in the collection basin.

Hot air ovens include, when it is necessary to control surface humidity, a steam inlet and a recirculation of hot air which is obtained by passage through heat exchangers.

In a microwave oven, food is heated by passing microwaves through it, the resulting generation of heat inside the food facilitates rapid cooking.

Environmental issues

Water

Waste water is generated during processing and cleaning and contains product residues. The waste water produced also contains dissolved organic material, TSS, FOG, dissolved solids and possibly nitrate, nitrite, ammonia and phosphate.

Emissions to air

Emissions to air include odour and VOCs.

Solid output

Solid output containing organic material and FOG may result from the cleaning of cooking equipment.

Energy

Cooking and boiling uses energy to provide heat, e.g. for steam production.

Roasting

Objective

The aim of the process is to cook the food to make it edible, to produce dry products and/or to enhance the structure of raw products.

Field of application

Typical ingredients that are roasted are coffee, nuts, cacao, chicory, fruit, cereals and pre-processed cereals.
Description of techniques, methods and equipment

The raw product is usually exposed to hot air at temperatures of over 100 °C. Sometimes the raw product is pre-dried. If so, first the water is evaporated from the product to decrease the moisture content of 8 to 20 % to less than 1 %. If the product reaches a sufficiently high temperature, i.e. over 120 °C, reactions take place in the product. These so-called Maillard reactions are important in the formation of aromas in coffee and cacao. The duration of this roasting process depends on the product and the specific aromas that are required. Roasting times for coffee range between 1 and 20 minutes, while for cacao and other products this can be up to 180 minutes. When the product temperature reaches the required level, the Maillard reactions are stopped by either cooling the product with air or by quenching the product with water followed by cooling with air.

Roasting can be carried out either batch wise or continuously. Typical equipment for batch roasting are a drum roaster, a column roaster, a rotating disc roaster, a fluidised bed roaster and a spouting bed roaster. Common to all equipment is that the product is heated and agitated at the same time. The product can be in direct contact with the hot air, called convective heat transfer, or in contact with a heated surface, called conductive heat transfer. Usually it is a combination of both. The cooling takes place in separate equipment. This can be a cooling sieve where air is pulled through or a spouting bed cooler or any other equipment where the raw product is in contact with fresh air. Quenching with water can take place in the roasting chamber and sometimes in the cooling equipment. Cyclones are used as an integral part of the process to remove dust, mainly consisting of product residues and skins (chaff) before it is exhausted to the air. The recovered material is then reprocessed. The cooling air is also emitted to the air.

Environmental issues (E.5)

Water

Small amounts of water are used for quenching, e.g. roasted coffee, cereals and chicory. This water is partly evaporated and emitted into the air and partly absorbed by the product, e.g. coffee.

Emissions to air

Solid output

Solid outputs include, e.g. the skins of coffee beans. For coffee, the solid output can be between 0.1 to 1.5 % of the amount of green coffee.

Energy

The actual energy consumption depends on the type of roaster being used and also on the layout of the flue-gas system.

Tempering

Objective
The objectives of tempering are to ensure product quality and appearance, enable handling of liquid chocolate for various applications, e.g. demoulding, and ensure viscosity control and enable net weight requirements to be met. Tempering is also the controlled thawing of meats.

Field of application

Tempering is applied in the manufacture of chocolate and products containing chocolate. Chocolate formulations containing cocoa butter, or cocoa butter equivalents, need to be tempered before use. Chocolate may be under-tempered, well-tempered or over-tempered depending on the particular application.

Tempering is done because cocoa butter can exist in various crystalline forms, which if left untempered transform into unstable forms that impact severely on production capability and product quality. The process ensures that the fat is crystallised into stable forms which then enables products to be manufactured with good gloss and hardness, and to be crispy if needed. It also delays the formation of grey white spots on the surface known as fat bloom.

Description of techniques, methods and equipment

The tempering process involves the melting of all the fat crystals present by heating to at least 40 °C or above, then cooling the mass to typically below 30 °C, known as the seeding temperature. This allows formation of stable crystalline forms, which, on holding, enables a further desirable transformation to occur. Finally the mass is warmed slightly to melt out any remaining unstable crystalline forms and to establish further crystallisation of the stable forms. Depending on the particular recipe or formulation, temperatures and holding times will vary accordingly to ensure the optimum product quality.

Single stream tempering uses the standard technique of inducing crystallisation of the stable forms from liquid followed by changes in temperature. The product is carried by a conveyor screw feed into a tempering tube where it is tempered in three stages.

Twin stream tempering requires an already seeded stream to be introduced into a molten untempered chocolate stream.

Finally, multistage tempering is based on gentle cooling to produce seed crystals, followed by gentle reheating to allow the formation of stable crystalline forms. The cooling and reheating zones are made up of multistages maintained at the required temperature ranges via a jacketed recirculating water system. Various tempering machines are available based on this principle and are widely used in industry for a wide range of applications.

Environmental issues

Water is used for the recirculating chilled water system for cooling. The waste water produced contains soluble organic material and TSS.

Energy

Electricity is needed for the pumps and drives and for the cooling system.

19.2.4.2 Pasteurisation, sterilisation and UHT

The conservation of food and feed products is achieved by the killing of the microorganisms present. Heat treatment for the conservation of products is one of the main techniques used in the FDM sector. Heat treatment stops bacterial and enzyme activity and so prevents loss of
quality and reduces food perishability. In heat treatment processes, various time/temperature combinations can be applied, depending on the product properties and shelf-life requirements.

Pasteurisation and sterilisation are used to treat all types of FDM products; these include milk, juices and beer. UHT is applicable to low viscosity liquid products.

Pasteurisation is a controlled heating process used to eliminate viable forms of any microorganism, i.e. pathogen or spoilage causing, that may be present in milk, fruit-based drinks, some meat products, and other foods, or to extend shelf-life as in the case with beer. A similar controlled heating process, referred to as blanching, is used in the processing of fruits and vegetables. Both pasteurisation and blanching are based on the use of the minimum heat requirement needed to deactivate specific microorganisms or enzymes, thus minimising any quality changes in the foods themselves [87, Ullmann, 2001]. In pasteurisation, generally a heating temperature below 100 °C is applied.

Sterilisation is a controlled heating process used to eliminate viable forms and spores of any microorganism, i.e. pathogen or spoilage causing, that may be present in a preserved food. This can be achieved by moist heat, dry heat, filtration, irradiation, or by chemical methods. Compared to pasteurisation, a heat treatment of over 100 °C is applied for a period long enough to lead to a stable product shelf-life.

UHT is a heat treatment of over 100 °C for a very short time.

Pasteurisation temperatures commonly range from 62 to 90 °C, and pasteurisation times vary from seconds to minutes. Batch wise pasteurisation uses a temperature of 62 to 65 °C for up to 30 minutes. High temperature short time (HTST) pasteurisation uses a temperature of 72 to 75 °C for 15 to 240 seconds. High heat short time pasteurisation (HHST) applies a temperature of 85 to 90 °C for 1 to 25 seconds.

Batch wise pasteurisation is carried out in agitated vessels. Sometimes the product, i.e. beer and fruit juices, is pasteurised after bottling or canning. Here the products in their containers are immersed in hot water or fed through a steam tunnel. For continuous pasteurisation, flow-through heat exchangers, e.g. tubular, plate and frame, are applied. These have heating, holding and cooling sections.

Table 19.2 shows examples of heat treatment combinations used in the FDM sector.

<table>
<thead>
<tr>
<th>Process</th>
<th>Heating temperature/ holding time</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk liquid pasteurisation</td>
<td>63 °C/30 min</td>
<td>Vat pasteurisation of milk</td>
</tr>
<tr>
<td>High temperature short time pasteurisation (HTST)</td>
<td>72 °C/15 s</td>
<td>Continuous pasteurisation of milk for food safety</td>
</tr>
<tr>
<td>Cooking of meat products</td>
<td>65 to 75 °C internal temperature</td>
<td>Ready-to-eat products, e.g. ham, meat loaves and frankfurters</td>
</tr>
<tr>
<td>Blanching of vegetables</td>
<td>Variable, e.g. 75 °C/5 min</td>
<td>Enzyme deactivation and tissue softening</td>
</tr>
<tr>
<td>In-bottle pasteurisation</td>
<td>60 °C/10 min*</td>
<td>Shelf-life extension of beer</td>
</tr>
</tbody>
</table>

*the parameter may vary depending on the type of beer

Source: [1, CIAA 2002]

Generally for sterilisation, the product is canned or bottled and then heat-treated in a steriliser with steam or hot water. Sterilisers may be batch or continuous. In sterilisation with moist heat, temperatures generally range from 110 to 130 °C with sterilisation times being from 20 to 40 minutes. For example, canned foods are sterilised in an autoclave at about 121 °C for 20 min. Higher temperatures and shorter times may have similar effects, e.g. 134 °C for 3 min. However, if conditions do not allow the germination of spores, lower temperatures...
and shorter times can also be applied. For example, with acid fruit juices, jam, or desserts, heating up to 80 to 100 °C for 10 minutes is normally sufficient.

For killing bacterial endospores by dry heat, longer exposure times and higher temperatures are required than with moist heat, e.g. up to 2 hours at 160 to 180 °C. Solutions containing thermolabile compounds can be sterilised by filtration through mediums such as nitrocellulose membranes, diatomaceous earth, e.g. kieselguhr, and porcelain. UV irradiation is used to keep rooms partially sterile. Bacteria and their spores are killed quickly, but fungal spores are only moderately sensitive to radiation. Ionising radiation, e.g. X-ray and gamma radiation, is used to sterilise food and other compact materials. Chemical means may also be applied. Ethylene oxide is used to sterilise food, plastics, glassware, and other equipment [87, Ullmann, 2001].

UHT treatment means a very short heat treatment at temperatures of 135 to 150 °C for only a few seconds. This results in a sterilised product with minimal heat damage to the product properties. UHT treatment is only possible in flow-through equipment. The product is thus sterilised before it is transferred to pre-sterilised containers in a sterile atmosphere. This requires aseptic processing. For UHT treatment, indirect heating in plate and frame or tubular heat exchangers is applied. Direct steam injection or steam infusion may also be applied.

**Environmental issues**

**Water**

Water or other chilling media are required for cooling after heat treatment. Cooling after UHT treatment can be performed in two steps, i.e. firstly, by flash cooling to atmospheric pressure in flash vessels, followed by cooling with water.

In the case of aseptic or hot filling, there are product losses of both organic and inorganic deposits from the heat transfer surface. These are later discharged in the waste water during the cleaning of the equipment. In the case of heat treatment after canning or bottling, chlorinated cold water is required. This results in waste water containing dissolved organic material and TSS.

**Energy**

Energy, usually in the form of steam or hot water, is required for heat treatment. After heat treatment, energy can be recovered by heat exchange in a recovery section. For the final cooling, a cooling medium is needed. Cooling can be accomplished by once-through cooling whereby the cooling water is cooled down in a cooling tower or with a recirculating chilled water system. The latter uses a mechanical refrigeration system, so energy is consumed.

### 19.2.5 Concentration by heat

#### 19.2.5.1 Evaporation (liquid to liquid)

Evaporation is the partial removal of water from liquid food by boiling. For instance, liquid products can be concentrated from 5% dry solids to 72%, or even higher, depending on the viscosity of the concentrates. Evaporation is used to pre-concentrate food, to increase the solid content of food, to change the colour of food and to reduce the water content of a liquid product almost completely, e.g. as in edible oil drying.

