Best Available Techniques (BAT) Reference Document for the Textiles Industry

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

Draft 1 (December 2019)

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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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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)
[EXECUTIVE SUMMARY]

Deleted because the recent BREFs no longer contain an executive summary.
Preface

1. Status of this document


This document forms part of a series presenting the results of an exchange of information between EU Member States and industries concerned on best available techniques (BAT), associated monitoring, and developments in them. It is published by the European Commission pursuant to Article 16(2) of the Directive, and must therefore be taken into account in accordance with Annex IV of the Directive when determining “best available techniques”.


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. Relevant legal obligations of the IPPC Directive and the definition of BAT

In order to help the reader understand the legal context in which this document has been drafted, some of the most relevant provisions of the IPPC Directive, including the definition of the term “best available techniques”, are described in this preface. This description is inevitably incomplete and is given for information only. It has no legal value and does not in any way alter or prejudice the actual provisions of the Directive.

The purpose of the Directive is to achieve integrated prevention and control of pollution arising from the activities listed in its Annex I, leading to a high level of protection of the environment as a whole. The legal basis of the Directive relates to environmental protection. Its implementation should also take account of other Community objectives such as the competitiveness of the Community’s industry thereby contributing to sustainable development.

More specifically, it provides for a permitting system for certain categories of industrial installations requiring both operators and regulators to take an integrated, overall look at the polluting and consuming potential of the installation. The overall aim of such an integrated approach must be to improve the management and control of industrial processes so as to ensure a high level of protection for the environment as a whole. Central to this approach is the general principle given in Article 3 that operators should take all appropriate preventative measures against pollution, in particular through the application of best available techniques enabling them to improve their environmental performance.

The term “best available techniques” is defined in Article 2(11) of the Directive as “the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole.” Article 2(11) goes on to clarify further this definition as follows:

“techniques” includes both the technology used and the way in which the installation is designed, built, antifoaming agents, maintained, operated and decommissioned;
“available” techniques are those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator.

“best” means most effective in achieving a high general level of protection of the environment as a whole.

Furthermore, Annex IV of the Directive contains a list of “considerations to be taken into account generally or in specific cases when determining best available techniques ... bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention”. These considerations include the information published by the Commission pursuant to Article 16(2).

Competent authorities responsible for issuing permits are required to take account of the general principles set out in Article 3 when determining the conditions of the permit. These conditions must include emission limit values, supplemented or replaced where appropriate by equivalent parameters or technical measures. According to Article 9(4) of the Directive, these emission limit values, equivalent parameters and technical measures must, without prejudice to compliance with environmental quality standards, be based on the best available techniques, without prescribing the use of any technique or specific technology, but taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In all circumstances, the conditions of the permit must include provisions on the minimisation of long-distance or transboundary pollution and must ensure a high level of protection for the environment as a whole.

Member States have the obligation, according to Article 11 of the Directive, to ensure that competent authorities follow or are informed of developments in best available techniques.

3. Objective of this Document

Article 16(2) of the Directive requires the Commission to organise “an exchange of information between Member States and the industries concerned on best available techniques, associated monitoring and developments in them”, and to publish the results of the exchange.

The purpose of the information exchange is given in recital 25 of the Directive, which states that “the development and exchange of information at Community level about best available techniques will help to redress the technological imbalances in the Community, will promote the world-wide dissemination of limit values and techniques used in the Community and will help the Member States in the efficient implementation of this Directive.”

The Commission (Environment DG) established an information exchange forum (IEF) to assist the work under Article 16(2) and a number of technical working groups have been established under the umbrella of the IEF. Both IEF and the technical working groups include representation from Member States and industry as required in Article 16(2).

The aim of this series of documents is to reflect accurately the exchange of information which has taken place as required by Article 16(2) and to provide reference information for the permitting authority to take into account when determining permit conditions. By providing relevant information concerning best available techniques, these documents should act as valuable tools to drive environmental performance.

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).

4. Information sources

This document represents a summary of information collected from a number of sources, including in particular the expertise of the groups established to assist the Commission in its work, and verified by the Commission services. All contributions are gratefully acknowledged.

3. How to understand and use this document—Structure and contents of this document

The information provided in this document is intended to be used as an input to the determination of BAT in specific cases. When determining BAT and setting BAT-based permit conditions, account should always be taken of the overall goal to achieve a high level of protection for the environment as a whole.

The rest of this section describes the type of information that is provided in each section of the document.

Chapter 1 and Chapter 2 provide general information on the industrial textiles sector concerned and on the industrial processes used within this sector.

Chapter 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, water consumption, use of energy and the generation of waste.

Chapter 4 describes in more detail the techniques to prevent or, where this is not practicable, to reduce the environmental impact of 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) which can be achieved by using the techniques, the associated monitoring and the costs and the cross-media issues associated with the techniques.

Chapter 5 presents the BAT conclusions as defined in Article 3(12) of the Directive, both general and process-specific.

Chapter 6 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 7.

Chapter 3 provides data and information concerning current emission and consumption levels reflecting the situation in existing installations at the time of writing.

Chapter 0 describes in more detail the emission reduction and other techniques that are considered to be most relevant for determining BAT and BAT-based permit conditions. This information includes the consumption and emission levels considered achievable by using the techniques, some idea of the costs and the cross-media issues associated with the technique, and the extent to which the technique is applicable to the range of installations requiring IPPC.
permits, for example new, existing, large or small installations. Techniques that are generally seen as obsolete are not included.

Chapter 5 presents the techniques and the emission and consumption levels that are considered to be compatible with BAT in a general sense. The purpose is thus to provide general indications regarding the emission and consumption levels that can be considered as an appropriate reference point to assist in the determination of BAT-based permit conditions or for the establishment of general binding rules under Article 9(8). It should be stressed, however, that this document does not propose emission limit values. The determination of appropriate permit conditions will involve taking account of local, site-specific factors such as the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In the case of existing installations, the economic and technical viability of upgrading them also needs to be taken into account. Even the single objective of ensuring a high level of protection for the environment as a whole will often involve making trade-off judgements between different types of environmental impact, and these judgements will often be influenced by local considerations.

Although an attempt is made to address some of these issues, it is not possible for them to be considered fully in this document. The techniques and levels presented in Chapter 5 will therefore not necessarily be appropriate for all installations. On the other hand, the obligation to ensure a high level of environmental protection including the minimisation of long-distance or transboundary pollution implies that permit conditions cannot be set on the basis of purely local considerations. It is therefore of the utmost importance that the information contained in this document is fully taken into account by permitting authorities.

Since the best available techniques change over time, this document will be reviewed and updated as appropriate. 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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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 textiles sector;
- 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;
Preface

- 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 Chapter 4. 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 plant 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 plants.

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 Joint Research Centre (JRC) at the following address:

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Internet: http://eippcb.jrc.ec.europa.eu
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SCOPE

This document covers the industrial activities specified in Section 6.2 of Annex I of Directive 96/61/EC, namely:

"Plants for the pretreatment (operations such as washing, bleaching, mercerisation) or dyeing of fibres or textiles where the treatment capacity exceeds 10 tonnes per day".

Particular attention is given to the following processes:

- fibre preparation
- pretreatment
- dyeing
- printing
- finishing.

Upstream processes which may have a significant influence on the environmental impact of the subsequent wet processing activities are also briefly described.

The backing of carpets is included in this document because it is an intrinsic part of carpet manufacturing and has the potential to pollute the environment.

All main textile fibre types, namely natural fibres, man-made fibres derived from natural polymers such as viscose and cellulose acetate as well as man-made fibres derived from synthetic polymers are described, including their blends.

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

- 6.2. Pretreatment (operations such as washing, bleaching, mercerisation) or dyeing of textile fibres or textiles where the treatment capacity exceeds 10 tonnes per day.
- 6.11. Independently operated treatment of waste water not covered by Directive 91/271/EEC provided that the main pollutant load originates from activities covered by these BAT conclusions.

This BREF also covers:

- The following activities when they are directly associated with activities specified in point 6.2 of Annex I to Directive 2010/75/EU:
  - coating;
  - dry cleaning;
  - fabric production;
  - finishing;
  - lamination;
  - printing;
  - singeing;
  - wool carbonising;
  - wool fulling;
  - yarn production.
- The combined treatment of waste water from different origins provided that the main pollutant load originates from activities covered by these BAT conclusions and that the waste water treatment is not covered by Directive 91/271/EEC.
- On-site combustion plants which are directly associated with the activities covered by these BAT conclusions provided that the combustion gases are put into direct contact with the textile fibres or textiles (such as direct heating, drying, heat setting) or when radiant and/or conductive heat is transferred through a solid wall (indirect heating) without using an intermediary heat transfer fluid.
This BREF does not cover:

- Coating and lamination where the organic solvent consumption capacity of more than 150 kg per hour or more than 200 tonnes per year. This is covered by the BAT conclusions on surface treatment using organic solvents including preservation of wood and wood products with chemicals (STS).
- Production of man-made fibres and yarns.
- Unhairing of hides and skins. This may be covered by the BAT conclusions for the tanning of hides and skins (TAN).

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

- Surface Treatment Using Organic Solvents including Preservation of Wood and Wood Products with Chemicals (STS);
- Tanning of Hides and Skins (TAN);
- Waste Incineration (WI);
- Waste Treatment (WT);
- Emissions from Storage (EFS);
- Energy Efficiency (ENE);
- Industrial Cooling Systems (ICS);
- Monitoring of Emissions to Air and Water from IED Installations (ROM);
1 GENERAL INFORMATION

Note to the TWG: only Section 1.4 of this chapter has been revised as only very little information has been provided. Please provide more information about the textiles sector in the EU, such as the sector organisation, the production and economics.

The textile industry is one of the longest and most complicated industrial chains in manufacturing industry. It is a fragmented and heterogeneous sector dominated by a majority of Small and Medium Enterprises, with a demand largely driven by three main end-uses: clothing, home furnishing and industrial use.

The importance of the textile (and clothing) industry in the European economy is shown in Table 1.1. The figures in the table cover only a part of the total number of manufacturing companies (i.e. they only cover companies with more than 20 employees).

This part of the industry represented:

- 3.4 % of EU manufacturing
- 3.8 % of the added valued and
- 6.9 % of industrial employment.

Table 1.1: Share of the EU-15 textile-clothing industry in the manufacturing industry (only companies with 20 employees or more)

<table>
<thead>
<tr>
<th></th>
<th>Turnover EUR Billion</th>
<th>Added value at f.c. EUR Billion</th>
<th>Employment Million</th>
<th>Turnover %</th>
<th>Added value %</th>
<th>Employment %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Textile</td>
<td>100.5</td>
<td>31.2</td>
<td>0.89</td>
<td>2.1</td>
<td>2.4</td>
<td>3.8</td>
</tr>
<tr>
<td>Clothing</td>
<td>61.5</td>
<td>18.2</td>
<td>0.73</td>
<td>1.3</td>
<td>1.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Total Textile &amp; cloth.</td>
<td>162</td>
<td>49.4</td>
<td>1.62</td>
<td>3.4</td>
<td>3.8</td>
<td>6.9</td>
</tr>
<tr>
<td>Total Manufacturing</td>
<td>4756.8</td>
<td>1308.0</td>
<td>23.62</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

f.c.: factor costs

Source: [315, EURATEX, 2002]

In reality, in 2000 the EU textile and clothing industry actually achieved a turnover of 198 billion euros, involving 114000 companies, who employed about 2.2 million people.

The textile industry’s activities are distributed right across Europe, but mainly concentrated in only a few EU states. Italy is the leading European producer, far ahead of Germany, the UK, France and Spain (in that order). These five countries together account for over 80 % of the Community textile and clothing industry [113, EURATEX, 1997].
Table 1.2: Country breakdown of the EU-15 textile and clothing industry in 2000

<table>
<thead>
<tr>
<th>Country</th>
<th>Textile % in 2000</th>
<th>Clothing % in 2000</th>
<th>Textile &amp; Clothing % in 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>14.4</td>
<td>13.1</td>
<td>13.8</td>
</tr>
<tr>
<td>France</td>
<td>13.1</td>
<td>13.0</td>
<td>12.9</td>
</tr>
<tr>
<td>Italy</td>
<td>29.7</td>
<td>30.8</td>
<td>30.1</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2.0</td>
<td>0.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Belgium</td>
<td>5.6</td>
<td>2.2</td>
<td>4.2</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>12.5</td>
<td>14.3</td>
<td>13.4</td>
</tr>
<tr>
<td>Ireland</td>
<td>0.7</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Denmark</td>
<td>1.0</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Spain</td>
<td>8.4</td>
<td>11.4</td>
<td>9.6</td>
</tr>
<tr>
<td>Greece</td>
<td>2.1</td>
<td>2.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Portugal</td>
<td>6.1</td>
<td>7.9</td>
<td>6.9</td>
</tr>
<tr>
<td>Austria</td>
<td>2.8</td>
<td>1.2</td>
<td>2.1</td>
</tr>
<tr>
<td>Finland</td>
<td>0.8</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Sweden</td>
<td>0.8</td>
<td>0.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EU-15</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: [315, EURATEX, 2002]

The textile and clothing chain is composed of a wide number of sub-sectors covering the entire production cycle from the production of raw materials (man-made fibres) to semi-processed materials (yarns, woven and knitted fabrics with their finishing process) and final/consumer products (carpets, home textiles, clothing and industrial use textiles).

The complexity of the sector is also reflected in the difficulty of finding a clear-cut classification system for the different activities involved. The old nomenclature system (old NACE 1995) still classified textile industry’s activities as follows:

- man-made fibres industry
- wool
- cotton
- silk
- flax/jute
- knitting
- finishing
- carpets
- other textiles
- household linen.

The new nomenclature system (NACE 1997) identifies the following categories:

- yarn and thread
- woven fabric
- textile finishing
- home textiles
- industrial & other textiles (this includes Carpets and Wool Scouring)
- knitted fabrics & articles.

The old nomenclature reflects the historical subdivision of the textile industry’s activities according to the fibre processed. This stems from the fact that historically the only textile fibres
available were natural fibres, with a predominance of wool and cotton, which resulted in the
development of two main sectors, wool and cotton. Because of the different physico-chemical
characteristics of these two fibres, different machinery and different techniques were developed.
Nowadays, with the proliferation of man-made fibres these two historical sectors now both
process all available fibres and it has become impractical to classify textiles activities by
reference to the fibre.

As for the scope of this document, it is confined to those activities in the textile industry that
involve wet processes. This means primarily activities falling within the following new NACE
classifications:

- textile finishing
- industrial and other textiles (including Carpets and Wool Scouring)
- home textiles.

Because of its very specialised nature, carpet manufacturing has always been considered as a
stand-alone sector, even though many of the operations carried out are very close to those
carried out elsewhere in textile finishing. This document follows that tradition, hence carpets are
the only sector where the end-product is taken as the point of reference.

Some general information is given below about the three sub-sectors of wool scouring, textile
finishing (excluding floor-coverings) and carpets.
1.1 Wool scouring sector

1.1.1 Sector organisation

Wool is processed to yarn mainly via two systems: woollen and worsted. Scourers tend to specialise in wools for one system or the other. Woollen system scourers normally only scour the wool, though some may blend it before despatch to the customer. Worsted system scourers (referred to as combers) scour, card and comb the wool and their product is called top.

Within Europe, significant quantities of wool are obtained from the skins of slaughtered animals by fellmongering. Fellmongers normally sell the wool they produce to merchants, who have it scoured on commission. In France there are several fellmongers who also scour the wool they produce.

The wool scouring and combing business in Western Europe is largely carried out on commission. There are a few exceptions to this system, notably in the UK, where three carpet yarn manufacturers have their own wool scouring plants.

1.1.2 Production and economics

shows estimates of the amounts of wool produced and scoured in the various Member States along with the number of existing scouring mills.
Table 1.3: Wool production and wool scouring production in EU Member States

<table>
<thead>
<tr>
<th>Country</th>
<th>Domestic production of greasy wool</th>
<th>Wool scoured for worsted processing (clean weight)</th>
<th>Wool scoured for woollen processing (clean weight)</th>
<th>Total wool scoured (clean weight)</th>
<th>Total wool scoured (approx. greasy equivalent) (c)</th>
<th>Estimated number of scouring mills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>(a) 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Belgium</td>
<td>(a) 1.8</td>
<td>2.0</td>
<td>3.8</td>
<td>5.4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>(a) 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Finland</td>
<td>(a) 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>France</td>
<td>20</td>
<td>56.3</td>
<td>9.1</td>
<td>65.4</td>
<td>93.4</td>
<td>n.d.</td>
</tr>
<tr>
<td>Germany</td>
<td>13</td>
<td>34.2</td>
<td>9.2</td>
<td>43.4</td>
<td>62.0</td>
<td>1 (d)</td>
</tr>
<tr>
<td>Greece</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ireland</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Italy</td>
<td>11</td>
<td>73.6</td>
<td>2.4</td>
<td>76.0</td>
<td>108.6</td>
<td>8 – 9</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>(a) 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Netherlands</td>
<td>(a) 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Portugal</td>
<td>9</td>
<td>3.3</td>
<td>2.0</td>
<td>5.3</td>
<td>7.6</td>
<td>2</td>
</tr>
<tr>
<td>Spain</td>
<td>36</td>
<td>13.5</td>
<td>12.7</td>
<td>26.2</td>
<td>37.4</td>
<td>n.d.</td>
</tr>
<tr>
<td>Sweden</td>
<td>(a) 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>UK</td>
<td>65</td>
<td>29.1</td>
<td>50.4</td>
<td>79.6</td>
<td>113.7</td>
<td>13</td>
</tr>
<tr>
<td>Other western Europe</td>
<td>10 (b)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>198</td>
<td>211.8</td>
<td>87.8</td>
<td>299.7</td>
<td>428.1</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>

Notes:
- Unit: '000 tonnes/year
- (a) Included in “Other western Europe”.
- (b) Austria, Belgium, Denmark, Finland, Iceland, Luxembourg, Malta, Netherlands, Norway, Sweden and Switzerland.
- (c) Assuming an average yield of 70 %.
- (d) A second scouring/combing mill in Germany is not believed to be operational.

Source: [187, INTERLAINE, 1999]

As it is possible to see from the reported data, ca. 90 % of the EU scouring activity is concentrated in France, Germany, Italy and UK, while eight EU Member States have no scouring plants.

The UK scouring and combing industry is the largest in Europe, though only slightly larger than that of Italy. About two thirds of the UK scouring production comprises coarse wools for woollen spun carpet yarn.

Figure 1.1 shows the amounts of wool scoured in the 15 EU Member States in terms of greasy wool weight. This is the unit most often used by scourers to express their throughput.
Chapter 1

During the period from 1993 to 1997 the total production in EU Member States has declined almost 10% from 326 million kg (clean wool) in 1993 to 300 million kg (clean wool) in 1997. Within this overall trend a steeper decline has been observed in northern Europe (Belgium, France, Germany and UK) alongside an increase in production in Italy and Spain. Although the overall decline in production in the European scouring sector has been relatively slow, there have been significant structural changes. The competitive nature of the industry and the cost and technical difficulties of complying with increasingly stringent environmental legislation have been the driving force behind these changes. Several large and small scouring mills have been forced beyond the limits of commercial and economic viability and have ceased trading. In most cases, their market share has been absorbed by competitors, so that now there are fewer companies in the sector, which on average process larger amounts of wool. This tendency towards consolidation is especially true in the UK, where a large part of the scouring industry’s trade is the processing of UK and Irish wools. Almost 80% of the British and Irish wool production, totalling 90000 tonnes is scoured in the UK and this trade is unlikely to be lost to competitors in other countries [187, INTERLAINE, 1999].

Figure 1.1: Estimates of the amounts of greasy wool scoured during 1997 in the 15 EU Member States

Source: [187, INTERLAINE, 1999]

A survey of UK wool scours, carried out by ENco in 1997, showed that they processed 71 million kg (greasy) of British and Irish wool during the previous year.
1.2 Textile finishing sector (excluding floor covering)

The following information is taken from [278, EURATEX, 2002].

1.2.1 Sector organisation

The essence of textile finishing is giving fabrics the visual, physical and aesthetic properties which consumers demand. The main processes involved are bleaching, dyeing (of yarn, fabric, ready-made garments), printing, coating / impregnating and the application of various functional finishings.

In most cases, the textile finishing process is combined with a manufacturing process, which gives the final product its particular shape. The main product categories cover clothing textiles, interior textiles (furnishing fabrics, curtains and carpets, which are discussed in Section 1.3), household textiles (bed / bath and table linen) and technical textiles (automotive fabrics, geo- and medical textiles).

Most companies in the textile finishing sector specialise in one type of process, although there are companies with several production processes. The following main types of companies can be distinguished:

- commission or merchant yarn dyers
- commission or merchant fabric dyers
- commission or merchant printers
- integrated companies, incorporating spinning and / or weaving plus finishing processes.

1.2.2 Production and economics

The total turnover of the EU-textile finishing industry amounted to nearly 11000 million euros in 2000, with more than 117000 employees. The majority of EU textile finishing companies are SMEs. The importance of the Textile Finishing Industry in EU Member States is shown in Figure 1.2.
The share of the main types of fibres used in the textile finishing industry is [315, EURATEX, 2002]:

- cotton  45
- wool    8
- polyester 14
- silk 2
- viscose 12
- acrylic 4
- others 15

Total 100 %

The fibres end up in processed goods, the main categories in percentage being:

- clothing textiles  45
- household textiles 20
- interior textiles 10
- technical textiles 18
- others 7

Total 100 %
1.3 Carpet

1.3.1 Sector organisation

The strong specialisation of this well integrated sector has already been mentioned. The carpet manufacturing, carpet yarn spinning and associated dyeing industry can be divided into a number of basic sub-sectors, although there may be considerable variations. All sectors may process combinations of 100% synthetic fibre, 100% natural fibre and/or blends of the two, as many of the processes and techniques used are not fibre specific.

As Table 1.4 shows there are five main different categories of companies where wet processes are normally carried out (in italics in the table):

- commission loose fibre dyehouses
- commission yarn dyehouses
- integrated yarn manufacturing mills, which in addition to the dyeing processes perform on-site conversion of the loose fibre to yarn, selling the finished yarn as end-product
- commission piece dyeing mills
- integrated carpet manufacturing mills, which carry out all the mechanical processes, dyeing and finishing operations required to convert natural and synthetic fibres into finished carpet.
### Table 1.4: Basic structure of the carpet manufacturing industry

<table>
<thead>
<tr>
<th>Sub-Sector</th>
<th>Main Characteristics and Principal Wet Processes (in italics)</th>
<th>End-Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commission Loose Fibre Processing</td>
<td>Loose fibre dyeing</td>
<td>Dyed loose fibre for yarn manufacture</td>
</tr>
<tr>
<td>Commission Yarn Processing</td>
<td>Yarn scouring and chemical finishing Yarn dyeing</td>
<td>Dyed yarn for carpet manufacture</td>
</tr>
<tr>
<td>Yarn Manufacture</td>
<td>Raw material (fibre) purchase or production on site Conversion to yarn Dyeing/wet processing carried out on commission Marketing of finished yarn</td>
<td>Coloured and ecru yarn for carpet manufacture</td>
</tr>
<tr>
<td>Integrated Yarn Manufacture (may be on several sites)</td>
<td>Raw material (fibre) purchase or production on site Loose fibre dyeing Conversion to yarn Yarn scouring and chemical finishing Yarn dyeing and chemical finishing Yarn setting Marketing of finished yarn</td>
<td>Coloured and ecru yarn for carpet manufacture</td>
</tr>
<tr>
<td>Commission Tufting, Weaving and Backing</td>
<td>Conversion of yarn to carpet Backing and mechanical finishing</td>
<td>Finished carpet</td>
</tr>
<tr>
<td>Commission Piece Dyeing</td>
<td>Dyeing and/or printing Backing and mechanical finishing Chemical finishing</td>
<td>Finished carpet</td>
</tr>
<tr>
<td>Carpet Manufacturing</td>
<td>Dyed and finished yarn purchase Conversion to carpet Foam applied chemical treatment Backing and mechanical finishing Marketing of finished carpet</td>
<td>Carpet for contract and retail sale</td>
</tr>
<tr>
<td>Integrated Carpet Manufacturing (may be on several sites)</td>
<td>Raw material (fibre) purchase/manufacture Raw wool scouring (1) Loose fibre dyeing Conversion to yarn Yarn scouring and chemical finishing Yarn dyeing and chemical finishing Yarn setting Conversion to carpet</td>
<td>Carpet for contract and retail sale</td>
</tr>
</tbody>
</table>

**Note (1)**: Raw wool scouring may be carried out within the group or on commission. Carpet piece colouration Foam applied chemical treatments Backing and mechanical finishing Marketing of finished carpet

**Source**: [32, ENco, 2001]

Table 1.5 indicates the locations of trading entities within the EU. Note that individual units may be part of a larger group, providing services to other members of the same organisation. In a similar way, a yarn spinning company with its own dyeing facilities may, if production schedules require, also have work carried out by a commission dyer or may carry out commission work for other companies if spare capacity is available.
Table 1.5: Sector Location and number of trading entities within the EU

<table>
<thead>
<tr>
<th>Country</th>
<th>Carpet (a) Manufacturers</th>
<th>Yarn (b) Spinners</th>
<th>Commission (c) Dye/ryers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>64</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Denmark</td>
<td>12</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>France</td>
<td>16</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Germany</td>
<td>38</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Greece</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ireland</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>9</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>34</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Portugal</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweden</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>United Kingdom</td>
<td>87</td>
<td>30</td>
<td>9</td>
</tr>
<tr>
<td>Luxembourg</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources:
(a) International Carpet Yearbook 2000 – includes all, product types and fibres
(b) International Carpet Yearbook 2000 & Wools of New Zealand – includes spinners with dyehouses
(c) ENco and Wools of New Zealand – includes all fibres
Source: [32, ENco, 2001]

1.3.2 Production and economics

As Figure 1.3 shows, European carpet industry accounts for 38% of world production (after the United States, with 58%).

Figure 1.3: Worldwide production of carpets and rugs in 1999

Source: [63, GuT/ECA, 2000]
Belgium, France, Germany, the Netherlands and the United Kingdom are all major producers for both internal EU consumption and world export markets. European carpet production exceeds carpet consumption by a significant margin (Figure 1.4), indicating the importance of export markets to the European industry.

Among the three typical end-products of the carpet manufacturing industry - tufted carpet, woven carpet and needle felts - tufted carpets account for 66% of EU production. This is shown in the 1995 production below in Figure 1.5 and Figure 1.6.

Source: [32, ENco, 2001]

**Figure 1.4:** Carpet production and consumption in some EU Member States

Source: [63, GuT/ECA, 2000]

**Figure 1.5:** European carpet and rug production in 1995 for the major producers of carpets and rugs in Europe
Figure 1.6: Total carpet and rug production in Europe in 1995.

Source: [63, GuT/ECA, 2000]
1.4 Main environmental issues

The main environmental issues arising from the activities in the textile industry which are covered in this document regard primarily emissions to water and air and energy consumption.

Among these, water is the most important concern. The textile industry uses water as the principal medium for removing impurities, applying dyes and finishing agents, and for the generation of steam.

Losses to the product are negligible, therefore, apart from a minor amount of water which is evaporated during drying, the bulk is discharged as aqueous effluent. The main concern is therefore about the amount of water discharged and the chemical load it carries.

An overview of these environmental loads is given in Table 1.6. The reported data have been extrapolated to European level from the results of a research study in Germany and Austria.