Evaporation is used in many FDM sectors. For example, it is used to process milk, starch derivatives, coffee, fruit juices, vegetable pastes and concentrates, seasonings, sauces, sugar, ethanol and edible oil.
Steam, vapour, or exhaust gases from other drying operations, are usually used as the heating medium. The latent heat of condensation is transferred to the liquid food to raise its temperature to boiling point, to evaporate the water. The vapour is then removed from the surface of the boiling liquid. Since food products are heat sensitive, it is often necessary to work at low temperatures. This is achieved by boiling the liquid part under vacuum. Evaporation normally occurs in the range of 50 to 100 °C, although it can be as high as 130 °C in the sugar industry.

In its simplest form, evaporation is carried out by boiling off water to the air using immersed electric heaters. However, in practice the most commonly used equipment is multistage shell and tube evaporators, or plate evaporators. Shell and tube evaporators may be natural or forced circulation, climbing or falling film types. Centritherm evaporators, wiped film evaporators (WFE), thin film evaporators and vacuum pans are specially designed for the evaporation of highly viscous products. Typical total solids concentrations for various types of evaporators are shown in Table 19.3. The emission level of total solids in the outlet depends on the composition of the product to be concentrated.

Table 19.3: Typical total solids concentrations for various types of evaporators

<table>
<thead>
<tr>
<th>Evaporator type</th>
<th>Total solids inlet (%)</th>
<th>Total solids outlet (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell and tubes, multistage</td>
<td>5–25</td>
<td>40–75</td>
</tr>
<tr>
<td>Plates, multistage</td>
<td>5–25</td>
<td>40–75</td>
</tr>
<tr>
<td>Vacuum pans</td>
<td>60–70</td>
<td>80–85</td>
</tr>
<tr>
<td>Centritherm, single-stage</td>
<td>5–25</td>
<td>40–60</td>
</tr>
<tr>
<td>WFE, single-stage</td>
<td>40–50</td>
<td>70–90</td>
</tr>
</tbody>
</table>

Source: [1, CIAA 2002]

Multiple-effect evaporators are used when evaporation requires significant energy, e.g. in sugar beet processing, starch production and the evaporation of milk and whey. These evaporators use fresh steam or exhaust gases from other operations, and so recover or reuse energy, to boil off water vapour from the liquid in the first effect. The evaporated water still has sufficient energy to be the heat source for the next effect, and so on. A vacuum is applied in a multiple-effect series to allow the water to boil off. The liquid being processed is passed from one evaporator body through the others so it is subjected to multiple stages of evaporation. In this way, one unit of steam injected in the first evaporator can remove three to six units of water from the liquid.

Additional energy can be saved by recompressing the vapour using a thermal vapour recompressor (TVR) or a mechanical vapour recompressor (MVR). However, this can lead to steam contamination, making it unsuitable for return to the boilers and, therefore, increasing the waste water load. In the final stage, the vapour may be condensed by cooling with cooling water. Some of the vapours can be drawn off the evaporators to be used as heat sources for other process requirements. The condensate may be of such a quality that it may even be fed to other processes as process water.

During processing, product compounds gradually deposit on the heat-exchange surfaces. This can affect the efficiency of the heat exchange and lead to heat losses in the system. These deposits may be inorganic or organic, depending on the product. The installation is, therefore, cleaned at regular intervals to prevent too high a heat loss occurring with a subsequent loss of product quality.

The removal of deposits during cleaning and product losses during start-ups and shut-downs contributes to the organic and inorganic load in the waste water. During evaporation, condensates from the product are also produced. Depending on their content, e.g. organic, inorganic and TSS, these condensates can be reused in the process or are treated in a WWTP.
The final vapours are condensed in an open or closed condenser using cooling water. The waste water contains dissolved organic and inorganic matter and TSS.

Sometimes non-condensable gases are vented to the air to ensure efficient heat transfer. The environmental effects arising depend on the gases being vented. Dust and odour may also be a problem.

Steam requirements for single-stage evaporators range from 1.1 to 1.2 tonnes of steam per tonne of evaporated water. Energy requirements may be reduced when using multi-effect evaporators. In the case of double or third effect, the steam requirement lowers respectively to 0.6 - 0.7 and 0.4 tonnes of steam per tonne of evaporated water. The steam consumption can also be reduced by applying mechanical or thermal vapour recompression. Sometimes exhaust gases can be used to recover energy from other processes such as drying.

Drying and evaporation are often the main energy using processes within the FDM sector. In some existing installations, complex combinations of different techniques are applied for various individual unit operations. Evaporation is widely applied to increase the solids content of liquids. Sometimes this is done as a preliminary step before drying, which can be done using a wide variety of techniques. Theoretically, for the evaporation of water 0.611 kWh/kg (2.2 MJ/kg) is required. In practice, this very much depends on the method of evaporation and the type of dryer used and it can range from 0.556–0.972 kWh/kg (2.0–3.5 MJ/kg). The energy consumption for drying can be less if the dry substance content of the wet material is higher. This can be achieved by pre-evaporation or by using special dewatering equipment such as presses or centrifuges. Steam dryers can have considerably lower energy consumption if they consist of more stages (see Section 0). Sometimes exhaust gases from combustion CHP equipment are used to dry the products, thereby reducing the energy requirement.

Falling film evaporators can be used for single and multistage evaporation. These are long, tubular structures made from stainless steel. Liquid is introduced at the top of the evaporator and flows as a thin film down the inside surface of heated tubes or plates which are packed into the evaporator. The principle of falling film evaporation is shown in Figure 19.1.
The outline of an evaporating system is shown in Figure 19.2.

![Diagram of an evaporating system](image)

**Figure 19.2: Milk evaporation using a falling film**

**Vapour compression/recompression**

By compressing exhaust vapours, it is possible to make major cuts in energy requirements for concentration processes in the FDM sector. For example, in wort boiling in breweries, the water vapour is given off when a solution is concentrated by condensation. The heat which is put in to evaporate the water and concentrate the solution, can be recovered by condensing the vapour that is driven off. Some common types of compressors used are rotary compressors, screw compressors, radial-flow turbo compressors and blowers.

To enable the heat of condensation stored in the vapour to be used to provide additional heat for the concentration process, condensation of the vapour takes place at a temperature higher than the boiling point. To raise the condensation temperature, the vapour is compressed by 0.1 - 0.5 bar (0.1 - 0.5 hPa). A heat exchanger is then used to return the heat of condensation from the compressed vapour to the concentration unit.

Apart from the energy needed to drive the compressor, no further energy input is required. The ratio of recovered energy to energy input, i.e. the performance figure, may be as high as 40. In addition to saving energy and reducing energy costs, another important reason for condensing vapours is to reduce odour emissions.

The feasibility of installing vapour compressing techniques greatly depends on the investment costs and the payback due to lower operating costs. Different and changing energy costs in different countries may also influence the decision. In some sectors, operation is seasonal, e.g. 50 days for tomatoes and, therefore, the length of the campaign is also an important factor.

Noise is often produced from the evaporation processes, in particular from the thermal compressor, the mechanical compressor, the steam ejectors and the high velocity of the fluids in the pipework. This can usually be managed by applying appropriate acoustic insulation. Noise is also generated in pumps due to cavitation.
19.2.5.2 Dehydration (solid to solid)

Dehydration is defined as the application of heat under controlled conditions to remove, by evaporation, the water present in solid foods or by-products from agricultural raw material processing. The main purpose of dehydration is to extend the shelf-life of foods by reducing their $a_w$.

Some examples of dried foods are dried potatoes, starch derivatives, sugar beet pulp, flour, pasta, beans, fruit, nuts, cereals, meal of oilseeds, tea leaves, vegetables and spices. The dehydration of wet germinated grain is applied in the production of malt which is also called kilning. For the malting process, the drying step is essential and is required to create the desired colour and flavour.

Dehydration affects food texture and colour, and causes the loss of volatile components, all of which have a detrimental effect on both the quality and the nutritional value of the food. The design and operation of dehydration equipment aims to minimise these changes by selecting appropriate drying conditions for individual foods. For dehydration, the two different principles are, i.e. hot air drying and surface drying by heat conduction through a heat transfer system.

Various types of dryers are used, i.e. fluidised, cabinet or tray, conveyor or belt, pneumatic, flash and/or ring, rotary, tunnel, steam bundle, steam, kiln and vacuum dryers.

FBDs are composed of metal trays with mesh or perforated bases that can contain a bed of particulate foods up to 15 cm deep. Hot air is blown through the bed, causing the food to become suspended and then vigorously agitated. The air acts as both the drying and the fluidising medium. They can be batch or continuously operated. FBDs are compact and allow a good control over the drying conditions and relatively high thermal efficiencies and high drying rates. These dryers have very high rates of heat and mass transfer and consequently short drying times. Drying can take place with air temperatures below 100 °C, but may also be up to 170 °C or higher depending on the product/process. FBD is often applied as a last drying step after spray drying, in the dairy industry.

Cabinet or tray dryers consist of an insulated cabinet fitted with a shallow mesh or perforated trays, each of which contains a thin layer of food. Hot air is circulated through the cabinet. A system of ducts and baffles are used to direct air over and/or through each tray to promote a uniform air distribution. These dryers are used for small scale production and have low capital and maintenance costs. They are relatively difficult to control and produce variable product quality.

Continuous conveyor or belt dryers are up to 20 metres long and 3 metres wide. The food is dried on a mesh belt. The airflow is initially directed upwards through the bed of food and then downwards in later stages to prevent dried food from blowing out of the bed.

In pneumatic, flash and/or ring dryers, powders or particulate foods are continuously dried in vertical or horizontal metal ducts. A cyclone separator or a bag filter is used to remove the dried product. The moist food is metered into the ducting and suspended in hot air. They have relatively low capital costs, high drying rates and thermal efficiencies, and good control over the drying conditions.

Rotary dryers are slightly inclined rotating metal cylinders fitted internally with flights that cause the food to cascade through a stream of hot air as it moves through the dryer. Airflow may be parallel or countercurrent. The agitation of the food and the large area of food exposed to the air produces high drying rates and a uniformly dried product. The method is especially suitable for foods that tend to mat or stick together in belt or tray dryers. It is used on a large scale in the sugar industry for sugar and beet pulp drying. In the case of pulp, exhaust gases from the combustion plant may be used as a heat source when the physical plant and the flue-gas
temperature allows. Some combustion plants can produce flue-gas temperatures of around 120 °C.

In tunnel dryers, thin layers of food are dried on trays, which are stacked on trucks programmed to move semi-continuously through an insulated tunnel in which hot air is circulated.

In steam bundle dryers, the heating medium or steam is not in contact with the wet product. A heat transfer surface is used to transfer the heat to the product’s surface for drying. The steam passes through the dryer, through cylindrical tubes/bundles which rotate, to avoid local overheating and to improve uniform drying. This dryer uses less air volume and subsequently emissions into the air are limited.

Steam drying is a special dryer design that uses superheated steam produced via a heat exchanger. The dryer consists of a pressure vessel in which the water from the product is driven off, turned into steam and then used to dry more product. This system is used in the sugar industry, on a limited scale, for drying beet pulp. One advantage is the low energy consumption for drying.

Drying in kilns is used for malting which is described in Section 16.10.