### Table 1.6: Main charging loads from textile industry in Europe

<table>
<thead>
<tr>
<th>Substances</th>
<th>Environmental load (t/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salts</td>
<td>200 000 – 250 000</td>
</tr>
<tr>
<td>Natural fibres impurities (including biocides) and associated material (e.g. lignin, sericine, wax, etc.)</td>
<td>50 000 – 100 000</td>
</tr>
<tr>
<td>Sizing agents (mainly starch, starch derivatives, but also polyacrylates, polyvinylalcohol, carboxymethylcellulose and galactomannans)</td>
<td>80 000 – 100 000</td>
</tr>
<tr>
<td>Preparation agents (mainly mineral oils, but also ester oils)</td>
<td>25 000 – 30 000</td>
</tr>
<tr>
<td>Surfactants (dispersing agents, emulsifiers, detergents and wetting agents)</td>
<td>20 000 – 25 000</td>
</tr>
<tr>
<td>Carboxylic acids (mainly acetic acid)</td>
<td>15 000 – 20 000</td>
</tr>
<tr>
<td>Thickeners</td>
<td>10 000 – 15 000</td>
</tr>
<tr>
<td>Urea</td>
<td>5 000 – 10 000</td>
</tr>
<tr>
<td>Complexing agents</td>
<td>&lt;5 000</td>
</tr>
<tr>
<td>Organic solvents</td>
<td>n.d.</td>
</tr>
<tr>
<td>Special auxiliaries with more or less ecotoxicological properties</td>
<td>&lt;5 000</td>
</tr>
</tbody>
</table>

Source: [77, EURATEX, 2000]

From the reported figures it appears that a large percentage of the total emission load from textile industry activities is attributable to substances that are already on the raw material before it enters the finishing process sequence. Typically these are:

- sizing agents
- preparation agents
- natural fibres impurities and associated material.

Sizing agents are used to assist the weaving process. They are removed from the woven fabric before the finishing process, thus producing high levels of organic load in the water.

Preparation agents and spinning oils, are applied to fibres in various steps of the process, from the manufacture of the fibre itself (for synthetic fibres only) to the formation of the yarn. These organic substances are removed during pretreatment at the finishing mill either through wet processing (washing) or through dry processing (heat-setting). In the former case they contribute to the increase of the organic load of the final water effluent, in the latter case they become airborne.

All natural fibres contain a percentage of impurities and associated material. Associated materials are an essential part of natural fibres (e.g. grease for wool, pectin and hemicellulose...
for cotton, lignin for flax and sericine for silk). Impurities are metals, mineral and pesticides. All these substances have to be removed from the fibre before it can undergo finishing processes. They therefore also have the potential for considerable environmental impact.

The input of chemicals and auxiliaries added at the finishing mills can be up to 1 kg per kg of processed textiles, which appears to be high. The range of these substances is very extensive: the latest issues of TEGEWA lists more than 7,000 auxiliaries. However, as shown in Figure 1.7, in a typical finishing mill, 80% of the annual consumption is covered by only 20% of the product types used.

On the basis of the data reported in Table 1.6, among the products applied during the process, the highest environmental loads arise from salts, detergents and organic acids (in that order).

Dyestuffs are not mentioned in the table because they do not represent a significant load compared to other substances used in the process. Nevertheless they are responsible for the colour of the effluent — which is mainly an aesthetic problem, although high doses of colour may also reduce light transmission to aquatic plants. Their presence in the water is therefore important, not only because of the colour, but also in relation with other environmental concerns (e.g. difficult to eliminate organic load, AOX, metals), particularly for certain classes of dyestuffs.

A number of chemicals that may be used in the textile process are worth specifically mentioning for their potential negative effects on the environment. These are:

- alkyl phenol ethoxylates (detergents, wetting agents, levelling agents, etc.): their metabolites (octyl- and nonyl phenols) are highly toxic to aquatic life and are reported to disturb the reproduction of aquatic species by disrupting the endocrine system (octyl and nonylphenol are on the list of “Priority Substances” targeted for priority action under the Water Framework Directive 2000/60/EC, in particular nonylphenol is identified as “Priority Hazardous Substance”). In addition, nonylphenol (NP) and nonylphenol ethoxylates (NPE) are subject to restriction (Annex XVII entries 46 and 46a) under the REACH Regulation [79, EU 2006].

- polybrominated diphenyl ethers and chlorinated paraffins (flame retardants), halogenated phenols and benzenes (reagents in the production of flame retardants): some members of these classes of substances (e.g., pentabromodiphenylether, C10H12Cl4) chloroparaffines) have already been identified as “Priority Hazardous Substances” for their toxicity, persistency...
and liability to bioaccumulate or they have been evaluated under the scope of Regulation (EEC) 793/93 on the evaluation and control of the risks of existing substances. For other members of these classes, the debate about their potentially negative effects on the environment is still ongoing (see Section 8.8.4): some brominated diphenylethers and some short-chain chloroalkanes are “Priority Hazardous Substances” as per the Water Framework Directive and/or prohibited by the POP regulation EC/850/2004. Some flame retardants are also subject to restriction or to authorisation as per the REACH regulation EC/1907/2006.

- perfluorinated compounds used for water-, oil- or soil-repellence: the use of perfluorooctanoic acid (PFOAS) is restricted by the REACH regulation and perfluorooctane sulphonics and its derivatives (PFOS) are “Priority Hazardous Substances” and prohibited by the POP regulation.
- mothproofing agents based on permethrin and cyfluthrin (carpet sector) and other biocides: these are highly toxic to aquatic life
- sequestering agents such as EDTA and DTPA and NTA: these are capable of forming very stable complexes with metals (EDTA and DTPA are also poorly bioeliminable)
- chlorine and chlorine-releasing compounds such as sodium hypochlorite (bleaching agent) and sodium dichloroisocyanurate (wool anti-felting agent): these are capable of reacting with organic compounds to form adsorbable organic halogens (AOX)
- metal-containing compounds such as potassium dichromate, whose use is subject to authorisation as per the REACH regulation EC/1907/2006.
- substances with carcinogenic potential, such as a number of aromatic amines, formed by cleavage of some azo dyes (see Section 2.7.8.1), or vinylcyclohexene and 1,3-butadiene, which can be present in polymer dispersions due to an incomplete reaction during polymerisation
- carriers such as trichlorobenzene, o-phenylphenol, etc.

It is reported that [77, EURATEX, 2000]:

- more than 90% of the organic chemicals and auxiliaries in pretreatment and dyeing operations does not stay on the fibre, whereas the reverse is true in the finishing treatment
- nearly 90% of the organic raw material load entering the textile process ends up in the waste water, the remaining amount being released to air.

With regard to emissions to air, volatile organic compounds are released from particular activities such as:

- printing processes, in cases when organic solvents are used (e.g. they are contained in pigment printing pastes)
- cleaning with organic solvents
- heat—thermal treatment (e.g. thermofixation, drying, curing) when the textile materials contain substances that evaporate or degrade thermally (for example, oils, plasticisers, finishing agents and residues from upstream processes). Emissions of formaldehyde and uncombusted methane can be particularly significant in poorly maintained, directly heated stenters
- vulcanisation of the backing layers (carpet sector).

Moreover, emissions of CO₂, SOₓ, NOₓ and particulates associated with the on-site burning of fossil fuels to produce thermal energy are also to be taken into account.

Energy is consumed primarily in raising the temperature of the baths (e.g. pretreatment, dyeing, etc.) and in drying and curing operations. To this aim steam is produced on-site. Electrical energy is required for driving the machinery.

Based on the information mentioned above, the Technical Working Group (TWG) in charge of reviewing this document decided upon a list of environmental issues to be investigated during
the review. These so-called Key Environmental Issues (KEI) are listed in Table 1.7 for emissions to water and in Table 1.8 for emissions to air.

### Table 1.7: KEIs for emission to water considered for the review of the BREF

<table>
<thead>
<tr>
<th>(Groups of) Substance(s)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total suspended solids (TSS)</td>
<td>KEI for direct discharges only</td>
</tr>
<tr>
<td>Chemical oxygen demand (COD)</td>
<td>KEI for direct discharges only</td>
</tr>
<tr>
<td>Total organic carbon (TOC)</td>
<td>KEI for direct discharges only</td>
</tr>
<tr>
<td>Total nitrogen (Total N)</td>
<td>KEI for direct discharges only</td>
</tr>
<tr>
<td>Total phosphorus (Total P)</td>
<td>KEI for direct discharges only</td>
</tr>
<tr>
<td>Hydrocarbon oil index (HOI)</td>
<td>KEI for the installations using sulphur dyes</td>
</tr>
<tr>
<td>Sulphide (S(^2))</td>
<td></td>
</tr>
<tr>
<td>AOX (adsorbable organically bound halogens)</td>
<td></td>
</tr>
<tr>
<td>Alkylphenols and alkylphenol ethoxylates</td>
<td></td>
</tr>
<tr>
<td>Brominated flame retardants</td>
<td></td>
</tr>
<tr>
<td>Pesticides</td>
<td>KEI for wool scouring</td>
</tr>
<tr>
<td>Toxicity</td>
<td></td>
</tr>
<tr>
<td>Antimony (Sb) and its compounds, expressed as Sb</td>
<td>KEI for certain types of processes or fibres</td>
</tr>
<tr>
<td>Chromium (Cr) and its compounds, expressed as Cr</td>
<td></td>
</tr>
<tr>
<td>Copper (Cu) and its compounds, expressed as Cu</td>
<td></td>
</tr>
<tr>
<td>Nickel (Ni) and its compounds, expressed as Ni</td>
<td></td>
</tr>
<tr>
<td>Zinc (Zn) and its compounds, expressed as Zn</td>
<td></td>
</tr>
</tbody>
</table>

Source: [251, EIPPCB 2018]

### Table 1.8: KEIs for emission to air considered for the review of the BREF

<table>
<thead>
<tr>
<th>(Groups of) Substance(s)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td></td>
</tr>
<tr>
<td>Nitrogen oxides (NO(_x))</td>
<td></td>
</tr>
<tr>
<td>Sulphur oxides (SO(_x))</td>
<td>KEI for combustion plants</td>
</tr>
<tr>
<td>Ammonia (NH(_3))</td>
<td></td>
</tr>
<tr>
<td>TVOC (Total volatile organic compounds)</td>
<td></td>
</tr>
<tr>
<td>Formaldehyde</td>
<td></td>
</tr>
<tr>
<td>Tetrachloroethylene (PER)</td>
<td>KEI for solvent-based wool scouring and dry cleaning</td>
</tr>
<tr>
<td>N-Methyl-2-pyrrolidone</td>
<td></td>
</tr>
<tr>
<td>N-Ethyl-2-pyrrolidone</td>
<td></td>
</tr>
<tr>
<td>Dimethylformamide</td>
<td></td>
</tr>
<tr>
<td>Dimethylacetamide</td>
<td>KEIs for certain types of processes or fibres</td>
</tr>
<tr>
<td>Toluene</td>
<td></td>
</tr>
<tr>
<td>Acrylonitrile</td>
<td></td>
</tr>
<tr>
<td>Acrylamide</td>
<td></td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td></td>
</tr>
<tr>
<td>Styrene</td>
<td></td>
</tr>
</tbody>
</table>

Source: [251, EIPPCB 2018]

The TWG decided to investigate also the water consumption and the amount of waste water discharged, the energy consumption and the amount of waste generated.
2 APPLIED PROCESSES AND TECHNIQUES

The textile chain begins with the production or harvest of raw fibre. The basic steps in this chain are schematically represented in Figure 2.1 below and will be described in this chapter.

![Diagram of textile processes]

Figure 2.1: General diagram of processes in the textile industry

The main part of this chapter will describe those treatments that are broadly referred to as ‘finishing processes’ (i.e. pretreatment, dyeing, printing, finishing and coating, including...
washing and drying). As the diagram shows, they can take place at different stages of the production process: the substrates for finishing can be fabrics, yarns or loose fibres.

‘Textile finishing’ cannot be defined as a standard sequence of treatments, but rather is a combination of unit processes that can be applied within the production of a textile product, depending on the requirements of the final user. For this reason, finishing treatments will be described (from Section 2.6 to Section 2.10.2) as unit processes without considering the possible sequences in which they can be applied.

In the second part of this chapter (see Section 2.13) a distinction has been made between the carpet finishing sector and the rest of the finishing industry. Some typical categories of industries have been identified within each sector. The wool scouring industry has also been identified as a stand-alone sector. These categories have typical features that are described in brief.

As well as fibres, the raw materials of the textile industry include a wide range of chemicals and auxiliaries. These chemicals and auxiliaries are often not process-specific and can be found in different steps within the process cycle. For this reason it has been considered more practical to report the description of these issues in separate annexes (Note to the TWG: this Annex has not been reviewed. It has not been edited and formatted either. Please provide information to update this Annex.)
ANNEX I Textile Auxiliaries and Note to the TWG: this Annex has not been reviewed. It has not been edited and formatted either.

Please provide information to update this Annex.

ANNEX II Dyes and Pigments). Only general information about textile raw materials, including common procedures for storage and handling, is given in this chapter.

In the same way, because most of the machines have a multifunctional use within the production cycle, equipment is also described in a specific annex (Note to the TWG: this Annex has not been reviewed. It has not been edited and formatted either.

Please provide information to update this Annex.

ANNEX III Wet Processes: Machinery and Techniques).
2.1 Raw materials

2.1.1 Fibres

Two general categories of fibres are used in the textile industry: natural and man-made. Man-made fibres encompass both purely synthetic materials of petrochemical origin and regenerative cellulosic materials manufactured from wood fibres. A more detailed classification of fibres is shown in Table 2.1 below.

Table 2.1: General classification of fibres

<table>
<thead>
<tr>
<th>Natural origin fibres</th>
<th>Animal origin</th>
<th>Raw wool&lt;br&gt;Silk fibre&lt;br&gt;Hair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetable origin</td>
<td>Raw cotton fibre&lt;br&gt;Flax&lt;br&gt;Jute</td>
<td></td>
</tr>
<tr>
<td>Mineral origin</td>
<td>Asbestos (not used in the textile industry)</td>
<td></td>
</tr>
</tbody>
</table>

Chemical fibres (man-made)

<table>
<thead>
<tr>
<th>Natural polymer fibres</th>
<th>Viscose, Cupro, Lyocell&lt;br&gt;Acetate&lt;br&gt;Triacetate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthetic polymer fibres</td>
<td>Inorganic polymer&lt;br&gt;Glass for fibre glass&lt;br&gt;Metal for metal fibre</td>
</tr>
<tr>
<td></td>
<td>Organic polymer&lt;br&gt;Polyester (PES)&lt;br&gt;Polyamide (PA)&lt;br&gt;Acrylic (PAC)&lt;br&gt;Polypropylene (PP)&lt;br&gt;Elastane (EL)</td>
</tr>
</tbody>
</table>

Fibres included in this document are described in more detail below, highlighting in particular the typical impurities present in them. Some of these impurities will enter the textile process and will influence the associated emissions.

2.1.1.1 Polyester fibres (PES)

Polyester fibres (PES) are made of linear macromolecules containing at least 85 % of an ester in the chain. To date, three polyester polymers are commercially available:

- poly(ethylene terephthalate) (PET), which is based on ethylene glycol;
- poly(butylene terephthalate) (PBT), which is based on butyl glycol; and
- poly(trimethylene terephthalate) (PTT), which is based on trimethylene glycol.

However, only one of these three polymers, poly(ethylene terephthalate), also known as PET, has so far been widely applied in the textile industry. Therefore in the following sections, unless otherwise specified, the term PES is used to indicate standard polyester fibres based on PET.

PET fibres have a very high degree of crystallinity, which allows for excellent heat-resistance and other mechanical properties. On the other hand, this compact structure inhibits the diffusion of the colourants into the fibre during dyeing. As a result, PET fibres cannot be dyed below 100 °C, unless dyeing accelerants (so-called carriers) are used. Carriers are harmful for the environment and in many cases are toxic for humans. Their use is now in decline, but it has been common practice for many years (see also Section 2.7.8.1 and Section 8.6.7).
Carrier-free dyeable PES fibres are now available on the market. They include ‘modified PES fibres’ and PTT fibres (see list above). ‘Modified PES fibres’ are based on PET. Thanks to physical and chemical alterations made to the structure of the fibre during the manufacturing process, they show lower crystallinity, which makes them easier to dye without the need for carriers. Because of their high cost, however, these fibres are applied only in specific segments of the market.

As far as PTT is concerned, this aromatic polyester (polytrimethylene terephthalate) is made by the polycondensation of 1,3-propanediol and terephthalic acid. The high cost of synthesis of 1,3-propanediol has for many years prohibited the commercialisation of this fibre. Recently Shell pursued a new lower-cost synthesis route for the production of this monomer, which has led to renewed interest in PTT polymers [87, VITO, 2001]. More information about these fibres is reported in Section 4.5.4.1.

On polyester fibres in general, it is also worth mentioning that during the polycondensation reaction, cyclic oligomers with very low water solubility can be formed (1-3 % of the weight of the fibre [77, EURATEX, 2000]). These oligomers tend to migrate to the surface of the fibre during dyeing, thus negatively affecting level dyeing and rub-fastness properties.

### 2.1.1.2 Polyamide fibres (PA)

The starting polymer comes from the polycondensation reaction between a diamine and a dicarboxylic acid. According to the number of carbon atoms of the end-product, one can speak of PA 6,6 or PA 6.

PA 6,6 is made by thermal polycondensation of equimolecular amounts of adipic acid and 1,6-hexamethylenediamine. The equilibrium condensate contains small amounts of monomers and cyclic dimers (2 %).

PA 6 is made by polymerisation of the cyclic monomer epsilon-caprolactame. The caprolactame content in the polymer can be reduced to 0.2 % by extraction with hot water. During the melting process for the production of the fibre (melt spinning), the caprolactame content rises again and is partially emitted during the following thermal treatments.

### 2.1.1.3 Acrylic fibres (PAC)

The polymer is obtained by radical polymerisation of acrylonitrile in aqueous emulsion or in solvent. The obtained polymer, made of 100 % acrylonitrile (also called PAN), gives fibres with insufficient dye-binding capability, due to the high glass transition temperature (above 100 °C). For this reason, this polymer is no longer used in the textile industry. Acrylic fibres (PAC), commonly found on the market today, are anionic copolymers containing 85-89 % acrylonitrile, 4-10 % of a non-ionic comonomer (vinyl chloride, vinylacetate, methyl acrylate) and 0.5-1 % of ionic comonomers containing sulphonic or sulphate groups.

Dry and wet spinning techniques can be used for the production of the fibre. When dry spinning is used, the polymer is dissolved in dimethylformamide (DMF). If the fibre is manufactured through wet spinning, besides DMF, dimethylacetamide, dimethylsulphoxide, ethyl carbonate and aqueous solutions of inorganic salts or acids are also used. Residues of these solvents (0.2-2 % of the weight of the fibre) are found in the waste water from pretreatment.

### 2.1.1.4 Polypropylene fibres (PP)

The isotactic polymer is used for fibre production. Due to the tertiary carbon atom, PP is very sensitive to high temperature and oxidation. Alkylated phenols or p-xylols, together with
sulphides or thio-derivatives (dilauryl- or distearyl thiopropionate) are used as stabilisers. Substances with benzotriazol groups, Ni complexes, anthracinon derivatives and sterically hindered diamines are used as UV-absorbents. These low-molecular-weight substances remain in the PP fibres and are considered possible emission-relevant substances.

2.1.1.5 Elastane (EL)

Elastane fibres are made out of an elastomer containing at least 85 % polyurethane (PU). For the production of the fibre (dry spinning), the polymer is dissolved in dimethylacetamide. Residues of this solvent remain in the fibre (< 1 % of the weight of the fibre) and are found in the waste water from pretreatment.

To reduce the high adhesive characteristics and to guarantee sufficient gliding properties during processing, preparation agents are applied to the fibre (approximately 6-7 % add-on). These auxiliaries contain 95 % silicone oils and 5 % surfactants. The high percentage of silicone oils will cause environmental concerns during pretreatment of the textile material, when these substances have to be removed.

2.1.1.6 Viscose (CV)

The starting material is the cellulose that is extracted from coniferous timber and supplied to the fibre manufacture in sheets about 1 cm thick. The wood contains around 40-50 % cellulose that is useable which can be used to make viscose. The cellulose is first allowed to swell in a NaOH solution. The white flakes obtained are then treated with carbon disulphide until the sodium cellulose xantogenate is formed. The xantogenate is soluble in diluted sodium hydroxide and the formed solution (pulp) is already called viscose. The pulp then needs to be spun. Spinning consists of coagulating the xantogenate solution at the outlet of the spinneret in an acid bath containing sulphuric acid, sodium sulphate and zinc sulphate.

2.1.1.7 Cupro (CU)

Cellulose (wood pulp) can also be dissolved in an aqueous solution of ammonia and copper sulphate. Cupro fibres are produced by wet spinning.

2.1.1.8 Acetate fibres

The cellulose molecule contains three alcohol groups. When between 2 and 2.5 of the 3 groups are esterified with acetic acid, the polymer is called diacetate. When all three alcohol groups are esterified, then the polymer is called triacetate. The acetate fibres contain less than 92 % cellulose acetate, but at least 74 % of the hydroxilic groups must be acetylated.

2.1.1.9 Wool

Wool is animal hair from the body of sheep. This hair is normally sheared once, or sometimes twice, a year and its quality and quantity vary widely, depending on the breed of sheep and its environment. Wool is a member of a group of proteins known as keratin, also found in horns, nails, etc.

In addition to wool fibre, raw wool contains the following.
Table 2.2: Impurities in the raw wool

<table>
<thead>
<tr>
<th>Natural impurities:</th>
<th>- Wool grease 2-25 % of greasy wool weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Suint (dried perspiration) 2-12 % of greasy wool weight</td>
</tr>
<tr>
<td></td>
<td>- Dirt 5-45 % of greasy wool weight</td>
</tr>
</tbody>
</table>

- Residues of insecticides, acaricides or insect growth regulators used as veterinary medicines to protect sheep from ectoparasites, such as lice, mites, blowfly, etc.

The percentage of the above-mentioned components may vary widely depending on the origin of the wool. For example, fine wool from merino sheep, used mainly in apparel, typically contains 13 % wool grease, whereas coarser wool of the types used for carpets contains an average of about 5 % grease.

The clean fibre content of raw wool usually lies within the 60 % to 80 % range, but may vary from 40 % to 90 %.

Wool grease is insoluble in water, but soluble in non-polar solvents such as dichloromethane or hexane. Refined wool grease is a valuable by-product.

Suint is water-soluble material arising from the secretion of the sweat glands in the skin. Suint is soluble in polar solvent such as water and alcohol.

Dirt can include a variety of materials such as mineral dirt, sands, clay, dust and organic materials.

Ectoparasiticides have important implications for the discharge of raw wool scouring effluent and disposal of the sludge generated by the treatment of the effluent. The chemicals known to be present in raw wool include the following.

Table 2.3: Pesticides found in raw wool

<table>
<thead>
<tr>
<th>Organochlorine insecticides (OCs)</th>
<th>- γ-Hexachlorocyclohexane (lindane)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Dieldrin</td>
</tr>
<tr>
<td></td>
<td>- DDT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Organophosphorous insecticides (OPs)</th>
<th>- Diazinon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Propetamphos</td>
</tr>
<tr>
<td></td>
<td>- Chlorehvinphos</td>
</tr>
<tr>
<td></td>
<td>- Chlorpyriphos</td>
</tr>
<tr>
<td></td>
<td>- Dichlorfenthion</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Synthetic pyrethroids insecticides (SPs)</th>
<th>- Cypermethrin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Deltamethrin</td>
</tr>
<tr>
<td></td>
<td>- Fenvalate</td>
</tr>
<tr>
<td></td>
<td>- Flumethrin</td>
</tr>
<tr>
<td></td>
<td>- Cyhalothrin</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Insect growth regulators (IGRs)</th>
<th>- Cyromazine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Dicyclanil</td>
</tr>
<tr>
<td></td>
<td>- Diflubenzuron</td>
</tr>
<tr>
<td></td>
<td>- Triflumuron</td>
</tr>
</tbody>
</table>

The organochlorines are hazardous due to their persistence and bioaccumulability. They are thus likely to have long-range effects (in terms of both distance from the source and time after release). γ-Hexachlorocyclohexane (also called lindane) is the most toxic (and also the most active as a pesticide) of the hexachlorocyclohexane isomers (α- and β-HCHs). The technical
crude product contains α- and β-HCH, the β-isomer being the most persistent. Lindane and DDT compounds are well-studied substances with demonstrated endocrine-disrupting capacity. The synthetic pyrethroid insecticides show high aquatic toxicity (predicted no-effect concentration for cypermethrin is estimated at 0.0001 μg/l, while the corresponding value for the OPs diazinon and propetamphos is 0.01 μg/l according to the UK environmental quality standards expressed as annual averages). Organophosphates have lower aquatic toxicity than synthetic pyrethroids and are less persistent than organochlorines. Nevertheless, they have high human toxicity (problems may therefore arise, for example for dyers with steam-volatile OPs) [279, L. Bettens, 2001].

All major grower countries have banned the use of organochlorine pesticides for sheep treatment. In Europe, biocides are regulated by the Biocidal Products Regulation (BPR) [88, EU 2012] and some substances listed above are banned in the European Union (lindane, DDT and dieldrin are banned by the Regulation on persistent organic pollutants [90, EU 2004]).

but There is however evidence that wool from some former Soviet Union states and South America contain lindane at detectable concentrations. This would suggest that either their grazing is heavily contaminated or that this compound continues to be used occasionally for sheep treatment against ectoparasites.

Wool from the majority of grower nations contains residual sheep treatment medicines which are used legally to control infestations of lice, ticks and mites. These materials may be organophosphates, typically diazinon, propetamphos and trans-chlorfenvinphos, synthetic pyrethroids, typically cypermethrin and insect growth regulators such as cyromazine. The incidence of these materials on wool is variable and depends on the permitted legal use pattern in each country.

Manufacturers can use a database containing quantitative information on the OC, OP and SP content of wool from major producing countries. ENco maintains one such database. Manufacturers use these data to avoid processing wool from suspect sources. The system is of immediate benefit to manufacturers who purchase and process wool from known sources. Manufacturers who do not own the Commission processors of either loose fibre or yarn (i.e. working on commission) may not be aware of the origin of the fibre they are processing and so find it more difficult to control their raw material inputs using this approach.

More information regarding ectoparasiticides is reported in Section 2.3.1 where the wool scouring process is discussed.

2.1.1.10 Silk

Silk accounts for only 0.2% of the total fibre production. Nevertheless, this fibre is very important for specific ‘niche’ articles such as ladies’ shirts, jackets and scarves.

Silk is derived from the silk worm, which spins a cocoon around itself. It is a protein fibre like wool and it is the only natural filament fibre to be used with success in the textile industry (the length of the thread is in the range of 700 m to 1 500 m).

The silk fibre is composed of fibroin filaments wrapped with sericine (silk gum), which has to be removed during the pretreatment.

2.1.1.11 Cotton and flax

Cotton fibre consists mainly of cellulose and some other components, as shown in Table 2.4 below.
Table 2.4: Chemical composition of cotton fibre

<table>
<thead>
<tr>
<th>Substance</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose</td>
<td>88-96%</td>
</tr>
<tr>
<td>Pectin substances</td>
<td>0.7-1.2%</td>
</tr>
<tr>
<td>Wax</td>
<td>0.4-1.0%</td>
</tr>
<tr>
<td>Proteins</td>
<td>1.1-1.9%</td>
</tr>
<tr>
<td>Ash</td>
<td>0.7-1.6%</td>
</tr>
<tr>
<td>Other organic components</td>
<td>0.5-1.0%</td>
</tr>
</tbody>
</table>

Source: [186, Ullmann's, 2000]

Cotton production may use chemicals such as pesticides, herbicides and defoliants and these may remain as a residue on raw cotton fibres that reach the textile mill. However, this is of little concern for the textile industry (the problem is rather with the growers). In fact, tests of cotton samples from around the world, performed from 1991 to 1993, reported levels of pesticides below the threshold limit values for foodstuffs [11, US EPA, 1995].

Other sources ([207, UK, 2001]) report that a few years ago bales of cotton were found to be contaminated with pentachlorophenol from its use not only as a defoliant, but also as a fungicide applied on the bales of cotton during transport.

Flax is a bast fibre. Many economic factors have contributed to this fibre losing much of its previous importance. Nevertheless, flax remains a noble fibre with a wide range of applications.

### 2.1.2 Chemicals and auxiliaries

A huge number of organic dyestuffs/pigments and auxiliaries are applied in the textile industry. In this document they will be divided into the following categories:

- Dyestuffs and pigments.
- Basic chemicals (also known as ‘Commodities’), which include all inorganic chemicals and organic reducing and oxidising agents as well as the aliphatic organic acids.
- Auxiliaries, which comprise all textile auxiliaries containing mainly organic compounds except organic reducing and oxidising agents and organic aliphatic acids. They are also known as ‘Specialities’ - blends and proprietary formulations whose composition is not fully disclosed.