Vacuum drying is used for temperature sensitive products. The external pressure is lowered to avoid drying at a high temperature. One simple type of vacuum drying is vacuum roller drying. In this method, either one or two rollers are installed in a vacuum housing. The resulting vapour precipitates in a condenser located between the vacuum chamber and the pump. The product is removed by a screw conveyor.

In the hot-air dehydration process, air, with water vapour containing VOCs and dust, is released. If dehydration is done using direct-fired burners, the exhaust gases might also contain CO₂, CO, SO₂, and NOₓ, depending on the heat source and burner type. Depending on the type of raw material or product, the dust may be glutinous and wet, e.g. meal from oilseed processing. Dry dust can be filtered and wet dust can be recovered using cyclones. Odour may also be a problem.

**Solid output**

Solid organic material may be generated when equipment is emptied for a next batch or for cleaning. These outputs can consist of raw material, product residues and dust. These solid products/dust can be recycled back into the process or sold as animal feed.

**Energy**

For the evaporation of water, theoretically 0.611 kWh/kg (2.2 MJ/kg) energy is required. However, in practice, this very much depends on the type of drier used and can range from 0.556 to 1.08 kWh/kg (2.0 to 3.9 MJ/kg). Steam driers can have a considerably lower energy consumption if they consist of more effects (multiple effect evaporation). Sometimes exhaust gases from a combustion (CHP) plant are used to dry products, thereby reducing the direct energy consumption. The energy consumption for dehydration can be further reduced by increasing the dry substance content of the wet product. This can be achieved by pre-evaporation or by using special dewatering equipment.

**Noise**

Noise may arise from the air inlet and outlet of the dryers.
19.2.6 Processing by the removal of heat

Cooling, chilling and cold stabilisation

Objective

Cooling is used to reduce the temperature of the food from one processing temperature to another or to a required storage temperature. Chilling is a processing technique in which the temperature of a food is reduced and kept at a temperature between –1 and 8 ºC. The objective of cooling and chilling is to reduce the rate of biochemical and microbiological changes in foods, to extend the shelf life of fresh and processed foods, or to maintain a certain temperature in a food process, e.g. in the fermentation and treatment of beer. Cooling is also used to promote a change of state of aggregation, e.g. crystallisation. The objective of cold stabilisation is to precipitate out tartrates in wines, or fatty acids in spirits before bottling.

Field of application

Cooling, chilling and cold stabilisation are widely used in the FDM sector.

Chilling is used for preservation of a lot of perishable foods. In the wine sector, cooling and chilling are applied to clarify the must before fermentation. Cold stabilisation is used in the beer, wine and spirit sectors. Beer is cold stabilised to precipitate the protein-polyphenol adduct. The beer is kept between –2 and –3 ºC for at least 12 hours.

Description of techniques, methods and equipment

Cooling of liquid foods is commonly carried out by passing the product through a heat-exchanger or cooler or by cooling the vessels. The cooling medium in the cooler can be groundwater, water recirculating over a cooling tower, or water, eventually mixed with agents like glycol, which is recirculated via a mechanical refrigeration system or ice-water system.

In cryogenic cooling, the food is in direct contact with the refrigerant, which may be solid or liquid carbon dioxide, or liquid nitrogen. As the refrigerant evaporates or sublimates, it removes heat from the food, thereby causing rapid cooling. Both liquid nitrogen and carbon dioxide refrigerants are colourless, odourless and inert.

The supply of chilled foods to consumers requires a sophisticated distribution system, involving chilled stores, refrigerated transport and chilled retail display cabinets. Chilled foods can be grouped into three categories according to the storage temperature [225, Hendley B., 1985]. A fourth category is applied to winemaking:

-1 to 1 ºC for fresh fish, meats, sausages and ground meats, smoked meats and fish
0 to 5 ºC for pasteurised canned meat, milk and milk products, prepared salads, baked goods, pizzas, unbaked dough and pastry
0 to 8 ºC for fully cooked meats and fish pies, cooked or uncooked cured meats, butter, margarine, cheese and soft fruits
8 to 12 ºC for the wine industry. The must is kept at this temperature for 6 to 24 hours.

The equipment used for freezing (see Section 0) can also be used for cooling and chilling.

Cold stabilisation is a technique for chilling wines before bottling to cause the precipitation of tartrate crystals. For spirits, this technique consists of bringing the spirit to a temperature of between –1 and –7 ºC, depending on the operators, and possibly performing a stabulation, i.e. storing at low temperature, in tanks at constant temperatures for between 24 and 48 hours.
cold filtration, around -1 °C, allows the fatty acid esters to be retained. For wines, three techniques can be employed: cold stabilisation by batch and stabulation, continuous cold stabilisation, and cold stabilisation by crystal seeding. The two last techniques are the most widely used. There can be many variations on these basic schemes.

Cold stabilisation by batch and stabulation is the oldest technique. It consists of bringing the wine to a temperature below zero close to freezing point and then stabulating it in an isothermal tank for a period of five to eight days.

\[
\text{Freezing point (°C)} = -\left(\frac{\text{alcohol (% v/v)}}{2}\right) + 1
\]

In continuous cold stabilisation, the stabulation tank is replaced by a cylindro-conical crystalliser and an agitator, in which the wine will remain for only 30 to 90 minutes.

Cold stabilisation is carried out by crystal seeding, consisting of refrigerating at between -1 and -2 °C, and seeding at 4 g/l of tartaric crystals with agitation over 2 to 4 hours, and later storage in tanks, followed by decantation after 12 to 48 hours.

Environmental issues (G.1)

Water

Water may be used as the cooling medium in a once-through system. When cooling water is recirculated, closed circuit cooling towers can be used for heat removal.

Emissions to air

In cryogenic cooling, emissions of gaseous N_2 or CO_2 occur. Leaking refrigeration equipment can lead to emissions of refrigerant.

Energy

Electrical energy is needed to drive the pumps circulating the cooling water or the fans in air cooling. Mechanical refrigeration systems generally require 0.3–1.0 kWh power per cooling effect. However, overall, their energy consumption is significantly less than the total energy required for the manufacture and use of liquid N_2 or CO_2.

Noise

Noise issues may occur from fans and cooling towers.

19.2.6.1 Freezing

Freezing is a preservation method. In freezing, the temperature of a food is reduced to below the freezing point and a proportion of the water undergoes a change in state to form ice crystals. The sector standard for freezing food is to reduce the temperature to around -18 °C. Several types of food can be frozen, e.g. fruits, vegetables, fish, meat, baked goods and prepared foods such as ice cream and pizzas.

During freezing, the heat is first removed to lower the temperature of the food to the freezing point. This includes removal of heat produced by respiration as in fresh foods. The latent heat of
crystallisation is then removed and ice crystals are formed. Table 19.4 shows the typical freezing points of various FDM products.

Table 19.4: Typical freezing points of various FDM products

<table>
<thead>
<tr>
<th>FDM product</th>
<th>Freezing point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meat, poultry, and fish</td>
<td>-0.6 to -2.0 °C</td>
</tr>
<tr>
<td>Vegetables, e.g. peas, cauliflowers, onions, carrots and tomatoes</td>
<td>-0.9 to -1.4 °C</td>
</tr>
<tr>
<td>Fruits, e.g. pears, plums and apricots</td>
<td>-1.8 to -2.5 °C</td>
</tr>
<tr>
<td>Berry fruits, e.g. strawberries and raspberries</td>
<td>-0.8 to -1.2 °C</td>
</tr>
<tr>
<td>Milk</td>
<td>-0.5 °C</td>
</tr>
<tr>
<td>Ice cream</td>
<td>-4.0 to -6.0 °C</td>
</tr>
</tbody>
</table>

Source: [18, Environment Agency of England and Wales 2000]

A whole range of methods and equipment for freezing foods is available. The most common freezers used are blast, belt, fluidised bed, cooled surface, immersion and cryogenic freezers. Cryo-extraction and concentration by cold are also used.

In blast freezers, cold air at -30 to -40 °C is circulated over the food at a velocity of 1.5 to 6 m/s. In batch blast freezers, the food is stacked on trays in rooms or cabinets. In continuous equipment, trays covered with food are stacked on trolleys or the food is moved through a freezing tunnel by conveyor belts. Sometimes multiphase tunnels are applied with a number of belts. The product falls from one belt onto another, this also breaks up clumps of frozen food. The thickness of the food layer on the belts can vary from 25 to 125 mm. In blast freezers, large volumes of air are recycled, however, this can cause freezer burn and oxidative changes to unpackaged food. Moisture from the food is transferred, via the air, to the refrigeration coils, which makes frequent defrosting necessary. Impingement freezing and cooling with air velocities of up to 45 m/s and down to -50 °C is also applied.

The operating principle of a countercurrent freezer, e.g. a belt freezer or a spiral freezer, is the same as that of a blast freezer, except the food being frozen is transported through a countercurrent of cold air or liquid nitrogen. This reduces the evaporation of water from the food.

In fluidised bed freezers, the food is fluidised with air of -25 to -40 °C by passing the air vertically upwards through a perforated tray or conveyor belt and through a bed of food 2 to 20 cm thick. The shape and size of the food pieces determine the thickness of the fluidised bed and the air velocity for fluidising. In this system, food comes into more extensive contact with the air than in blast freezers, so that all surfaces are frozen simultaneously and uniformly. This results in faster freezing and less dehydration, which also results in less frequent defrosting. Fluidised bed freezing is restricted to small particulate foods, e.g. peas, sweet maize kernels, shrimps, and strawberries.

In cooled surface freezers, vertical or horizontal hollow plates are cooled with a refrigerant of about -40 °C. The food is put on the surface in thin layers. Sometimes the plates are pressed slightly together. This improves the contact between the food and the freezing plates. One advantage of such freezers is that little dehydration of the food takes place, which reduces the frequency of defrosting. A special form is the scraped surface freezer. This consists of a freezing cylinder containing rotating knives which remove the frozen material from the freezing surface. This type of equipment is used, e.g. in ice-cream production.

In immersion freezers, packaged food is passed through a bath of refrigerated glycol, brine, glycerol or calcium chloride solution on a submerged mesh conveyor. High freezing rates are obtained with this method. It is used, e.g. for freezing concentrated orange juice in cans and for pre-freezing film wrapped poultry prior to blast freezing.
In cryogenic freezing, the food is in direct contact with the refrigerant, which can be solid or liquid carbon dioxide or liquid nitrogen. The refrigerant evaporates or sublimates away removing the heat from the food and causing rapid freezing. Liquid nitrogen and carbon dioxide refrigerants are colourless, odourless and inert.

Cryo-extraction is a method of subtractive enrichment which consists of removing water from bunches of grapes to increase the sugar content of the must. The objective of cryo-extraction is to eliminate some water present in the raw material by selective freezing. The grapes are placed in a coldroom at a temperature midway between the freezing temperature of the richest grapes and that of the least rich grapes. The duration of the treatment of the grape crop is from 12 to 20 hours at temperatures of between -3 and -6 °C. The technique is performed only on grapes harvested manually and carried out in low, perforated crates, to achieve a slow and homogeneous lowering of the temperature over all the grapes. The pressing makes it possible to select the ripest juices, i.e. those which flow out first. The maximum pressure used for pressing is 4 bar.