To give an idea of the variety of products available on the market (in particular, auxiliaries), it is worth noting that in the “2000 International Textile Auxiliaries Buyers’ Guide more than 7000 commercial products are reported, based on 400 to 600 active components [93, TEGEWA 2018]. They are classified according to the well established TEGEWA nomenclature, according to their functional use in the production process, although the chemical nature of these products is too varied to allocate them unequivocally to one category [94, TEGEWA 2018].

For practical reasons, the information about dyestuffs and textile auxiliaries is reported in this document in separate annexes (see Chapter 8 and Chapter 9 Section 0 and Section 0).

### 2.1.3 Materials handling and storage

Basic fibrous raw materials arrive on site in press-packed bales and are stored in covered warehousing, which may also be used to store and dispatch finished goods to customers.

Basic chemical intermediates, acids, alkalis and bulk auxiliary chemicals are normally held within a bound or contained storage area. Large bulk containers may be situated in the open.
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High-value and moisture- or environmentally sensitive materials are normally transferred directly to the preparation area (‘colour kitchen’) from where they are dispensed.

Some synthetic organic colourants are regarded as a potential health hazard. Therefore colour kitchens are normally equipped with air extraction and filter systems to suppress dust levels in the workplace during dispensing.

The chemicals (dyestuffs, pigments, basic chemicals and auxiliaries) are metered out either in powder form or as solutions. This operation can be done manually or with computer-aided metering devices.

The required measured amount of products must be dispersed, diluted or mixed before being fed to the finishing machinery. Various systems are found in the industry, ranging from completely manual procedures to fully automatic ones. In the case of manual systems, the prepared chemicals are added directly into the machine or in a storage container near the equipment, from which they are then pumped into the machine. In larger companies, the chemicals are usually mixed in a central mixing station, from which they are supplied to the various machines through a network of pipes. The quantities and the addition of chemicals and auxiliaries are normally called up determined automatically according to predetermined programmes (further details about dosing and dispensing systems are given in Section 4.1.6.6).
2.2 Fibre manufacturing: chemical (man-made) fibres

The manufacturing of man-made fibres is not covered by this document. However, some preparation agents used in manufacturing may have an impact on the emissions from subsequent fibre processing (pretreatment). This is why some information about manufacturing of man-made fibres is given in this section.

Man-made fibres are typically extruded into continuous filaments. The continuous filaments can then be:

- used directly (in general, following further shaping or texturing);
- cut into staple length and then spun in a process resembling the one used for wool or cotton (see Section 2.4).

Three main methods are used to produce the continuous filaments (primary spinning):

- melt spinning;
- dry spinning;
- wet spinning.

*Melt spinning:* The polymer is melted in a melt-extruder. The liquid is forced through the spinner opening under pressure and cooled by a jet of air to form the filament. A spinning preparation (spin finish) is generally applied at the bottom of the spinning duct. The melting process is suitable for thermoplastic fibres such as polyester, polyamide, polyolefins (e.g. polypropylene) and glass fibre.

*Dry spinning:* The polymer is dissolved in a solvent. The dissolved polymer is extruded through a spinneret into a chamber of heated air or gas where the solvent evaporates and the filament forms. This filament is further after-treated with a spin finish. The dry spinning process is principally used for acetate, triacetate and polyacrylonitrile.

*Wet spinning:* The polymer is dissolved in solution. The solution is forced under pressure through an opening into a liquid bath in which the polymer is insoluble. As the solvent is dissipated, the fibre forms. The solvent can be dissipated through extraction or by means of a chemical reaction between the polymer solution and a reagent in the spinning bath (reactive spinning). The residual solvent can be extracted by simple washing. After the thread is formed and the solvent is washed out, a spin finish can be applied. Wet spinning produces viscose and acrylic fibres.

Following primary spinning, the applied treatments vary, depending on the final product and the processed fibre. Two simplified process sequences can be identified for this stage:

- process for the manufacturing of continuous filament in flat or texturised form;
- process for the manufacturing of staple fibres.
Figure 2.2: Simplified process sequences for manufacturing of continuous filaments (flat and texturised) and staple fibres

As shown in the diagrams Figure 2.2 above, preparation agents can be applied at various stages during the manufacture of the chemical fibres. Application of preparation agents in primary spinning (fibre manufacturing) is usually followed by further additions during secondary spinning, when the yarn is manufactured, including operations such as coning, twisting, warping, etc.

The preparation agents need to be removed to ensure uniform penetration of dyes and finishing agents and to avoid reaction or precipitation with them. Due to their high organic content and...
their often-low bioeliminability, these substances are responsible for waste water pollution and emissions to air in the subsequent fibre pretreatment. Particularly relevant in this respect is the production of continuous filaments destined for the production of knitted fabric and the manufacturing of elastomeric fibres, because in this case the amount of preparation agents applied is higher.

The amount of preparation agents applied varies according to the fibre (e.g. PES, PA) and make-up (flat or texturised filament, staple fibre). Information about the chemistry of the preparation agents and the amount applied on the fibre is given in Section 8.2.
2.3 Fibre preparation: natural fibres

2.3.1 Wool

Wool is usually opened and de-dusted before it is fed to the scouring bowls. This is a mechanical process designed to shake out dirt from the wool and to open the fleeces in order to improve the efficiency of the scouring bowls in removing contaminants. The process also roughly blends the wool and produces a layer of fibres suitable for presentation to the scouring bowls. The opening and de-dusting processes vary considerably in severity depending on the characteristics of the particular wool being processed. The process produces a solid waste comprising dirt, sand, fibre fragments and vegetable matter.

The object of subsequent raw wool scouring processes is to remove contaminants from the wool fibre and to make it suitable for further processing.

Almost all of the scouring plants are based upon aqueous washing. Solvent scouring is much less widely practised. There are worldwide only about five companies that degrease with organic solvents [18, VITO, 1998].

2.3.1.1 Cleaning and washing with water

A conventional wool scouring set is shown in Figure 2.3. The process is carried out by passing the wool through a series of four to eight wash bowls, each followed by a mangle or squeeze press which removes excess scouring liquor from the wool and returns it to the bowl. Clean water is added to the last bowl and passes via a counter-flow system from bowl to bowl with final discharge from the first bowl in a controlled manner to drain.

![Conventional wool scouring arrangement](image)

Source: [8, Danish EPA, 1997]

In the scouring bowls, suint is removed from the wool by dissolution, grease by emulsification and dirt by suspension.

For merino wools, the first bowl may be charged with water only and, in that case, its purpose is the removal of water-soluble suint before the wool enters the scouring process proper (this bowl is usually called ‘de-suint’).

In order to achieve grease emulsification, the scouring bowls are charged with detergent and often with sodium carbonate, or another alkali, which acts as a detergent builder. Concentrations
of detergent and builder are usually highest in the first scouring bowl and they decrease in subsequent bowls.

Detergents used by scourers are mainly synthetic non-ionic surfactants, namely alcohol ethoxylates and alkylphenol ethoxylates. Some scourers also report the use of ‘solvent-assisted detergents’ for the removal of marking fluids from fleeces.

Finally, the wool is rinsed by passing it through bowls containing water only.

In coarse wool scouring plants, the final bowl of the scouring train is sometimes used for chemical treatments. In this case, it is isolated from the countercurrent liquor flow system and may also be isolated from the drain if the chemical treatment uses ecotoxic chemicals. The most commonly used treatment is bleaching, in which hydrogen peroxide and formic or acetic acid are added to the bowl. Other treatments sometimes applied include mothproofing, using a synthetic pyrethroid insecticide and acetic or formic acid, and sterilisation (of goat hairs) using formaldehyde.

Wool grease has a melting point around 40 °C. Since removal of solid grease from wool by detergents is slow and difficult, 40 °C is the lowest temperature at which aqueous scouring liquors are effective for removing grease. In addition, non-ionic detergents lose efficiency rather rapidly below 60 °C, which means that scour and rinse bowls are typically operated at 55-70 °C.

After leaving the final squeeze roller, the wool will contain 40% to 60% moisture. It is therefore dried by convection in a hot-air dryer. The dryer is usually heated either by closed steam pipes or by direct gas firing. The heat supply to the dryer may be controlled by a signal from a device which senses the humidity of the dryer atmosphere or the moisture content of the wool at the output end, thus saving energy and avoiding overdrying the wool.

The mechanical design of wool scours and the arrangements for circulating the scour and rinse liquors vary widely. Since these matters have a direct influence on energy and water usage, as well as the partial removal of contaminants from the effluent, it is important to illustrate them in more detail.

New-generation scouring plants like the one illustrated in Figure 2.4 have an integrated system for grease and dirt recovery.
The dirt tends to settle at the bottom of the bowl and modern scouring bowls usually have hopper-shaped bottoms from which the sludge is removed by gravity through a valve. Opening of the valve may be under the control of a timer or may respond to a signal from a turbidity meter which senses the thickness of the dirt suspension in the hopper bottom. The discharge from the scouring bowl hopper bottoms is led to a heavy-solids settling tank where it is gravity-settled and the settled liquor partly recycled to scouring bowl 1 and partly discharged. Flocculant may be added to the heavy-solids settling tank to assist the separation of dirt, or a decanter centrifuge or hydrocyclone may be used in preference to gravity settling for dirt removal.

For grease recovery, modern scouring bowls have a side tank in which the grease-rich liquors removed from the wool by the squeeze press are collected. From here, part of the flow may be pumped to the previous bowl or, in the case of bowl 1, to a primary grease centrifuge. The centrifuge separates the liquor into three phases. The top phase, referred to as the cream, is rich in grease and passes to secondary and possibly tertiary centrifuges for further dewatering, finally producing anhydrous grease; the bottom phase is rich in dirt and goes to the heavy-solids settling tank; the middle phase is impoverished low in both grease and dirt compared with the input and this is split, part being recycled to scouring bowl 1 and part being discharged.

In a commonly used variation of the above recycling arrangements, the dirt and grease removal and recycling loops may be combined. In this case, scouring liquor may be removed from the bottoms of the bowls only, or from top and bottom, and passed first through the dirt removal equipment, then through the primary grease centrifuge.

Some scourers recycle rinsing water (see Figure 2.4). The flowdown from the first rinse bowl can be treated to make it suitable for addition to the feed to the final rinse bowl. Normally, this
is accomplished by removing dirt in a hydrocyclone and processing the water through a membrane filtration plant to remove other impurities. It is normally necessary to purge dirty liquors which collect at the bottoms of the rinse bowls, but this is not always the case.

Purging of rinse bowls will depend upon the efficiency of the bowls. Some modern scours control the rinse bowls’ discharge using solids detectors, but generally rinse bowls merely have a timed discharge of bottom liquor which operates automatically whatever the state of the liquor [208, ENco, 2001].

The dirt removal and grease recovery loops described above serve several purposes. They save water, by recycling effluent to the scouring bowls and they act as a process-integrated partial effluent treatment. The recovered wool grease can be sold, although the market for this by-product has been variable in most recent years. Finally, since the discharges from the loops are the only points at which heavily contaminated scouring liquors are discharged, valves and meters at these points can be used to control the rate of water usage in the scouring section.

For more information about the performance of the dirt removal and grease recovery loops, see Sections 3.7.1, 4.2.2.1 and 4.2.2.2.

2.3.1.2 Environmental issues associated with wool scouring (with water)

This section discusses the environmental issues associated with the overall scouring process including the treatment of the process effluent.

The main environmental issues associated with the wool scouring process arise from emissions to water, but solid waste and the emissions to air also need to be taken into account.

2.3.1.2.1 Potential for pollution of water

The removal of contaminants present on the raw fibre leads to the discharge of an effluent in which the main polluting contributors are:

- highly concentrated organic material in suspension and in solution, along with dirt in suspension;
- micro-pollutants resulting from the veterinary medicines applied to protect sheep from external parasites.

There are also detergents in the discharged water, which contribute to the increase of the chemical oxygen demand of the effluent. The detergent is recycled via the grease recovery/dirt removal loop. As a result, low efficiency in this recovery system is associated with higher amounts of detergent in the effluent. Compared to the chemical oxygen demand attributable to wax, dirt, etc., the detergents can be considered minor contributors to water pollution, but this is not the case when harmful surfactants such as alkylphenol ethoxylates are used as detergents (for more detail on environmental issues regarding detergents, see Section 8.1).

As for the organic matter coming from wax and dirt, according to “Stewart, 1988” [96, Stewart 1988] the COD of effluent and of greasy wool can be calculated using the following equation:

\[
\text{COD (mg/kg)} = (8 \, 267 \times \text{suint (\%))} + (30 \, 980 \times \text{oxidised grease (\%))} + (29 \, 326 \times \text{top grease (\%))} + (6 \, 454 \times \text{dirt (\%))} + 1 \, 536
\]
Since the coefficients for top grease and oxidised grease in this equation are similar and since approximately equal quantities of top grease and oxidised grease are present in many wools, it is possible to combine the two grease terms in the above equation as follows:

\[
\text{COD (mg/kg)} = (8.267 \times \text{suint} \%) + (30.153 \times \text{total grease} \%) + (6.454 \times \text{dirt} \%) + 1.536
\]

It is then possible to calculate the COD content of ‘typical’ merino and crossbred wools:

**Merino wool:** suint = 8 %; grease = 13 %; dirt = 15 %

\[
\text{COD} = (8.267 \times 8) + (30.153 \times 13) + (6.454 \times 15) + 1.536 = 556 \text{ g/kg greasy wool}
\]

**Crossbred wool:** suint = 8 %; grease = 5 %; dirt = 15 %

\[
\text{COD} = (8.267 \times 8) + (30.153 \times 5) + (6.454 \times 15) + 1.536 = 315 \text{ g/kg greasy wool}
\]

These high levels of oxygen-depleting substances must be removed from the effluent before it can be safely discharged to the environment without potential for harmful effects.

Organohalogens, organophosphorus compounds and biocides are among the priority polluting substances listed for emission control in the IPPC Directive IED. [31, EU 2010]

Worldwide, the most common ectoparasiticides used for treating sheep are diazinon (OP), propetamphos (OP), cypermethrin (SP) and cyromazine (fly-specific IGR), for control of blowfly. Insect growth regulators such as dicyclanil, diflubenzuron and triflumuron are registered only in Australia and New Zealand. Organochlorine pesticides (in particular, hexachlorocyclohexane) are still found on wool coming from the former Soviet Union, the Middle East and some South American countries [187, INTERLAINE, 1999] (see also Section 2.1.1.9).

Concerning the fate of ectoparasiticides when they enter the scouring process, a distinction has to be made between lipophilic and hydrophylic compounds such as cyromazine. The lipophilic compounds – OCs, OPs and SPs – associate strongly with the wool grease and are removed with it during scouring (although a fraction – up to 4 % – is retained by the fibre and will be released in the subsequent finishing wet processes). This behaviour also applies to diflubenzuron (IGR). Recent studies have shown that triflumuron (IGR) associates partially with the dirt and partially with the grease. As a result, compared to other lipophilic compounds, a higher proportion of this pesticide is likely to be retained on site (on the wool fibre and on the recovered wool grease and dirt) and not be discharged in the aqueous effluent [103, G. Savage, 1998]. In contrast, IGRs such as cyromazine and dicyclanil are appreciably water-soluble (11 g/l at 20 °C, for cyromazine), which means that they are not removed in wool grease recovery systems.

In the waste water treatment systems, an additional fraction of the pesticide residues is removed. Physico-chemical separation techniques remove the biocide residue at approximately the same rate as the grease and the dirt with which they are associated. On the other hand, evaporation systems remove OCs and SPs in significant quantities, but up to 30 % of the OPs may appear in the condensate because they are steam-volatile. The water-soluble compounds, such as the IGR cyromazine are probably not removed from the effluent stream except by evaporating treatments [187, INTERLAINE, 1999].

Despite these treatments, the removal of pesticides is often incomplete and there is potential for pesticides to enter the aquatic environment when the effluent is discharged. The environmental concentrations of ectoparasiticides in the receiving water depend greatly on local circumstances.

---

2 Top grease is unoxidised grease which is readily separated from scour liquor by centrifuging; oxidised grease is less hydrophobic and is less readily separated.
in particular the amount of scouring activity concentrated in a given catchment and the dilution available between scouring discharges and the river which receives the treated effluent.

In areas of Europe with a high concentration of scouring activity, there is a risk of high concentration levels of pesticides in the receiving water. In this case, it is preferable to define discharge limits on the basis of risk assessment models. In UK for example, statutory environmental quality standards (EQS) for the OCs and non-statutory standards for the OPs and cypermethrin have been defined. Discharge limits are set up for processing mills by comparing the given EQS targets with predicted environmental concentrations based on tonnage of wool processed and typical effluent treatment systems.

The control of the discharge limits at the scouring mills is carried out by using data from the ENco Wool & Hair Pesticide database (to define the initial amount of residues on the incoming wool) in combination with the above mentioned water-grease partition factors for the different pesticides. For more detailed information see also Sections 2.1.1.9 and (“Ectoparasiticides”).

2.3.1.2.2 Potential for pollution of land

Two main ‘wastes’, grease and sludge, are produced as a consequence of the scouring activities (and related effluent treatment).

Depending on its oxidation extent, it may be possible to recover from 20 % to 40 % of the grease initially present on the raw wool. This is to be regarded as a by-product rather than a waste, since it can be sold to lanolin refiners for the production of high-value products in the cosmetic industry. However, high levels of pesticides residues in the grease can also be a problem for the lanolin refiners, especially for the production of lanolin-based pharmaceuticals and cosmetics, since more expensive and sophisticated techniques have to be used to reduce the pesticides to acceptable levels. Acid-cracked grease has no market value and has to be landfilled.

The sludge produced as a result of physico-chemical treatment of waste water also contains grease, dirt and the portion of pesticides which are strongly associated with either grease or dirt. Concentrates and slurdes from evaporation or membrane filtration may also contain suint, which is mainly potassium chloride and potassium salts of fatty acids. Suint is a by-product which can be used in agriculture.

Sludge and concentrate disposal may follow several routes:

- incineration (with heat recovery);
- pyrolysis/gasification;
- brick manufacturing;
- composting or co-composting with other organic material;
- landfill.

The first three sludge disposal routes destroy the organic material in the sludge, including grease and pesticides. The ash from incineration may contain potassium salts, derived from suint, and heavy metals characteristic of the soil on which the sheep producing the wool have grazed. The ash is normally disposed of to landfill. The characteristics of the char from pyrolysis/gasification are unknown and this char is also typically disposed of to landfill. The use of wool scouring slurdes in brick manufacture results in no residues for immediate disposal. These three sludge disposal methods probably have the least potential to pollute land.

Wool scouring slurdes cannot be composted alone, but require the addition of carbon-rich organic material. Green waste from agriculture or horticulture has been used. Composting is not
yet regarded as a fully developed, fail-safe technique and only partly degrades the pesticides present in the sludge. However, since the pesticides present in the sludge are there because of their lipophilicity or their strong propensity to be absorbed by solids, they are likely to be immobile in soil, and spreading of compost derived from wool scouring sludges on agricultural land is unlikely to pose an environmental risk of any significance.

Landfill is the simplest and often cheapest method of disposal of sludges. In the longer term, however, landfill is not believed to be either economically or environmentally sustainable. The fate of wool scouring sludges in landfill is not known, but there is a small potential for the ectoparasiticides present to arise in leachate. Anaerobic degradation of the organic material in the sludge will give rise to methane emissions [187, INTERLAIN, 1999].

### 2.3.1.2.3 Potential for pollution of air

Air pollution is not a major issue for wool scouring processes. Nevertheless, two issues can be mentioned.

Hot acid cracking, which involves heating the scouring effluent with sulphuric acid, when used near residential areas, has been the subject of odour complaints.

Incineration is used in conjunction with evaporation of the effluent because the surplus heat from the incinerator can be used in the evaporation process. Incineration of wool scouring sludges has potential for air pollution. Since sludges contain relatively high levels of chloride (from suint) as well as organically bound chlorine from ectoparasiticides etc., there is potential for the production of polychlorodibenzodioxins and furans, when they are incinerated (catalytic and high-temperature incinerators are now available to prevent these emissions). The sludges also contain relatively high levels of sulphur and nitrogen and the combustion process therefore produces SO\textsubscript{X} and NO\textsubscript{X}. Dust and odours should also be taken into account.

### 2.3.1.3 Cleaning and washing with solvent

[98, Wooltech 2001]

**Note for the TWG: this section and the following are proposed to be deleted because:**
- the technique uses trichloroethylene which is now in Annex XIV to REACH;
- no plant of the data collection has reported solvent scouring;
- it is not clear whether solvent scouring is actually used in the sector.

Various solvent processes exist that use a non-aqueous solvent for scouring wool.

The Wooltech wool cleaning system involves the use of trichloroethylene and does not use any water in the washing process. A schematic layout of the solvent-based process is shown in Figure 2.5.

The following information was submitted by [201, Wooltech, 2001].

**Wash bowls**

Wool is received in bales, unpacked and then fed into the reception area. This wool is lightly broken up and fed through a series of solvent wash bowls (typically 3 or 4) and washed with a countercurrent flow of solvent. Up to 10 kg of solvent is added for the production of 500 kg of clean wool, however this is a function of plant management and maintenance, the exact plant arrangement, and the quality of wool being processed.

Clean, solvent-saturated wool is taken from the last wash bowl to a centrifuge where the solvent concentration is reduced to around 4 wt%. A centrifuge has been found to be particularly effective in this duty owing to the low surface tension and significant density of the solvent used.
trichloroethylene. The wool with a small quantity of solvent is taken to a dryer where warm air is used to evaporate the last quantity of solvent. The processing area from the wash bowls through to the centrifuge and the dryer is all fully enclosed and is kept under a slight negative pressure by evacuating air to a vapour recovery system.

The solvent from the first washing bowl is processed through high-speed centrifuge equipment to remove solid particles and recycled back to bowl 1. A proportion of the fluid is drawn off for grease removal and upgrading for recycling.

**Dirt separation**

The dirt slurry from the dirt separation stage is sent to an indirect heated dirt dryer, where the solvent is evaporated off (and recovered), leaving a warm, dry, and solvent-free dirt stream.

Expected pesticide analysis of dirt will result in no organochlorines (OC), less than 1 ppm organophosphates (OP) and less that 0.1 ppm synthetic pyrethroids (SP). Further reducing these levels requires the relatively simple modification of fitting the process may be fitted with a small solid bowl centrifuge, such that the dirt slurry, on its way to the dirt dryer, is rinsed with fresh solvent. This will remove the grease-associated pesticides from the dirt and send these back to the evaporator where they will leave with the grease stream.

**Solvent evaporation system**

Solvent is recycled by various stages of evaporation in the solvent evaporation system. The first stage of evaporation is a multiple effect evaporator, which does the bulk of the solvent recovery work. It boils the spent solvent from a concentration of typically 2 wt% grease up to 20 wt% grease (i.e. 90% recovery of solvent). To recover all possible solvent from the grease, it has been found necessary to use three stages of evaporation – each at progressively lower pressure and higher temperature. It has been found practical to evaporate the grease down to containing <1 wt% solvent, corresponding to a 99.98% recovery of solvent through the evaporation stage.

**Vapour recovery unit**

Other areas where solvent is recovered include when the vapour leaves the dirt dryer, when the solvent-laden air leaves the wool dryer, and when the air saturated with solvent is extracted from the wash bowl area/wool centrifuge/wool dryer area. The combined stream from these areas is sent to a vapour recovery unit. This consists of a refrigerated primary collection system followed by activated carbon adsorption recovery system.

**Solvent destruction**

As discussed, the Wooltech solvent-based wool cleaning system does not use any water in the washing process. There is, however, a small flow of water into the solvent system. This is due to moisture in the wool, moisture in the air and some input from vacuum raising equipment (steam ejectors). This water, referred to as fleece and steam moisture, is separated from the clean solvent in the solvent recovery section by gravity. Whilst the solubility of the solvent in this water is low, it is nevertheless saturated in solvent, which is thus removed in a two-step process.

In the first step, most of the small proportion of solvent in fleece and steam moisture is removed by heating the water and stripping it with air in the solvent air stripping unit. The small flow of solvent is recovered by condensing it and then by passing it through the vapour recovery unit.

In the second step, a free radical process based on Fenton’s reaction (a redox reaction between iron and hydrogen peroxide) is used to remove the traces of solvent left after stripping in fleece and steam moisture. Using an improved Fenton effect, the residual solvent destruction Unit is effective in eliminating all traces of solvent from water by oxidizing/de-halogenating, thereby destroying the solvent molecules. The solvent is broken down into chloride ions, carbon dioxide and water upon treatment with hydrogen peroxide. Provision is allowed to ensure the water is neutralized prior to discharge. The fine detail of the destruction process is confidential, however processes that use the improved Fenton Effect are well established.
Another source of waste in the Wooltech plant is contaminated liquids from maintenance activities or as a result of recovered spills. These fluids are treated in a very similar manner to process water. The first step of maintenance/spill recovery and recycle is the recovery of the bulk of the solvent, which is performed by boiling most of the solvent from the water. Finally, the mildly contaminated water is treated in the residual solvent destruction unit.

It is expected that the enhanced Fenton Process residual solvent destruction unit will reduce hazardous substances in water (including solvents, breakdown products and water-solubilized pesticides) to near zero. This is consistent with the long-term objectives (2020) set by OSPAR (protection of the marine environment) and the European Water Framework Directive (for surface waters).

2.3.1.4 Environmental issues associated with wool scouring (with organic solvent)
[98, Wooltech 2001]

Air emissions
Stack emissions of solvent trichloroethylene (TCE) in air will meet new VOC directives of <2ppm are treated by using a scrubbing fluid comprising of activated carbon slurry in water. This fluid will then be treated as outlined above in the residual solvent destruction unit. It should be noted, however, that TCE is very unstable and is readily broken down by free radicals that are photo-induced in the air by ultraviolet radiation (the Photo-Fenton effect). The hydroxyl radicals involved in the destruction are the same as used in the liquid treatment described above.

Auxiliary water
A small boiler unit is also used as a separate utility with a boiler blowdown of approximately 11 kg/h. The water quality in the boiler is directly related to the characteristics of the local water sources.

Energy consumption
The consumption of electricity in the cleaning process (not including treatment of emissions) is 0.243 kWh/kg of greasy wool. Natural gas consumption is 0.79 MJ/kg of greasy wool.

The Wooltech system described above, uses trichloroethylene as solvent. Trichloroethylene is a non-biodegradable and persistent substance (trichloroethylene is on the EPER list). Unaccounted losses of this solvent arising from spills, residues on the fibre, etc., if not adequately treated to destroy the solvent, may lead to diffuse emissions resulting in serious problems of soil and groundwater pollution.

As far as water and energy consumptions are concerned, the Wooltech system shows lower consumption levels compared to a typical scouring process using water. A more accurate balance of the inputs and outputs in this process is reported in Section.

Source: [98, Wooltech 2001]

Figure 2.5: Simplified scheme of the Wooltech process

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2.3.2 Cotton and flax

Raw cotton is a much cleaner raw fibre than wool and initial operations are mainly dry. The fibres are supplied to the spinning mill in compressed bales. The fibres are sorted by grade, cleaned to remove particles of dirt and blended with fibres from different bales to improve the consistency of the fibre mix. Sorting and cleaning is performed in machines known as openers.

With flax, the isolation of the fibre from the flax stem is done in different steps. After crop plucking, the flax is retted (dew retting, water retting, enzymatic, microbiotic, steam or chemical retting). Retting is a wet process that can result in waste water with high contents of COD and BOD: pectinic and hemicellulosis substances are degraded in this step. Rovings are produced by further mechanical treatment before spinning.

2.3.3 Silk

For silk production, the silk worm is killed with steam and the filament is unwound directly from the cocoon. The filament is submitted to pretreatment processes to remove the silk gum and other organic impurities (see Section 2.6.3).
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2.4 Yarn manufacturing

Almost all textile apparel products are made from spun yarns of 100% natural fibres, 100% man-made staple fibres or blends. Only a few apparel products, for instance smooth sportswear, are made exclusively of filament yarns (although increasing use is being made of fabrics that contain multifilament yarns, generally textured, and one or more staple fibre yarns).

Secondary spinning is the process by which staple fibres are transformed into yarn suitable for the textile industry. There are two main spinning processes:

- the wool spinning process;
- the cotton spinning process.

2.4.1 The wool spinning process

The wool spinning process is mainly used to produce wool and wool-blend yarns. A distinction is made between the worsted and woollen process. In worsted spinning, higher-quality and longer fibres are processed and the result is a fine yarn which is used to produce worsted fabric. In the woollen spinning system, shorter fibres are processed.