Finally, concentration by cold is a technique applied only for wines. It consists of eliminating a part of the water from a wine to increase its alcohol strength. This technique is regulated. The wine is cooled below the temperature where ice crystal forms, but the alcohol does not freeze. The crystals are prevented from congealing together by constant mixing. When a sufficient quantity of water has thus solidified, the liquid is separated from the crystals by centrifuges or pressure operated extractors.

Environmental issues (G.2)

Water

Waste water, sometimes containing used brines may result from immersion freezing.

Emissions to air

In cryogenic freezing, emissions of gaseous \( \text{N}_2 \) or \( \text{CO}_2 \) are produced.

Energy consumption is the major environmental issue. Electrical energy is needed for the fans for air circulation and the freezing system. For example, deep freezing is the most energy-consuming step in the manufacture of deep frozen vegetables consuming 80–280 kWh/t of frozen vegetable. Energy amounting to about 0.003 kWh/m\(^2\) (0.01 MJ/m\(^2\)) floor surface of tunnel/hour of operation is also consumed in the form of hot water. The energy consumption of a freezing tunnel depends on various factors and the following list uses the deep freezing of fruit and vegetables to illustrate these [15, Van Bael J., 1998]. Energy consumption depends on, e.g.:

- the type of food to be frozen, e.g. voluminous vegetables, such as cauliflower florets are more difficult to freeze than small vegetables such as peas or diced carrots;
- the temperature of the food at the entrance to the freezing tunnel. The higher this temperature is, the more heat has to be removed from the food before it is frozen;
- the mass flowrate of the food. The higher the flowrate, the higher the quantity of energy that needs to be removed, and the greater the demand for cold air in the tunnel;
- the residence time, which also determines the demand for cold air in the freezing tunnel. The longer the residence time, the more chance the food has to freeze. The thickness of the layer of food is directly proportional to the required residence time;
the energy consumption which is determined by the airflow rates in the freezing tunnel. The higher the airflow rates, the better the heat exchange between the evaporators and the air on one hand, and the air and the food on the other hand. Higher airflow rates lead to higher energy consumption by the fans and higher cooling loads for the freezing tunnel; the full output of the motors needs to be cooled;

- the efficiency or the COP, which plays a role in the energy consumption of freezing tunnels. As explained earlier, the efficiency is mainly determined by the condensation and evaporator temperature.

The energy consumption per unit of weight of frozen product depends very much on the parameters set for the evaporator temperature, fan rating and product flowrate, and the condensation pressures and type of product being processed. Since many factors affect the specific energy consumption, it is, therefore, only possible to give broad ranges for consumption [15, Van Bael J. 1998].

### 19.2.7 Post processing operations

**Gas flushing and storage under gas**

**Objective**

Gas flushing is a process in which products are stored in an artificially produced atmosphere, normally within a plastic container such as a hermetically sealed tray or pouch. The process is also referred to as modified atmosphere packing (MAP), and is used to enhance the colour-retention of, e.g., fresh meat or cured meats such as bacon and cooked ham, especially in sliced form. MAP is also applied to extend shelf-life. The impact of MAP depends on the combination of product, packaging materials and gas mix.

Storage under gas is applied to wines. Inert gas is applied to wines in tanks in place of sulphur dioxide (SO₂). This is carried out to preserve an adequate CO₂ content and the organoleptic qualities of the wine, to protect it from oxidation, and to the prevention of bacterial deviations. It also allows the prevention in the alteration of tanks which would be emptied, e.g., in the case of bulk sales to private individuals. Finally, it permits the conservation of sterile fruit juices.

**Field of application**

Gas flushing is mainly used for meat and meat products. It is also used for bakery products. Storage under gas is, above all, applied to white wines, rosés and red primeurs.

**Description of techniques, methods and equipment**

In gas flushing, the gas mixtures used will vary depending on whether the meat to be protected is fresh or cured. The desirable bright red colour of fresh meat can be prolonged by storage in an atmosphere with some oxygen, whereas the purple-red colour of uncooked cured meat and the pink colour of cooked cured meat is preserved better in an atmosphere completely free of oxygen. In all types of meat or meat products, gas mixtures are used which also contain carbon dioxide (CO₂). This inhibits bacterial growth on the meat and marginally extends the shelf-life. Normal air contains 78% nitrogen, 21% oxygen, and less than 1% CO₂. In comparison, typical gas mixes for use with meats and meat products are shown in Table.

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Oxygen</th>
<th>CO₂</th>
</tr>
</thead>
</table>

**Table: Typical gas mix composition for gas flushing**
Solid CO\textsubscript{2}, usually in pellet form, can be added to meat during size reduction. This has the effect of rapidly reducing the temperature of the mixture and creating a blanket of inert gas over the surface of the meat, thereby enhancing the colour retention. A temporary increase in the CO\textsubscript{2} content of the air surrounding the equipment will occur, but this dissipates rapidly.

Solid or liquid nitrogen or CO\textsubscript{2} is sometimes used to partially freeze meats prior to slicing. This involves passing the pieces of meat to be sliced through a tunnel in which they are sprayed with the liquefied gas to reduce their temperature to about -8 °C. In such instances, extractor fans are located near the ends of the tunnel to expel the surplus gas to the air. No adverse effects have been reported.

Storage under gas consists of putting a gas, which can be either food quality nitrogen or a nitrogen/CO\textsubscript{2} mixture, in a tank under very slight overpressure of 0.1 to 0.2 bar. Nitrogen is used in a compressed state in steel containers. CO\textsubscript{2} is used in a liquefied form under pressure.

### Environmental issues

**Emissions to air**

Gas mixtures used in the above processes are all supplied to the packing installation either in premixed form or as individual gases that are mixed \textit{in situ}. Gas emissions, e.g. CO\textsubscript{2}, may occur during the process or as a result of accidents.

#### 19.2.8 Utility processes

##### 19.2.8.1 Vacuum generation

Vacuums are used primarily to reduce the temperature at which operations take place, thereby reducing potential deterioration in the quality of the material being processed or, in the case of edible oil processing, to avoid unwanted oxidation of the product during processing at higher temperatures. A vacuum is applied to many unit operations in the FDM sector, e.g. drying, evaporation, neutralisation and filtration.

There are three basic systems for producing a vacuum, i.e. steam jet ejectors, reciprocating pumps, and rotary vacuum pumps.

A steam jet ejector, which can produce absolute pressures down to 1 or 2 mm Hg (133 or 267 Pa), consists of a steam nozzle that discharges a high velocity jet across a suction chamber connected to the equipment. The gas is entrained in the steam and carried into a venturi-shaped diffuser that converts the velocity energy of the steam into pressure energy. The steam and vaporised material from the ejector are condensed either directly in a spray of water, e.g. barometric condensers, or indirectly with surface type condensers or especially condensed under low temperature conditions, e.g. ice condensation below -20 °C.

With barometric condensers, the cooling water can be used on a once-through basis or recirculated, e.g. in a closed-circuit. In edible oil processing, for saponification of FFA, this is done over cooling towers, e.g. under high pH conditions. With indirect condensers, the condensate can be recovered. The size of the condenser depends on the cooling temperature used, and this also controls the amount of steam required. Chilling or freezing systems can be used to enable operation at low temperature, thereby reducing steam usage.
The reciprocating pump, which can produce absolute pressures down to 10 mm Hg (1333 Pa), is of the positive displacement type. Air is drawn into the pump chamber and then compressed by means of a piston before being discharged. Reciprocating vacuum pumps can be either single or multistage devices. The number of stages is determined by the compression ratio. The compression ratio per stage is generally limited to four.

Rotary vacuum pumps, which can produce absolute pressures as low as 0.01 mm Hg (1.33 Pa), are again of the positive displacement type, i.e. essentially constant volume with variable discharge pressure. The discharge pressure will vary with the resistance on the discharge side of the system. The widely used water-ring vacuum pump has the inlet and outlet ports located on the impeller hub. As the vaned impeller rotates, centrifugal forces drive the sealing liquid against the walls of the elliptical housing, causing the air to be successively drawn into the vane cavities and expelled with the discharge pressure.

Water is used in water-ring type vacuum pumps for cooling and for sealing. To reduce water consumption, the water is normally recirculated in closed-circuit systems with a bleed off determined by the condensable matter. Waste water is produced which contains soluble organic material.

If steam jet ejectors are used for vacuum production, not only the media coming from the evacuated plant has to be condensed, but also the driving steam of the jet ejector. This is normally done in spray condensers. Here, water is used to condense the steam along with any volatiles carried over. For large installations, the volume of water used to condense the steam can be significant, i.e. during refining of sugar or edible oil. The volatile material carried over is condensed in the water thereby increasing the level of dissolved organic material. To reduce water consumption, water can be recirculated over cooling towers. In this case a bleed from the system is required for the condensed steam. This can lead to a concentration of the organic material condensed in the water. With indirect condensers or heat exchangers, the volume of condensate is equivalent to the condensed live steam and other condensable matter, and will contain any organic volatiles carried over. With chilling or freezing systems, the volume of condensate is reduced further.

Depending on the material being processed, air evacuated by vacuum pumps may contain volatile material, which, if not properly controlled, may result in odour problems.

Non-condensable material may be discharged into the air with steam jet ejectors. Depending on the material being processed, this discharge may result in odour emissions. If condenser water is recirculated over cooling towers, the drift/mist from the towers may result in odour emissions. Indirect recirculation with heat exchangers with two cycles may be used in this case. Heat exchangers have to be cleaned regularly.

Energy

The energy usage will depend on the type of compressor used, the absolute pressure to be achieved and the size of the system. For large operations, the consumption can be reasonably high.

Noise

Noise may occur due to the operation of the fans associated with the cooling towers.

Refrigeration
Objective

The objective of refrigeration is to preserve products. Refrigeration equipment is needed for cooling, chilling and freezing (see Sections 0 and 0).

Field of application

In many FDM manufacturing processes, cooling is an important process step. Often mechanical cooling using refrigeration equipment is applied. Furthermore, many products are stored and distributed either chilled or frozen.

Description of techniques, methods and equipment

The main components of a mechanical refrigeration plant are the evaporator, the compressor, the condenser and the expansion chamber. The refrigerant circulates through these four components, changing in state from liquid to gas, and back to liquid again. In the evaporator, heat is absorbed from the surroundings. This causes part of the refrigerant to vaporise. Where ammonia is used as the refrigerant, the common temperatures of evaporation are -20 to -25 °C, which correspond to a pressure of 100 to 200 kPa.

Refrigerant vapour goes from the evaporator to the compressor where the pressure is raised to about 1000 kPa, which corresponds to a temperature of about 25 °C. The pressurised vapour then goes into the condenser, where the vapour is condensed. The heat absorbed by the refrigerant in the evaporator is released in the condenser. The condenser is cooled by water or air. The resultant liquid refrigerant then goes to the expansion chamber, where the pressure and temperature are reduced to restart the refrigeration cycle.

The common refrigerants used are ammonia (NH$_3$), halogen refrigerants, i.e., chlorofluorocarbons (CFCs) and partially halogenated CFCs (HCFCs). Ammonia has excellent heat transfer properties and is not miscible with oil, but it is toxic and flammable. Halogen refrigerants are non-toxic, non-flammable and have good heat transfer properties. The interaction of halogen refrigerants with ozone in the air has resulted in the progressive prohibition of the placing on the market and use of ozone depleting substances and of products and equipment containing those substances [258, Regulation EC/1005/2009 2009]. There is a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases [259, Regulation 517/2014 2014].