In the worsted process, the fibres are paralleled in a combing machine and are then drawn and spun. In the woollen system, the fibres are only carded and then spun. The resulting yarn is then twisted (if required) and finally prepared for the subsequent treatments (dyeing, weaving, tufting, etc.) through an operation called winding.

In both the woollen and worsted systems, the various fibres (e.g. wool fibres from different sources, different types of synthetic fibres) are combined during the blending operation. In order to allow efficient mechanical processing in the subsequent operations, spinning lubricants are applied to the fibres at this stage (or later, before or after carding, depending on the system applied).

2.4.2 The cotton spinning process

The cotton spinning process is generally used for cotton and man-made fibres. As has already been described in Section 2.3.2, cotton fibres are first submitted to opening and cleaning operations. The following steps, which are the same for cotton and man-made fibres, are:

- carding;
- combing;
- drawing;
- roving;
- spinning;
- twisting (if required);
- winding.

2.4.3 Environmental issues

The preparation agents (conditioning agents and spinning lubricants) applied to the fibre during the spinning process have significant environmental implications for the subsequent finishing steps of the textile chain. Since these auxiliaries, together with spin finishes added in primary
spinning (in the case of man-made staple fibres), need in general to be completely removed before dyeing, they are found either in the exhaust air from the high-temperature processes or in the water from wet treatments. In the first case they give rise to air pollution, whereas in the second they contribute to the organic load of the final effluent.

Spinning lubricants may be responsible for the emission not only of hard-to-biodegrade organic substances such as mineral oils, but also of hazardous compounds such as polyaromatic hydrocarbons, APEO and biocides.

The resulting pollution depends on the type and amount of lubricant applied to the fibre. In the wool spinning process, for example, a distinction must be made between fabric derived from carded yarn (woollen process) and fabric manufactured using combed yarn (worsted process). There is a substantial difference, in fact, not only from a mechanical point of view, but also in the quantity of lubricants applied. This is approximately 5% in the woollen process and is always less than 2% in the worsted process (this consideration only holds for textiles, because in the woollen process for carpet yarn, the amount of lubricants ranges from 1% to 1.5%).

As regards synthetic fibres (staple fibres), the amount of preparation agents applied at the yarn manufacturing stage is especially relevant in the case of elastomeric fibres where the final content of preparation agents (mainly silicone oils) can be in the order of 7% of the weight of the fibre.

Additional information about the composition of spinning oils is given in Section 8.2. It is however difficult to analyse in detail the environmental aspects associated with the use of these substances because of the large variety of commercial products. Spinning mills usually buy lubricants from dealers who buy chemical products from large petrochemical producers, and mix them according to the specific needs of each spinning mill. This makes even more difficult the identification of the chemical substances present on the yarn when this enters the finishing mill even more difficult.
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2.5  [Cloth] Fabric production

Raw materials for cloth production are spun yarns and filament yarns. These raw materials can then be converted into:

- woven textiles;
- knitted textiles;
- floor-coverings and non-woven fabrics.

The last item covers a number of different end-products which are typical of the carpet industry.

2.5.1  Woven textiles

2.5.1.1  Warping

Before weaving, warp yarns are wound onto beams in a process called warping. During this operation, there is no consumption of auxiliary agents that could have a negative influence on the emissions from the subsequent finishing processes.

In some cases (wool mills) the warp yarn is not sized, but treated with liquid paraffin.

2.5.1.2  Sizing

In order to lubricate and protect the warp yarn during weaving, sizing agents (in the form of water solutions or water dispersions) are applied after warping. The main sizing agents can be grouped into two classes:

- Sizing agents based on native polysaccharides:
  - starch;
  - starch derivates such as carboximethyl starch or hydroxiethyl starch ether;
  - cellulose derivates, especially carboximethyl cellulose (CMC);
  - galactomannans;
  - protein derivates.

- Fully synthetic polymers:
  - polyvinyl alcohols (PVA);
  - polyacrylates;
  - polyvinylacetate;
  - polyester.

The ratio of synthetic sizing agents to native sizing agents is variable (e.g. about 1:3 in Germany [179, UBA, 2001], 1:4-1:5 in Spain [293, Spain, 2002]).

It is important to bear in mind that:

- the type of sizing agent applied varies according to the fibres to be processed, the weaving technique adopted and the demands of any system used for recycling the sizing agents;
- sizing agent formulations are usually mixtures of the substances mentioned above.
With cotton, additional auxiliaries are present in the sizing mixtures. These are mainly the following [186, Ullmann's, 2000]:

- **Viscosity regulators**: complex formation between borax and the hydroxyl groups of starch increases the viscosity of the paste, while urea reduces it. Important viscosity regulators include starch-degrading agents such as peroxodisulphates, peroxosulphates that act by oxidative cleavage of the macromolecules.

- **Sizing fats**: they are used to improve the weaving behaviour of the warp. Suitable materials include sulphated fats and oils and mixtures of fatty acid esters with non-ionic and anionic emulsifiers.

- **Antistatic agents** (mainly based on polyglycol ethers).

- **Wetting agents**: fatty alcohols poly(glycol ethers) with a low degree of ethoxylation.

- **De-foaming agents**: their addition is often necessary when the sizing agents tend to produce foam (e.g. with PVA) or if wetting agents are added. Suitable products are based on paraffin oils, phosphoric esters, fatty acid esters or silicone oils.

- **Preservatives**: for sizing liquors that are stored for long periods and contain degradable components such as starch and starch derivatives, fungicides and/or bacteriocides are added. Typical preservatives include formaldehyde, phenol derivatives, heterocyclic compounds of the isothiazoline type.

Sizing agents used for synthetic fibres (e.g. polyacrylates, polyesters) do not contain these auxiliaries, except for the preservatives, which are always to prevent attacks by bacteria attack that are present when aqueous systems are used.

Sizing agents are introduced by the weaving firm, but have to be removed by the finisher (during the operation called desizing). This desizing process results in high waste water loads. In the case of woven fabric, sizing agents can represent 30-70 % of the total COD load in waste water. The lower percentage is for finishing of woven fabric consisting mainly of flat filament yarns and the higher for staple fibres, especially for cotton and in the case of native sizing agents. Therefore it is important to know the COD of these substances and their characteristics in terms of biodegradability and bioeliminability. Note that additives present in the formulations (e.g. the preservatives) also influence the aquatic toxicity and biodegradability of the resulting emissions (toxicity and biodegradability cannot be discriminated by using only COD measurements).

Section 8.3 gives more details about:

- characteristics of the chemical substances commonly used as sizing agents and specific COD and BOD₅ values;
- typical amounts applied on the various fibres.

### 2.5.1.3 Weaving

Weaving is the process by which yarns are assembled together on a loom and a woven fabric is obtained. The process only requires electricity. Lubricants and oils are used to lubricate the loom, but in particular cases they may contaminate the fabric.
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2.5.2 Knitted textiles

2.5.2.1 Waxing

The yarn specially made for the knitting industry is lubricated or waxed (generally with paraffin wax) to allow knitting at higher speed and protect the yarn from mechanical stresses. Waxing may be done while re-winding the yarn onto bobbins, in which case the process is normally called ‘preparation for knitting’.

2.5.2.2 Knitting

Like weaving, knitting is a mechanical process and involves knotting yarn together with a series of needles. Mineral oils are widely used to lubricate the needles and other parts of the knitting machinery. The quantity of oils used depends on the technology of the machine and on the speed of the needles. The value ranges between 4% and 8% of the weight of the fabric (when mineral oils are used the amount may rise to 10%).

The oil and the wax that remain on the final fabric will be washed out during the finishing treatments. Their contribution to the total pollution load coming from finishing mills may be significant.

Additional information about knitting oils is reported in Section 8.2.5.

The main knitting production methods are: straight knitting (flat or circular), its advancements: fully fashioned knitting and integral knitting, and the most recent: complete garment. [122, Beton et al. 2014 ], [123, Peterson et al. 2007 ]

Straight knitting
Knitting, whether by hand or on a machine, is usually done by using warp and weft knitting techniques. Straight knitting most commonly relies on the weft technique which consists of using one continuous yarn which is fed to and looped in rows by one or more needles at a time. Two common types of straight weft knitting machines used are:

- Flat knitting machine – also known as a ‘cut and sew’ technique that creates rectangular panels of fabric.
- Circular knitting machine – which is used to create cylindrical panels of knitted fabric (e.g. used for making socks and sweaters).

Both types of machines are also able to create different textures and patterns, such as ribbing.

Fully fashioned knitting
The fully fashioned knitting is an advancement of the straight knitting technique. The advantage of this knitting machine is that it can produce a custom-shaped sheet of fabric by adding/removing the stiches, so that there is little or no need for cutting panels, and therefore little or no fabric is discarded in the process. [123, Peterson et al. 2007 ]

Integral knitting
Integral knitting is a further advancement of the fully fashioned knitting technique. An integral knitting machine is able to add additional trimmings as an integrated part of the fabric panel (e.g. pockets, collars, V-necks). Along with the advantage of reducing fabric losses from cutting, this technique also reduces sewing requirements. [123, Peterson et al. 2007 ]

Complete garment
State-of-the-art integral knitting machines are now available which are able to knit complete garments, and therefore eliminate cutting and sewing steps altogether. This type of technology
is becoming increasingly attractive as it eliminates the costs of expensive post-knitting steps, decreases raw material consumption, and also produces higher-quality garments. A recent study of the influence of novel knitting production methods on the environmental impacts of the total textile production chain in the EU showed that fully fashioned and integral knitting use more energy than flat knitting, but they also significantly reduce material losses. These trade-off leads to a net benefit in many of the environmental indicators (e.g. ozone and water depletion, natural land transformation), making these production methods most favourable. [122, Beton et al. 2014]

Fully fashioned, integral or complete garment knitting machines require a significant amount of initial capital investment. However, these costs can be offset by long-term savings in labour and resource costs. Also, there is a growing trend in computerised machines which not only produce at higher efficiencies, but also at much higher outputs and greater speeds, and allow for greater flexibility in design.

2.5.3 Textile floor-coverings

Textile floor-covering is a collective noun for articles having a usable surface of textile material. This particular class of cloth products can be schematically described as composite substrates made up of the following layers:

- A pile yarn (or more generically a face fibre), which can equally well be made from filament or staple fibre yarns (mainly polypropylene, polyamide, polyester, wool, acrylic fibres).
- A carrier layer (or primary backing), which is mainly made of polypropylene strips of fabric (75% of cases), PP or PES webs (16% and 8% of cases, respectively) and less commonly of jute fabric (1% of cases) [18, VITO, 1998].
- A pre-coating layer, which is typical of tufted carpet and whose function is to anchor the pile onto the carrier layer. This pre-coating layer is made from synthetic rubber or an artificial dispersion based on carboxylated styrene-butadiene rubber latex.
- A back-coating layer, which is an additional layer applied to the bottom side of the carpet. It is possible to distinguish between foam coating, textile back-coating and heavy coating methods. The purposes of this final layer are various. Mainly, it is intended to strengthen the attachment of the pile, improve the dimensional stability of the carpet and provide the carpet with properties such as anti-slip, heat insulation, stepping elasticity, or even flame retardancy (carpet coating techniques are described in more detail under the finishing treatments in Section 2.10.2).

This is, however, a very general definition. In fact, the characteristics of the end-product and the applied manufacturing techniques can vary significantly. The principal methods of manufacturing carpet/floor-coverings are tufting, weaving and needling (other methods are knotting, bonding, knitting, etc.). The best way to describe these techniques is probably to describe the different types of carpets.

2.5.3.1 Tufting

As the Figure 2.6 below shows, tufted carpets are made up of the following several different components.

- the face yarn (pile), which can be made from either staple fibres (PA, PP, PES, PAC, wool and cotton) or synthetic filaments;
- the primary backing (carrier layer);
- the pre-coating layer.
- the back-coating layer (which can consist of a textile back-coating or of a foam coating layer).

![Diagram of carpet cross-section](source: [63, GuT/ ECA, 2000])

**Figure 2.6: Cross-section of a tufted carpet**

In the tufting process, pile yarns (face) are inserted by needles into a woven or non-woven carrier material (primary backing), made of polypropylene, polyester or jute, across the entire width of the substrate (up to 5 m). During subsequent manufacturing processes, the base of the pile yarn is anchored in the back of the carpet by means of an applied coating (see Section 2.10.2).

Figure 2.7 is a simplified representation of a tufting plant.

![Diagram of tufting plant](source: [63, GuT/ ECA, 2000])

**Figure 2.7: Simplified representation of a tufting plant**

Through variations of the tufting technique, different three-dimensional pile structures can be produced as well as patterned carpets (e.g. level loop pile, multi-level loop pile, cut and loop, velvet and velour, saxony).

Figure 2.8 shows two examples of carpet styles.
2.5.3.2 Needle-felting

Figure 2.9 shows the manufacturing process for needle-felt carpets. The fibres lie criss-cross to each other and are compressed with needles. This compression is fixed with binding agents [18, VITO, 1998]. Needle-pile felt carpets can consist of one or several layers, with or without a carrier layer. They may be equipped with various types of backings (textile backing, foam, heavy coating). For lasting binding of the fibres, the needled substrate is subsequently subjected to further thermal or chemical treatment (chemical reinforcement).

Almost all fibres may be used for the production of needle-felts; however, man-made fibres are mostly used (PP, PA, PES, PAC, wool, jute/sisal, viscose).
2.5.3.3 Carpet weaving

The manufacturing process for woven carpets is similar to the manufacturing of any other woven good (see Section 2.5.1.3). Since coarse types of yarns are used for woven carpets, the warp is normally not sized. A scheme of the production process for woven carpets is reported in Figure 2.10.

![Figure 2.10: Representation of the production process for woven carpets](image)

Source: [63, GuT/ECA, 2000]

As a rule, woven carpets are provided with a stabilising back-coating. Only in rare cases is an additional heavy coating (e.g. PVC or bitumen) applied.

2.5.4 Non-woven textiles

Textiles manufactured without an intermediate yarn-processing step are called non-wovens. The application of these textiles is quite broad, ranging from backings for coatings, filters, geotextiles and other technical textiles to dishcloths, etc.