Condensers of refrigeration equipment can be divided into three types. In air-cooled condensers, the refrigerant goes through fin elements, around which the cooling air circulates. Water-cooled condensers operate by circulating cooling water inside the tubes. This condenses the refrigerant on the external tube surface. The water-cooled condenser is cooled according to the water once-through system or with water which circulates over a cooling tower. The most common type of water-cooled condenser is the tube condenser. Finally, the evaporation condenser is a combination of an air-cooled condenser and a cooling tower. Water evaporates at the surface of the condenser.

Environmental issues

Water

Water consumption can be significant when water is used as the cooling medium for the condenser in a once-through system. Recirculating the cooling water over a cooling tower reduces water consumption. Accidental release of liquid ammonia needs to be prevented.
Emissions to air

Refrigeration equipment which contains mainly NH₃ or (H)CFCs does not emit refrigerants, if properly operated and maintained, as the systems are closed. An accidental breakage or leakage could cause releases into the atmosphere, so the risk of an accident needs to be minimised.

Energy

Refrigeration equipment needs a high electricity input.

Noise

Noise produced by the compressors of refrigeration equipment may be a problem.

Compressed air generation (U.6)

Objective

Compressed air is generated to run simple air tools, e.g. for pneumatic transfer, or for more complicated tasks such as the operation of pneumatic controls.

Field of application

Widely used in the FDM sector, e.g. on manufacturing and packaging lines.

Description of techniques

Oil-free compressed air is required in the FDM sector. The air used has to be of food quality. This is achieved by passing it through several filters at the outlet of the compressor.

Environmental issues (U.6)

Emissions to air

Emissions to air are generally minimised due to the use of filters to remove oil and other impurities to ensure that the compressed air is of food grade quality.

Energy

Energy is consumed in the compressor.

Noise

Noise emissions can be a problem.
20 GLOSSARY

This glossary is meant to facilitate the understanding of the information contained in this document. The definitions of terms in this glossary are not legal definitions (even if some of them may coincide with definitions given in European legislation), they are meant to help the reader understand some key terms in the context of their use in the specific sector covered by this document.

This glossary is divided up into the following sections:
I. ISO country codes
II. Monetary units
III. Unit prefixes, number separators and notations
IV. Units and measures
V. Chemical elements
VI. Chemical formulae commonly used in this document
VII. Acronyms
VIII. Technical definitions

20.1 ISO country codes

<table>
<thead>
<tr>
<th>ISO code</th>
<th>Member State (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>Austria</td>
</tr>
<tr>
<td>BE</td>
<td>Belgium</td>
</tr>
<tr>
<td>CZ</td>
<td>Czech Republic</td>
</tr>
<tr>
<td>DE</td>
<td>Germany</td>
</tr>
<tr>
<td>DK</td>
<td>Denmark</td>
</tr>
<tr>
<td>ES</td>
<td>Spain</td>
</tr>
<tr>
<td>FI</td>
<td>Finland</td>
</tr>
<tr>
<td>FR</td>
<td>France</td>
</tr>
<tr>
<td>IE</td>
<td>Ireland</td>
</tr>
<tr>
<td>IT</td>
<td>Italy</td>
</tr>
<tr>
<td>NL</td>
<td>Netherlands</td>
</tr>
<tr>
<td>PL</td>
<td>Poland</td>
</tr>
<tr>
<td>PT</td>
<td>Portugal</td>
</tr>
<tr>
<td>SE</td>
<td>Sweden</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom</td>
</tr>
</tbody>
</table>

(*) The protocol order of the Member States is based on the alphabetical order of their geographical names in the original language(s).

20.2 Monetary units

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Currency</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATS</td>
<td>Austrian schilling</td>
</tr>
<tr>
<td>BEF</td>
<td>Belgian franc</td>
</tr>
<tr>
<td>CZK</td>
<td>Czech koruna</td>
</tr>
<tr>
<td>DEM</td>
<td>German mark</td>
</tr>
<tr>
<td>DKK</td>
<td>Danish krone</td>
</tr>
<tr>
<td>EFK</td>
<td>Estonian kroon</td>
</tr>
<tr>
<td>ESP</td>
<td>Spanish peseta</td>
</tr>
<tr>
<td>EUR</td>
<td>Euro</td>
</tr>
<tr>
<td>FIM</td>
<td>Finish markka</td>
</tr>
<tr>
<td>FRF</td>
<td>French franc</td>
</tr>
<tr>
<td>GBP</td>
<td>Pound sterling</td>
</tr>
<tr>
<td>GRD</td>
<td>Greek drachma</td>
</tr>
</tbody>
</table>
20.3 Unit prefixes, number separators and notations

Numbers in this document are written using the `.` character as the decimal separator and the space as the separator for thousands.

The symbol ~ (around; approximately) is the notation used to indicate approximation.

The following table contains the frequently used prefixes:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Prefix</th>
<th>$10^n$</th>
<th>Word</th>
<th>Decimal Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>k</td>
<td>kilo</td>
<td>$10^3$</td>
<td>Thousand</td>
<td>1 000</td>
</tr>
<tr>
<td>h</td>
<td>hecto</td>
<td>$10^2$</td>
<td>Hundred</td>
<td>100</td>
</tr>
<tr>
<td>da</td>
<td>deca</td>
<td>$10^1$</td>
<td>Ten</td>
<td>10</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>------</td>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>d</td>
<td>deci</td>
<td>$10^{-1}$</td>
<td>Tenth</td>
<td>0.1</td>
</tr>
<tr>
<td>c</td>
<td>centi</td>
<td>$10^{-2}$</td>
<td>Hundredth</td>
<td>0.01</td>
</tr>
<tr>
<td>m</td>
<td>milli</td>
<td>$10^{-3}$</td>
<td>Thousandth</td>
<td>0.001</td>
</tr>
</tbody>
</table>

20.4 Units and measurements

<table>
<thead>
<tr>
<th>TERM</th>
<th>MEANING</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACkWh</td>
<td>kilowatt-hours (alternating current)</td>
</tr>
<tr>
<td>atm</td>
<td>normal atmosphere (1 atm = 101325 N/m$^2$)</td>
</tr>
<tr>
<td>bar</td>
<td>bar (1.013 bar = 1 atm)</td>
</tr>
<tr>
<td>barg</td>
<td>bar gauge (bar + 1 atm)</td>
</tr>
<tr>
<td>billion</td>
<td>thousand million ($10^9$)</td>
</tr>
<tr>
<td>°C</td>
<td>degree Celsius</td>
</tr>
<tr>
<td>cgs</td>
<td>centimetre gram second. A system of measurements now largely replaced by SI</td>
</tr>
<tr>
<td>cm</td>
<td>centimetre</td>
</tr>
<tr>
<td>cSt</td>
<td>centistokes = $10^{-2}$ stokes</td>
</tr>
<tr>
<td>d</td>
<td>day</td>
</tr>
<tr>
<td>°C/W</td>
<td>thermal resistance</td>
</tr>
<tr>
<td>dB</td>
<td>Decibel. The unit of measuring noise emission levels</td>
</tr>
<tr>
<td>dB(A)</td>
<td>Noise is measured in decibels (dB). To address the way the human ear responds to sound of different frequencies (pitches), an A-weighting is commonly applied, and the measurements are expressed in dB(A). Every 3 dB(A) reduction is equivalent to halving the noise emission level.</td>
</tr>
<tr>
<td>eV</td>
<td>electron volt</td>
</tr>
<tr>
<td>g</td>
<td>gram</td>
</tr>
<tr>
<td>GE</td>
<td>gigajoule</td>
</tr>
<tr>
<td>GJ</td>
<td>gigajoule</td>
</tr>
<tr>
<td>Hz</td>
<td>hertz</td>
</tr>
<tr>
<td>TERM</td>
<td>MEANING</td>
</tr>
<tr>
<td>------</td>
<td>---------</td>
</tr>
<tr>
<td>h</td>
<td>hour</td>
</tr>
<tr>
<td>ha</td>
<td>hectare ($10^4$ m$^2$) (=2.47105 acres)</td>
</tr>
<tr>
<td>hl</td>
<td>hectolitre</td>
</tr>
<tr>
<td>hPa</td>
<td>hectopascal (1 hPa = 100 Pa)</td>
</tr>
<tr>
<td>J</td>
<td>joule</td>
</tr>
<tr>
<td>K</td>
<td>kelvin ($0 ^\circ C = 273.15$ K)</td>
</tr>
<tr>
<td>kA</td>
<td>kiloampere</td>
</tr>
<tr>
<td>kcal</td>
<td>kilocalorie (1 kcal = 4.19 kJ)</td>
</tr>
<tr>
<td>kg</td>
<td>kilogramme (1 kg = 1000 g)</td>
</tr>
<tr>
<td>kJ</td>
<td>kilojoule (1 kJ = 0.24 kcal)</td>
</tr>
<tr>
<td>kPa</td>
<td>kilopascal</td>
</tr>
<tr>
<td>kt</td>
<td>kilotonne</td>
</tr>
<tr>
<td>kW</td>
<td>kilowatt</td>
</tr>
<tr>
<td>kW$_e$</td>
<td>kilowatt in the form of electrical energy</td>
</tr>
<tr>
<td>kWh</td>
<td>kilowatt-hour (1 kWh = 3600 kJ = 3.6 MJ = 0.0036 GJ)</td>
</tr>
<tr>
<td>kWh$_e$</td>
<td>kilowatt-hour in the form of electrical energy</td>
</tr>
<tr>
<td>l</td>
<td>litre</td>
</tr>
<tr>
<td>m</td>
<td>metre</td>
</tr>
<tr>
<td>m$^2$</td>
<td>square metre</td>
</tr>
<tr>
<td>m$^3$</td>
<td>cubic metre</td>
</tr>
<tr>
<td>m$^2$.ºC/W</td>
<td>thermal resistance unit</td>
</tr>
<tr>
<td>mg</td>
<td>milligram (1 mg = $10^{-3}$ gram)</td>
</tr>
<tr>
<td>MJ</td>
<td>megajoule (1 MJ = 1000 kJ = $10^6$ joule)</td>
</tr>
<tr>
<td>nm</td>
<td>nanometre (1 nm = $10^{-9}$ m)</td>
</tr>
<tr>
<td>mm</td>
<td>millimetre (1 mm = $10^{-3}$ m)</td>
</tr>
<tr>
<td>m/min</td>
<td>metres per minute</td>
</tr>
<tr>
<td>mmWG</td>
<td>millimetre water gauge</td>
</tr>
<tr>
<td>Mt</td>
<td>megatonne (1 Mt = 10$^6$ tonne)</td>
</tr>
<tr>
<td>Mt/yr</td>
<td>megatonnes per year</td>
</tr>
<tr>
<td>mV</td>
<td>millivolts</td>
</tr>
<tr>
<td>MW$_e$</td>
<td>megawatts electric (energy)</td>
</tr>
<tr>
<td>MW$_{th}$</td>
<td>megawatts thermal (energy)</td>
</tr>
<tr>
<td>ng</td>
<td>nanogram (1 ng = $10^{-9}$ gram)</td>
</tr>
<tr>
<td>Nm$^3$</td>
<td>normal cubic metre (101.325 kPa, 273 K)</td>
</tr>
<tr>
<td>OU$_E$</td>
<td>European odour unit</td>
</tr>
<tr>
<td>Pa</td>
<td>pascal</td>
</tr>
<tr>
<td>ppb</td>
<td>parts per billion</td>
</tr>
<tr>
<td>ppm</td>
<td>parts per million (by weight)</td>
</tr>
<tr>
<td>ppmv</td>
<td>parts per million(by volume)</td>
</tr>
<tr>
<td>s</td>
<td>second</td>
</tr>
<tr>
<td>sq ft</td>
<td>square foot (= 0.092 m$^2$)</td>
</tr>
<tr>
<td>St</td>
<td>stokes. An old, cgs unit of kinematic viscosity 1 St = $10^{-6}$ m$^2$/s</td>
</tr>
<tr>
<td>S unit (S/m or mS/cm)</td>
<td>electrical conductivity (Siemens per metre or milliSiemens per centimetre)</td>
</tr>
<tr>
<td>TJ</td>
<td>terajoule (1 TJ = $10^9$ MJ = $10^{12}$ joule)</td>
</tr>
<tr>
<td>t</td>
<td>metric tonne (1000 kg or $10^3$ gram)</td>
</tr>
<tr>
<td>t/d</td>
<td>tonnes per day</td>
</tr>
<tr>
<td>trillion</td>
<td>million million ($10^{12}$)</td>
</tr>
<tr>
<td>t/yr</td>
<td>tonne(s) per year</td>
</tr>
<tr>
<td>V</td>
<td>volt</td>
</tr>
<tr>
<td>vol-%</td>
<td>percentage by volume</td>
</tr>
<tr>
<td>wt-%</td>
<td>percentage by weight</td>
</tr>
<tr>
<td>W</td>
<td>watt (1 W = 1 J/s)</td>
</tr>
</tbody>
</table>
### Glossary

<table>
<thead>
<tr>
<th>TERM</th>
<th>MEANING</th>
</tr>
</thead>
<tbody>
<tr>
<td>wt-%</td>
<td>percentage by weight</td>
</tr>
<tr>
<td>yr</td>
<td>Year</td>
</tr>
<tr>
<td>ΔT</td>
<td>increase of temperature</td>
</tr>
<tr>
<td>~</td>
<td>around; more or less</td>
</tr>
<tr>
<td>μm</td>
<td>micrometre (1 μm = 10^{-6} m)</td>
</tr>
<tr>
<td>Ω</td>
<td>ohm, unit of electrical resistance</td>
</tr>
<tr>
<td>Ω cm</td>
<td>ohm centimetre, unit of specific resistance</td>
</tr>
</tbody>
</table>

### 20.5 Chemical elements

### 20.6 Chemical formulae commonly used in this document

### 20.7 Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADMS</td>
<td>Atmospheric dispersion modelling system</td>
</tr>
<tr>
<td>AOCl</td>
<td>Adsorbable organic chlorine compounds</td>
</tr>
<tr>
<td>AOX</td>
<td>Adsorbable organic halogen compounds. The total concentration in milligrams per litre, expressed as chlorine, of all halogen compounds (except fluorine) present in a sample of water that are capable of being adsorbed on activated carbon</td>
</tr>
<tr>
<td>ATMP</td>
<td>Amino trimethylene phosphonic acid</td>
</tr>
<tr>
<td>a_w</td>
<td>Water activity The water activity (a_w) of a given food is defined as a_w = p_f/p_w, where p_f and p_w are the pressures of water vapour in equilibrium with the given food system and with pure water, respectively, both at the same temperature</td>
</tr>
<tr>
<td>BAFF</td>
<td>Biological aerated flooded filter</td>
</tr>
<tr>
<td>BAT</td>
<td>Best Available Technique(s), as defined in Article 3(10) of the IED</td>
</tr>
<tr>
<td>BAT-AEL</td>
<td>Best Available Techniques - associated emission level, as defined in Article 3(13) of the IED</td>
</tr>
<tr>
<td>BAT-AEPL</td>
<td>Best Available Techniques - associated performance emission level, as described in section 3.3.2 of Commission Implementing Decision 2012/119/EU</td>
</tr>
<tr>
<td>BOD</td>
<td>Biochemical oxygen demand: the quantity of dissolved oxygen required by microorganisms in order to decompose organic matter. The unit of measurement is mg O_2/l. In Europe, BOD is usually measured after 3 (BOD_3), 5 (BOD_5) or 7 (BOD_7) days</td>
</tr>
<tr>
<td>BREF</td>
<td>Best available techniques (BAT) reference document</td>
</tr>
<tr>
<td>BSE</td>
<td>Bovine spongiform encephalopathy</td>
</tr>
<tr>
<td>C_1, C_2 etc.</td>
<td>Organic compounds indicated by the number of carbon atoms</td>
</tr>
<tr>
<td>CaO</td>
<td>Calcium oxide</td>
</tr>
<tr>
<td>Ca(OH)_2</td>
<td>Calcium hydroxide</td>
</tr>
<tr>
<td>CCl_4</td>
<td>Carbon tetrachloride</td>
</tr>
<tr>
<td>CEN</td>
<td>The European Committee for Standardisation</td>
</tr>
<tr>
<td>CEFS</td>
<td>Comité Européen des Fabricants de Sucre</td>
</tr>
<tr>
<td>CFC</td>
<td>Chlorofluorohydrocarbons</td>
</tr>
<tr>
<td>CFM</td>
<td>Cross flow microfiltration</td>
</tr>
<tr>
<td>CFU</td>
<td>Colony-forming unit</td>
</tr>
<tr>
<td>CGS</td>
<td>Co-generation system (for power generation)</td>
</tr>
<tr>
<td>CH_4</td>
<td>Methane</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>CHCl₃</td>
<td>Trichloromethane (chloroform)</td>
</tr>
<tr>
<td>CHP</td>
<td>Co-generation of heat and power (combined heat and power)</td>
</tr>
<tr>
<td>CIAA</td>
<td>Confederation of the food and drink industries of the EU</td>
</tr>
<tr>
<td>CIP</td>
<td>Cleaning-in-place</td>
</tr>
<tr>
<td>Cl₂</td>
<td>Chlorine</td>
</tr>
<tr>
<td>CMF</td>
<td>Cross-flow microfilter</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>COD</td>
<td>Chemical oxygen demand: the amount of potassium dichromate, expressed as oxygen, required to chemically oxidise at approximately 150 °C substances contained in waste water</td>
</tr>
<tr>
<td>COP</td>
<td>Coefficient of performance</td>
</tr>
<tr>
<td>CWW BREF</td>
<td>BAT Reference Document in the Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector</td>
</tr>
<tr>
<td>DAF</td>
<td>Dissolved air flotation</td>
</tr>
<tr>
<td>DC</td>
<td>Dry condensing</td>
</tr>
<tr>
<td>DDGS</td>
<td>Distiller’s dried grains with solubles</td>
</tr>
<tr>
<td>DMRI</td>
<td>Danish Meat Research Institute</td>
</tr>
<tr>
<td>DT</td>
<td>Desolventiser-toaster</td>
</tr>
<tr>
<td>DTPMP</td>
<td>Diethylenetriamine pentakis methylene phosphonic acid</td>
</tr>
<tr>
<td>ED</td>
<td>Electro dialysis</td>
</tr>
<tr>
<td>EDTA</td>
<td>Ethylenediaminetetraacetic acid</td>
</tr>
<tr>
<td>e.g.</td>
<td>For example (Latin: exempli gratia)</td>
</tr>
<tr>
<td>EBPR</td>
<td>Enhanced biological phosphorus removal</td>
</tr>
<tr>
<td>EGSB</td>
<td>Expanded granular sludge blanket (reactor)</td>
</tr>
<tr>
<td>EIPPCB</td>
<td>European IPPC Bureau</td>
</tr>
<tr>
<td>EMAS</td>
<td>Eco-Management and Audit Scheme</td>
</tr>
<tr>
<td>EMS</td>
<td>Environmental management system</td>
</tr>
<tr>
<td>EN</td>
<td>European Norming (EN standards)</td>
</tr>
<tr>
<td>EP</td>
<td>Electrostatic precipitator</td>
</tr>
<tr>
<td>EPA</td>
<td>US Environment Protection Agency</td>
</tr>
<tr>
<td>ESP</td>
<td>Electrostatic precipitator</td>
</tr>
<tr>
<td>ETBPP</td>
<td>Environmental Technology Best Practice Programme (UK)</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EU-15</td>
<td>AT, BE, DE, DK, EL, ES, FI, FR, IE, IT, LU, NL, PT, SE and UK</td>
</tr>
<tr>
<td>EU-28</td>
<td>AT, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LV, LT, LU, MT, NL, PL, PT, RO, SE, SI, SK and UK</td>
</tr>
<tr>
<td>EUCA</td>
<td>European Coffee Association</td>
</tr>
<tr>
<td>FBD</td>
<td>Fluidised bed dryer</td>
</tr>
<tr>
<td>FDM</td>
<td>Food, drink and milk</td>
</tr>
<tr>
<td>FFS</td>
<td>Form, fill and seal</td>
</tr>
<tr>
<td>Fe</td>
<td>Iron</td>
</tr>
<tr>
<td>FeCl₃</td>
<td>Iron trichloride</td>
</tr>
<tr>
<td>FFA</td>
<td>Free fatty acids</td>
</tr>
<tr>
<td>F/M ratio</td>
<td>Food to microorganism ratio</td>
</tr>
<tr>
<td>FOG</td>
<td>Fats, oils and greases</td>
</tr>
<tr>
<td>GE</td>
<td>A standard odour unit (OU) defined as the quantity of odour carrier in 1 m³ neutral air that causes a smell perception</td>
</tr>
<tr>
<td>GMO</td>
<td>Genetically modified organisms</td>
</tr>
<tr>
<td>HACCP</td>
<td>Hazard Analysis Critical Control Points</td>
</tr>
<tr>
<td>HCFC</td>
<td>Hydrochlorofluorocarbon</td>
</tr>
<tr>
<td>HCH</td>
<td>Hexachlorocyclohexane (lindane). An insecticide</td>
</tr>
<tr>
<td>HCl</td>
<td>Hydrochloric acid</td>
</tr>
<tr>
<td>HDPE</td>
<td>High density poly-ethylene</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>HEPA</td>
<td>High efficiency particulate air</td>
</tr>
<tr>
<td>HFC</td>
<td>Hydrofluorocarbons</td>
</tr>
<tr>
<td>HHST</td>
<td>High heat short time (pasteurisation)</td>
</tr>
<tr>
<td>HP</td>
<td>High pressure</td>
</tr>
<tr>
<td>H₂SO₄</td>
<td>Sulphuric acid</td>
</tr>
<tr>
<td>HTD</td>
<td>High temperature drying</td>
</tr>
<tr>
<td>HTST</td>
<td>High temperature short time (pasteurisation)</td>
</tr>
<tr>
<td>IC</td>
<td>Internal circulation (waste water treatment reactor)</td>
</tr>
<tr>
<td>ICW</td>
<td>Integrated constructed wetlands</td>
</tr>
<tr>
<td>IDS</td>
<td>Iminodisuccinate</td>
</tr>
<tr>
<td>IMPEL</td>
<td>European Union Network for the Implementation and Enforcement of Environmental Law</td>
</tr>
<tr>
<td>ISCST</td>
<td>Industrial source complex short term (model)</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organisation for Standardisation</td>
</tr>
<tr>
<td>IPPC</td>
<td>Integrated pollution prevention and control</td>
</tr>
<tr>
<td>LAS</td>
<td>Linear alkylated benzene sulfonamides</td>
</tr>
<tr>
<td>LDPE</td>
<td>Low density polyethylene</td>
</tr>
<tr>
<td>LOEC</td>
<td>Lowest observed effect concentration. The lowest experimentally determined concentration of a test substance at which adverse effects can be observed</td>
</tr>
<tr>
<td>LP</td>
<td>Low pressure</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquified petroleum gas</td>
</tr>
<tr>
<td>LTD</td>
<td>Low temperature drying</td>
</tr>
<tr>
<td>LTDM</td>
<td>Long-term frequency distribution model</td>
</tr>
<tr>
<td>MAP</td>
<td>Modified atmosphere packing</td>
</tr>
<tr>
<td>MBR</td>
<td>Membrane bioreactor</td>
</tr>
<tr>
<td>MF</td>
<td>Microfiltration</td>
</tr>
<tr>
<td>MLSS</td>
<td>Mixed liquor suspended solids</td>
</tr>
<tr>
<td>Mo</td>
<td>Molybdenum</td>
</tr>
<tr>
<td>MS(s)</td>
<td>Member state(s) of the European Union</td>
</tr>
<tr>
<td>MVR</td>
<td>Mechanical vapour recompression</td>
</tr>
<tr>
<td>MWWTP</td>
<td>Municipal waste water treatment plant</td>
</tr>
<tr>
<td>n.d.</td>
<td>No data</td>
</tr>
<tr>
<td>n.e.c</td>
<td>Not elsewhere classified</td>
</tr>
<tr>
<td>NFR</td>
<td>Nanofiltration</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-governmental organisation</td>
</tr>
<tr>
<td>NH₃</td>
<td>Ammonia</td>
</tr>
<tr>
<td>NH₄</td>
<td>Ammonium</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>Ammonium nitrogen</td>
</tr>
<tr>
<td>NPV</td>
<td>Net present value</td>
</tr>
<tr>
<td>N-tot</td>
<td>Total nitrogen</td>
</tr>
<tr>
<td>NTA</td>
<td>Nitrilotriacetate</td>
</tr>
<tr>
<td>NTU</td>
<td>Nephelometric turbidity units</td>
</tr>
<tr>
<td>OU</td>
<td>Odour unit(s) (see also GE)</td>
</tr>
<tr>
<td>P</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>PAH</td>
<td>Polynuclear aromatic hydrocarbons</td>
</tr>
<tr>
<td>PE</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>PET</td>
<td>Polyethylene terephthalate</td>
</tr>
<tr>
<td>Pid</td>
<td>Process and instrumentation diagrams</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate matter</td>
</tr>
<tr>
<td>PP</td>
<td>Polypropylene</td>
</tr>
<tr>
<td>PS</td>
<td>Polystyrene</td>
</tr>
<tr>
<td>PTA</td>
<td>Peseta</td>
</tr>
<tr>
<td>PTFE</td>
<td>Polytetrafluoroethylene</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl chloride</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
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</tr>
<tr>
<td>RBC</td>
<td>Rotating biological contactors</td>
</tr>
<tr>
<td>RO</td>
<td>Reverse osmosis</td>
</tr>
<tr>
<td>RPM</td>
<td>Rotations per minute</td>
</tr>
<tr>
<td>RTD</td>
<td>Research, technology and development</td>
</tr>
<tr>
<td>SBAF</td>
<td>Submerged biological aerated filter</td>
</tr>
<tr>
<td>SBR</td>
<td>Sequencing batch reactor</td>
</tr>
<tr>
<td>SEC</td>
<td>Specific energy consumption</td>
</tr>
<tr>
<td>SME</td>
<td>Small and medium enterprise(s)</td>
</tr>
<tr>
<td>SO\textsubscript{x}</td>
<td>Sulphur oxides</td>
</tr>
<tr>
<td>SO\textsubscript{2}</td>
<td>Sulphur dioxide</td>
</tr>
<tr>
<td>SO\textsubscript{3}</td>
<td>Sulphur trioxide</td>
</tr>
<tr>
<td>SS</td>
<td>Suspended solids</td>
</tr>
<tr>
<td>TDS</td>
<td>Total dissolved solids</td>
</tr>
<tr>
<td>TKN</td>
<td>Total Kjeldahl nitrogen</td>
</tr>
<tr>
<td>TOC</td>
<td>Total organic carbon</td>
</tr>
<tr>
<td>TS</td>
<td>Total solids</td>
</tr>
<tr>
<td>TSE</td>
<td>Transmissible spongiform encephalopathy</td>
</tr>
<tr>
<td>TSS</td>
<td>Total suspended solids</td>
</tr>
<tr>
<td>TVR</td>
<td>Thermal vapour recompression</td>
</tr>
<tr>
<td>TWG</td>
<td>Technical working group</td>
</tr>
<tr>
<td>UASB</td>
<td>Upflow anaerobic sludge blanket (reactor)</td>
</tr>
<tr>
<td>UF</td>
<td>Ultrafiltration</td>
</tr>
<tr>
<td>UHP</td>
<td>Ultra-high pressure</td>
</tr>
<tr>
<td>UHT</td>
<td>Ultra-high temperature (sterilisation)</td>
</tr>
<tr>
<td>UV</td>
<td>Ultraviolet</td>
</tr>
<tr>
<td>VDI</td>
<td>Verein Deutscher Ingenieure (The Association of German Engineers)</td>
</tr>
<tr>
<td>VOC(s)</td>
<td>Volatile organic compound(s) (not limited to the definition of volatile organic compound in Council Directive 1999/13/EC)</td>
</tr>
<tr>
<td>WFE</td>
<td>Wiped film evaporator</td>
</tr>
<tr>
<td>WHB</td>
<td>Waste heat boiler</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organisation</td>
</tr>
<tr>
<td>WT BREF</td>
<td>BAT Reference Document for Waste Treatment</td>
</tr>
<tr>
<td>WWTP</td>
<td>Waste water treatment plant</td>
</tr>
<tr>
<td>XPP</td>
<td>Expanded polypropylene</td>
</tr>
</tbody>
</table>
20.8 Technical definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated sludge process</td>
<td>A biological waste water treatment by which bacteria that feed on organic wastes are continuously circulated and put in contact with organic waste in the presence of oxygen to increase the rate of decomposition</td>
</tr>
<tr>
<td>Aeration</td>
<td>A biological process by which air is introduced to increase the oxygen concentration in liquids. Aeration may be performed by bubbling air through the liquid, spraying the liquid into the air or agitating the liquid to increase surface absorption. Blowing fresh and dry air through stored crops such as cereal grains, in order to decrease its temperature and/or humidity</td>
</tr>
<tr>
<td>Agronomic interests</td>
<td>relating to the science of soil management and crop production</td>
</tr>
<tr>
<td>Anaerobic</td>
<td>A biological process which occurs in the absence of oxygen</td>
</tr>
<tr>
<td>A/O process</td>
<td>The proprietary A/O process for mainstream phosphorus removal is used for combined carbon oxidation and phosphorus removal from waste water. This process is a single-sludge suspended-growth system that combines anaerobic and aerobic sections in sequence</td>
</tr>
<tr>
<td>Aquifer</td>
<td>A water-bearing layer of rock (including gravel and sand) that will yield water in usable quantity to a well or spring</td>
</tr>
<tr>
<td>Asbestos</td>
<td>A mineral fibre that can pollute air or water and cause cancer or asbestosis when inhaled</td>
</tr>
<tr>
<td>Aseptic</td>
<td>Sterile or free of bacterial contamination</td>
</tr>
<tr>
<td>Aseptic processing and packaging</td>
<td>Commonly used to describe food processing and packaging techniques for non-refrigerated storage or long-life products, in which packages and food products are sterilised in separate continuous systems. The sterile package is then filled with sterile product, closed and sealed under aseptic conditions</td>
</tr>
<tr>
<td>Assimilative capacity</td>
<td>The ability of a natural body of water to receive waste water or toxic materials without harmful effects and without damage to aquatic life</td>
</tr>
<tr>
<td>Bactericide</td>
<td>A substance used to control or destroy bacteria</td>
</tr>
<tr>
<td>Baffle</td>
<td>Plate which hinders or regulates the flow of fluid</td>
</tr>
<tr>
<td>Bank-filtered water</td>
<td>River water abstracted from outside the river bank</td>
</tr>
<tr>
<td>Biochemicals</td>
<td>Chemicals that are either naturally occurring or identical to naturally occurring substances. Examples include hormones, pheromones and enzymes. Biochemicals function as pesticides through non-toxic, non-lethal modes of action, such as disrupting the mating pattern of insects, regulating growth or acting as repellents</td>
</tr>
<tr>
<td>Biocoenoses</td>
<td>Association of different organisms forming a closely integrated community. The relationship between such organisms</td>
</tr>
<tr>
<td>Biodegradable</td>
<td>That can be broken down physically and/or chemically by microorganisms. For example, many chemicals, food scraps, cotton, wool and paper are biodegradable</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>The number and variety of different organisms in the ecological complexes in which they naturally occur. Organisms are organised at many levels, ranging from complete ecosystems to the biochemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species and genes that are present in a healthy environment. A large number of species characterises the food chain, representing multiple predator-prey relationships</td>
</tr>
<tr>
<td>Biomass</td>
<td>Organic matter available on a renewable basis. Biomass includes forest, agricultural crops and wastes, wood and wood wastes, animal wastes, livestock operation residues, aquatic plants, fast-growing trees and plants, and municipal and industrial wastes</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-----------------------------</td>
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</tr>
<tr>
<td>Brix degree (°brix)</td>
<td>Also called % DSSC (% dry soluble substances content). Concentration, expressed as sucrose content, of all substances dissolved in a liquid. X°brix is equivalent to the concentration of all substances dissolved in a juice which causes a refractometric deviation equal to that caused by a solution of X grams of sucrose per 100 grams of solution</td>
</tr>
<tr>
<td>Cake</td>
<td>Carbonation slurry after concentration with filter presses to about 70 % DS, e.g. with precipitated calcium carbonate</td>
</tr>
<tr>
<td>Catchpot</td>
<td>Fine mesh basket placed over floor drains, to prevent solids from entering the drainage system and the WWTP</td>
</tr>
<tr>
<td>Caustic</td>
<td>Sodium hydroxide</td>
</tr>
<tr>
<td>Cephalopod</td>
<td>Mollusc of class Cephalopoda</td>
</tr>
<tr>
<td>CIP system</td>
<td>Acronym for cleaning-in-place. It is a practice for cleaning tanks, pipelines, processing equipment and process lines by circulating water and cleaning solutions through them without dismantling the pipelines or equipment</td>
</tr>
<tr>
<td>Coliform bacteria</td>
<td>Microorganisms found in the intestinal tracts of humans and animals. Their presence in water indicates fecal pollution and potentially dangerous bacterial contamination by disease-causing microorganisms</td>
</tr>
<tr>
<td>Conching</td>
<td>Conching is a special method of kneading used in the chocolate industry</td>
</tr>
<tr>
<td>Condition</td>
<td>Bring to a desired state or condition</td>
</tr>
<tr>
<td>Confectionery</td>
<td>Sweets and sweet preparations such as cakes</td>
</tr>
<tr>
<td>Cossettes</td>
<td>Thin slices of sugar beet</td>
</tr>
<tr>
<td>Crustacean</td>
<td>Member of the Crustacea, a large class of arthropod (animal of phylum Arthropoda, with segmented body and jointed limbs) with hard shells, mainly aquatic, e.g. crab, lobster, shrimp</td>
</tr>
<tr>
<td>Culm</td>
<td>The stem of a plant</td>
</tr>
<tr>
<td>Decoction</td>
<td>Concentration of, or extraction of the essence of a substance by boiling</td>
</tr>
<tr>
<td>Defrost</td>
<td>The removal of frost from the inside of a refrigerator or cold store</td>
</tr>
<tr>
<td>Degumming</td>
<td>The removal of gums in vegetable oil to avoid colour and taste reversion during subsequent refining steps</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>The pollution of a body of water by sewage, fertilisers washed from the land, and industrial wastes (inorganic nitrates and phosphates). These compounds stimulate the growth of algae, reducing the oxygen content in the water, and so killing animals with a high oxygen requirement</td>
</tr>
<tr>
<td>Evisceration</td>
<td>Step in the slaughter process by which the contents of the chest and belly cavities of the animals are removed</td>
</tr>
<tr>
<td>Fouling</td>
<td>The process of becoming dusty or clogged, e.g. in which undesirable foreign matter accumulates in a bed of filter or ion exchanger media, clogging pores and coating surfaces, thus inhibiting or delaying proper bed operation. The fouling of a heat exchanger consists of the accumulation of dirt or other materials on the wall of a heat exchanger, causing corrosion, roughness and ultimately leading to a lowered rate of efficiency</td>
</tr>
<tr>
<td>Fresh-pack</td>
<td>Fruit or vegetables which have been packed fresh</td>
</tr>
<tr>
<td>Fuller’s earth</td>
<td>Soft, greenish-grey rock resembling clay, but without clay’s plasticity. It is formed largely of clay minerals, rich in montmorillonite, but a great deal of silica is also present. Its absorbent properties make it suitable for removing oil and grease</td>
</tr>
<tr>
<td>Germination</td>
<td>The process whereby seeds or spores sprout and begin to grow, also called sprouting</td>
</tr>
<tr>
<td>Gram-negative bacteria</td>
<td>Those bacteria which fail to stain with Gram’s reaction. The reaction depends on the complexity of the cell wall and has for long determined a major division between bacterial species</td>
</tr>
<tr>
<td>Herbicide</td>
<td>Any chemical toxic substance, usually used to kill specific unwanted plants, especially weeds</td>
</tr>
<tr>
<td>Glossary</td>
<td>Definition</td>
</tr>
<tr>
<td>----------</td>
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</tr>
<tr>
<td>HEPA filter</td>
<td>High efficiency particulate air filter</td>
</tr>
<tr>
<td>Hull</td>
<td>Outer covering of fruit and seeds, especially pod of peas and beans, husk of grain, or green calyx of strawberry</td>
</tr>
<tr>
<td>Ice-water</td>
<td>Cooled water which is then used for cooling</td>
</tr>
<tr>
<td>Immission</td>
<td>Pollutant mass/concentration that is dissipated to the environment. It is measured where the environmental impact occurs.</td>
</tr>
<tr>
<td>Kieselguhr</td>
<td>A light soil consisting of siliceous remains of microscopic one-celled or colonial algae, used for filtering purposes, also called diatomaceous earth</td>
</tr>
<tr>
<td>Lecithin</td>
<td>Any of a group of natural phospholipids which are esters of a phosphatidic acid with choline; such phospholipids collectively; a mixture containing these, used commercially as a food emulsifier etc.</td>
</tr>
<tr>
<td>Lees</td>
<td>The sediment of wine or some other liquids</td>
</tr>
<tr>
<td>Lyophilisation (freeze-drying)</td>
<td>The process of preserving food products by freezing them and then evaporating the water (in the form of ice) by sublimation</td>
</tr>
<tr>
<td>Malt sprouts</td>
<td>The shoots which grow during germination of malt</td>
</tr>
<tr>
<td>Marc</td>
<td>The residue, e.g. skins, pits and seeds, remaining after the juice has been pressed from a fruit, usually apple or grapes</td>
</tr>
<tr>
<td>Mash</td>
<td>Malt mixed with hot water to form wort</td>
</tr>
<tr>
<td>Miscella</td>
<td>Mixture of crude vegetable oil and hexane formed during solvent extraction of vegetable oils</td>
</tr>
<tr>
<td>Mitzithra cheese</td>
<td>Cheese made from whey</td>
</tr>
<tr>
<td>Mollusc</td>
<td>Soft-bodied and usually hard-shelled animal belonging to the phylum Mollusca</td>
</tr>
<tr>
<td>Must</td>
<td>Any juice or liquid prepared undergoing alcoholic fermentation, e.g. grape juice or the pulp of apples or pears</td>
</tr>
<tr>
<td>Native starch</td>
<td>Refined starch without any chemical and/or physical modification</td>
</tr>
<tr>
<td>Nibs</td>
<td>Pieces of peeled fermented cacao beans</td>
</tr>
<tr>
<td>Oenology</td>
<td>Of or pertaining to the knowledge of making wines</td>
</tr>
<tr>
<td>Ostwald combustion diagram</td>
<td>The Ostwald combustion diagram shows in graphical form the theoretical relationships among the products of combustion of hydrocarbons. The interdependence of CO₂, O₂, CO, and air-fuel ratio is given. By this, it is possible to determine the CO and air-fuel ratio when the values for CO₂ and O₂ are known.</td>
</tr>
<tr>
<td>Pasteurisation</td>
<td>Thermal process, treatment, or combination thereof, that is applied to food to reduce the most resistant microorganisms of public health significance to a level that is not likely to present a public health risk under normal conditions of distribution and storage. Thermal pasteurisation treatments are time/temperature equivalent combinations to obtain a certain decimal (log) reduction of viable organisms with a reduced detrimental effect on flavour and chemistry of the food</td>
</tr>
<tr>
<td>Perry</td>
<td>A juice like cider, made from pears</td>
</tr>
<tr>
<td>Pesticide</td>
<td>Biological, physical or chemical agent used to kill pests. In practice, the term pesticide is often applied only to chemical agents. Various pesticides are known as insecticides, nematicides, fungicides, herbicides and rodenticides, i.e., agents primarily effective against insects, nematodes (or roundworms), fungi, weeds and rodents, respectively</td>
</tr>
<tr>
<td>PhoStrip process</td>
<td>In the proprietary PhoStrip process for side-stream phosphorus removal, a portion of the return activated sludge process is diverted to an anaerobic phosphorus stripping tank</td>
</tr>
<tr>
<td>Pomace</td>
<td>The residue, e.g. skins, pits and seeds, remaining after the juice has been pressed from, e.g. apples, pears and olives</td>
</tr>
<tr>
<td>Pome</td>
<td>A fleshy fruit with a central seed-bearing core, e.g. apple</td>
</tr>
<tr>
<td>Primary packaging</td>
<td>Packaging conceived so as to constitute a sales unit to the final user or consumer at the point of purchase</td>
</tr>
<tr>
<td>Residue</td>
<td>Substance or object generated by the activities covered by the scope of</td>
</tr>
<tr>
<td><strong>Re values</strong> (Reynolds number)</td>
<td>The Reynolds number is the ratio of inertial forces, as described by Newton’s second law of motion, to viscous forces. If the Reynolds number is high, inertial forces dominate, resulting on a turbulent flow. If it is low, viscous forces prevail, resulting on a laminar flow.</td>
</tr>
<tr>
<td><strong>Rootlet</strong></td>
<td>A small root, e.g. on grain during malting.</td>
</tr>
<tr>
<td><strong>Sankey diagram</strong></td>
<td>Diagrams used for displaying flows through a system, e.g. to show mass and energy flows.</td>
</tr>
<tr>
<td><strong>Secondary packaging</strong></td>
<td>Packaging conceived so as to constitute at the point of purchase a grouping of a certain number of sales units whether the latter is sold as such to the final user or consumer or whether it serves only as a means to replenish the shelves at the point of sale; it can be removed from the product without affecting its characteristics.</td>
</tr>
<tr>
<td><strong>Sparge</strong></td>
<td>To sprinkle, e.g. water, aerate a liquid with air or inject steam. In brewing, a spray of hot water sprinkled over the malt.</td>
</tr>
<tr>
<td><strong>Stabulation</strong></td>
<td>Storing wine at low temperature.</td>
</tr>
<tr>
<td><strong>Standardised milk</strong></td>
<td>Milk which has been treated to adjust the fat content to a specified percentage which depends on the milk's intended use.</td>
</tr>
<tr>
<td><strong>Soil tare</strong></td>
<td>The weight of soil, gravel and stones carried with crops when they are harvested.</td>
</tr>
<tr>
<td><strong>Sump</strong></td>
<td>A pit, well or hole used for collecting water or other fluid.</td>
</tr>
<tr>
<td><strong>Surimi</strong></td>
<td>Minced, processed fish used in the preparation of an imitation of seafood, especially shellfish.</td>
</tr>
<tr>
<td><strong>Tempering</strong></td>
<td>A process used in chocolate processing that ensures product quality and appearance; enable handling of liquid chocolate for various applications; ensure viscosity control; and enable net weight requirements to be met. Tempering is also the controlled thawing of meats.</td>
</tr>
<tr>
<td><strong>Tertiary packaging</strong></td>
<td>Packaging conceived so as to facilitate handling and transport of a number of sales units or grouped packagings in order to prevent damage due to physical handling and transport.</td>
</tr>
<tr>
<td><strong>Thaw</strong></td>
<td>To unfreeze food or raw materials.</td>
</tr>
<tr>
<td><strong>Thermal resistance (K/W or °C/W)</strong></td>
<td>The thermal resistance of an insulating material, in thermal ohms, is the R-value (a commercial unit used to measure the effectiveness of thermal insulation) divided by the thickness of the material, in meters.</td>
</tr>
<tr>
<td><strong>Trub</strong></td>
<td>A coarse coagulum of proteinaceous precipitated material which is separated from the wort as part of the brewing process.</td>
</tr>
<tr>
<td><strong>Vanillin</strong></td>
<td>A sweet smelling crystalline aldehyde which is the chief essential constituent of vanilla.</td>
</tr>
<tr>
<td><strong>Van der waals forces</strong></td>
<td>Forces that exist between molecules of the same substance. These forces are much weaker than chemical bonds, and random thermal motion around room temperature can usually overcome or disrupt them. The forces operate only when molecules pass very close to each other, during collisions or near misses.</td>
</tr>
<tr>
<td><strong>Vinasses</strong></td>
<td>A by-product that is generated when processing molasses. After the fermentable sugar in molasses has been used by the microorganisms (e.g. yeasts) and the compounds produced have been separated out (e.g. alcohol is distilled), this is the remaining nutrient medium. The non-sugar substances that have not been assimilated and metabolic side products are in this liquid. Vinasses may be concentrated to give a solids content of 70% by multiple-effect evaporators.</td>
</tr>
<tr>
<td><strong>Viscera</strong></td>
<td>The organs contained within the trunk, considered collectively, e.g. the digestive tract, heart and lungs.</td>
</tr>
<tr>
<td><strong>Wort</strong></td>
<td>A sweet infusion of ground malt or other grain before fermentation, used to produce, e.g. beer and distilled malt liquors.</td>
</tr>
</tbody>
</table>
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