In the fabrication of non-woven textiles the only significant environmental impact is normally associated with the off-gases emitted during the thermal and chemical bonding steps. The volatile compounds mainly originate from fibre-inherent monomers (especially caprolactame), monomers in the bonding polymers, etc.
2.6 Pretreatment

Pretreatment processes should ensure:

- the removal of foreign materials from the fibres in order to improve their uniformity, hydrophilic characteristics and affinity for dyestuffs and finishing treatments;
- the improvement of the ability to absorb dyes uniformly (which is the case in mercerising);
- the relaxation of tensions in synthetic fibres (without this relaxation of tension, unevenness and dimension instabilities can occur).

The position of pretreatment within the production scheme is closely related to the position of dyeing in the sequence. The point is that pretreatment comes immediately before dyeing (and printing).

Pretreatment processes and techniques depend on the following:

- The kind of fibre to be treated: for raw goods made of natural fibres such as cotton, wool, flax and silk, the technical task is more difficult than for those made of synthetic and artificial fibres. Natural fibres in fact are accompanied by a higher amount of substances that can interfere with later processing. Man-made fibres, in turn, usually contain only preparation agents, water-soluble synthetic size and soil.
- The form of the fibre (flock, yarn, woven or knitted fabrics).
- The amount of material to be treated (for example, continuous methods are more efficient, but are only economically viable for large production capacities).

Pretreatment operations are often carried out in the same type of equipment used for dyeing (in batch processing, in particular, the material is most often pretreated in the same machine in which it is subsequently dyed). For ease of reading of this part of the document, machines that are not specific to a given treatment are described in a separate annex (see Chapter 10).

2.6.1 Pretreatment of cotton and cellulose fibres

2.6.1.1 Principal [manufacturing] processes

Cotton pretreatment includes various wet operations, namely:

- singeing;
- desizing;
- scouring;
- mercerising (and caustification);
- bleaching.

Some of these treatments are obligatory steps only for certain make-ups (e.g. desizing is carried out only on woven fabric).

Moreover, some of these treatments are often combined together in one single step in order to respond to the need to reduce production time and space as much as possible. Nevertheless, for practical reasons they will be described in this section as separate treatments, leaving the discussion about description of possible process sequences for specific make-ups to the following sections.
2.6.1.1.1 Singeing

Singeing can be carried out both on yarns and woven fabrics, but it is more common on fabrics, especially on cotton, cotton/PES and cotton/PA substrates.

Protruding fibre ends at the fabric surface disturb the surface appearance and produce an effect known as ‘frosting’ when dyed. It is therefore necessary to remove the surface fibres by passing the fabric through a gas flame. The fabric is passed over a row of gas flames and then immediately into a quench bath to extinguish the sparks and cool the fabric. The quench bath often contains a desizing solution, in which case the final step in singeing becomes a combined singeing and desizing operation.

Before singeing, the fabric is combed under aspiration to eliminate remaining dust and fibres.

Singeing has no effect on the effluents because only cooling water is necessary. During singeing, relatively strong odours and emissions of dust and organic compounds are observed [209, Germany, 2001]. Odorous substances can be destroyed using catalytic oxidation techniques (see Section 4.1.8.6).

2.6.1.1.2 Desizing

Desizing is used for removing (from woven fabric) sizing compounds previously applied to warp (see Section 2.5.1.2) and is usually the first wet finishing operation performed on woven fabric.

Desizing techniques are different depending on the kind of sizing agent to be removed. Currently applied techniques can be categorised as follows:

- techniques for the removal of starch-based sizing agents (water-insoluble sizes);
- techniques for the removal of water-soluble sizes;
- techniques for the removal of water soluble and insoluble sizes.

Techniques for the removal of starch-based sizes

Starch-based sizes are difficult to remove and require either the catalytic action of an enzyme (catalytic degradation) or another chemical treatment in order to be converted into a washable form. This chemical degradation is mainly achieved by either enzymatic or oxidative desizing.

**Enzymatic desizing** is the most widely used method for the removal of starch, amylases being particularly suitable. The advantage in the use of enzymes is that starches are decomposed without damaging cellulose fibre.

In order to reduce the number of steps in the pretreatment process, it is common practice to combine desizing with cold bleaching in a single step. In this case, the process is also called ‘oxidative desizing’. The fabric is impregnated in a bath containing hydrogen peroxide and caustic soda, together with hydrogen peroxide stabilisers and complexing agents. Persulphate is also usually added to the solution.

Due to the action of NaOH, this treatment, besides a desizing/bleaching effect, also serves as a pre-scouring treatment. Furthermore, oxidative desizing is particularly useful when the textile contains enzyme poisons (fungicides) or when sizes are present that are difficult to degrade. However, because starch scarcely differs from cellulose in the cross-linking of the cellulose rings, chemical oxidation, if not well controlled, can damage the fibre. Desizing is usually carried out in pad-batch, but discontinuous (e.g. jigger) and continuous (pad-steam) processes can also be applied. In the case of enzymatic desizing, pad-steam is applied.
only for big lots and with enzymes that are stable under steaming conditions. After the reaction time, the fabric is thoroughly washed in hot water (95 °C).

Techniques for the removal of water-soluble sizes
The removal of water-soluble sizes such as PVA, CMC and polyacrylates theoretically only requires washing with hot water and sodium carbonate. However, the washing efficiency can be increased by:

- adding suitable auxiliaries (wetting agents) to the desizing liquor (with some restrictions in the case of size recovery);
- allowing adequate time for immersion in the desizing liquor (this ensures maximum liquor pick-up and adequate time for the size to swell);
- washing thoroughly with hot water in order to remove the solubilised size.

In this case, the process is carried out in normal washing machines: Continuous washers are often used, but sometimes the treatment time may be too short to allow complete desizing. Pad-batch and pad-steam or discontinuous processes for prolonging the residence time are therefore also in use.

Techniques for the removal of water-soluble and insoluble sizes
The ‘oxidative desizing’ technique mentioned above is applicable not only for water-insoluble sizing agents, but also for water-soluble ones. This technique is particularly useful for textile finishers dealing with many different types of fabrics and therefore sizing agents (see also Section 4.4.1).

2.6.1.1.3 Mercerising

Mercerising is carried out in order to improve the tensile strength, dimensional stability and lustre of cotton. Moreover, an improvement in dye uptake is obtained (a reduction of 30-50 % of dyestuff consumption can be achieved thanks to the increased level of exhaustion).

Mercerising can be carried out on yarn in hanks, woven and knitted fabric through one of the following different treatments:

- mercerising with tension;
- caustification (without tension);
- ammonia mercerising.

**Mercerising with tension**

Caustic soda mercerising is the most commonly applied mercerising technique (it is not applied to flax). Cotton is treated under tension in a solution of concentrated caustic soda (270-300 g NaOH/l, which means also 170-350 g NaOH/kg of textile) for approximately 40-50 seconds.

During mercerising, the temperature is adjusted at low values (5-18 °C) when the lustre is the priority and at slightly higher levels when the improvement of the other characteristics is preferred. Because the reaction between caustic soda and cellulose is exothermic, cooling systems are applied to keep the temperature of the bath down.

Beside the conventional cold treatment, a hot mercerising process is also now increasingly applied (for hanks and fabric). The material is soaked in a solution of caustic soda close to boiling point. After hot stretching, the fabric is cooled down to ambient temperature and washed under tension.
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In order to ensure a homogeneous penetration of the liquor, especially when operating at ambient temperature, wetting agents are employed. Sulphonates mixed with non-ionic surfactants and phosphoric esters are the most commonly used.

**Caustification**

In the caustification process, the material is treated at 20-30 °C with caustic soda at lower concentrations (145-190 g/l) without applying tension. The material is allowed to shrink, thus improving the dye absorption.

**Ammonia mercerising**

Cotton yarn and fabric can be treated with anhydrous liquid ammonia as an alternative to caustic soda. Effects similar to mercerising are obtained, although the lustre grade is inferior to caustic soda mercerising. Traces of ammonia have to be removed, preferably with dry heat treatment followed by steaming.

This method is not widely used. Only a few plants are reported to use ammonia mercerising in Europe. Only one plant of the data collection reported using this method.

[ 196, TWG 2019 ]

Two examples of mercerising machines respectively for woven fabric (Figure 2.11) and for knitted fabric in tubular form (Figure 2.12) are shown below.

![Figure 2.11: Example of mercerising equipment for woven fabric](source: [69, Corbani, 1994])

![Figure 2.12: Example of mercerising equipment for knitted fabric in tubular form](source: [318, Sperotto Rimar, 2002])

### 2.6.1.1.4 Scouring

Scouring (also known as boiling-off or kier boiling) is aimed at the extraction of impurities present on the raw fibre or picked up at a later stage such as:
• pectins;
• fat and waxes;
• proteins;
• inorganic substances such as alkali metal salts, calcium and magnesium phosphates, aluminium and iron oxides;
• sizes (when scouring is carried out on woven fabric before desizing);
• residual sizes and sizing degradation products (when scouring is carried out on woven fabric after desizing).

Scouring can be carried out as a separate step of the process or in combination with other treatments (usually bleaching or desizing) on all kind of substrates: woven fabric (sized or desized), knitted fabric and yarn.

For yarn and knitted fabric, scouring is usually a batch process which is carried out in the same equipment that will subsequently be used for dyeing (mainly autoclaves or hank dyeing machines for yarn and overflows, jets, etc. for knitted fabric). Woven fabric is scoured in continuous mode using the pad-steam process.

The action of scouring is performed by the alkali (sodium hydroxide or sodium carbonate) together with auxiliaries that include:

• non-ionic (alcohol ethoxylates, alkyl phenol ethoxylates) and anionic (alkyl sulphonates, phosphates, carboxylates) surfactants;
• NTA, EDTA, DTPA, gluconic acid, phosphonic acids as complexing agents, which are used to remove metal ions (and, in particular, iron oxides, which catalyse the degradation reaction of cellulose when bleaching with hydrogen peroxide);
• polyacrylates and phosphonates as special surfactant-free dispersing agents;
• sulphite and hydrosulphite as reducing agents (to avoid the risk of formation of oxycellulose when bleaching with hydrogen peroxide).

2.6.1.1.5 Bleaching

After scouring, cotton becomes more hydrophilic. However, the original colour stays unchanged due to coloured matter that cannot be completely removed by washing and alkaline extraction.

When the material has to be dyed in dark colours, it can be directly dyed without the need for bleaching. In contrast, bleaching is an obligatory step when the fibre has to be dyed in pastel colours or when it will need to be subsequently printed. In some cases, even with dark colours a pre-bleaching step may be needed, but this is not a full bleaching treatment.

Bleaching can be performed on all kinds of make-ups (yarn, woven and knitted fabric).

The most frequently used bleaches for cellulosic fibres are oxidative bleaches, namely hydrogen peroxide ($H_2O_2$). Sodium hypochlorite (NaClO) and sodium chlorite (NaClO$_2$) are still used by a small number of installations.

1. sodium hypochlorite (NaClO);
2. sodium chlorite (NaClO$_2$).

Apart from these, peracetic acid is also applicable [7, UBA, 1994]. Also, optical brightening agents are commonly used to obtain a whitening effect.
Out of the 52 plants from the data collection (see Section 3.1) carrying out bleaching, only one reported using sodium hypochlorite. Four plants use sodium chlorite, five use sodium dithionite, one uses paracetic acid and two apply enzyme bleaching. The rest use hydrogen peroxide. [196, TWG 2019]

Bleaching with hydrogen peroxide

Bleaching can be carried out as a single treatment or in combination with other treatments (e.g. bleaching/scouring or bleaching/scouring/desizing can be carried out as single operations).

The textile is treated in a solution containing hydrogen peroxide, caustic soda and hydrogen peroxide stabilisers at pH 10.5-12 (the optimal pH for scavenging of the OH\(^{-}\) radical is 11.2, as described in Section 4.4.7.2). Recent investigations ([210, L. Bettens, 1995]) have shown that the bleaching agent of peroxide is not the anion HOO\(^{-}\), but the dioxide radical anion OO\(^{-}\) (also known as superoxide). In competition with the formation of the bleaching agent, the OH\(^{-}\) radical is formed, which is responsible for attacking and depolymerising the cellulose fibre. The formation of the OH\(^{-}\) radical is catalysed by metals such as iron, manganese and copper. The prevention of catalytic damage as a consequence of uncontrolled formation of OH\(^{-}\) is mostly taken care of by using complex formers that inactivate the catalyst (stabilisers). Sodium silicate together with Mg salts (MgCl\(_2\) or MgSO\(_4\)) and sequestering/complexing agents (EDTA, DTPA, NTA, gluconates, phosphonates and polyacrylates) are commonly used as stabilisers (see also Section 8.5 for more information about stabilisers and Sections 4.1.6.8.2 and 4.4.7.2 for alternative techniques).

Other auxiliaries used in hydrogen peroxide bleaching are surfactants with emulsifying, dispersing and wetting properties. Employed surfactants are usually mixtures of anionic compounds (alkyl sulphonates and alkyl aryl sulphonates) with non-ionic compounds such as alkylphenol ethoxylates or the biologically degradable fatty alcohol ethoxylates [186, Ullmann's, 2000]. Operating temperatures can vary over a wide range from ambient to high temperature. Nonetheless, a good bleaching action occurs when operating at around 60-90 °C.

Bleaching with hydrogen peroxide in neutral conditions (pH range of 6.5-8) is also possible in some cases (e.g. when treating cotton in blends with alkali-sensitive fibres such as wool). At these pH conditions, activators are required to give prompt the bleaching activity. Note that below pH 6.5 \(H_2O_2\) decomposes into \(H_2O\) and \(O_2\) by HOO\(^{-}\)/O\(^{-}\) disproportionation. Under these conditions, hydrogen peroxide is wasted (production of inactive \(O_2\) gas).

A wide range of bleaching processes can be used, including cold pad-batch (see description of the process in Section 2.7.3.1), bleaching under steaming conditions and bleaching processes in long baths.

Because the bleaching agent of peroxide is anionic in nature (hydrophilic behaviour), it is not possible with this bleaching method to selectively destroy the coloured hydrophobic material present on natural fibres without attacking the polymer itself.

Bleaching with sodium hypochlorite

The high reactivity of this bleaching agent imposes softer operating conditions than hydrogen peroxide (pH 9-11 and temperatures not above 30 °C). Otherwise, there is a risk of damage to the cellulose fibre.

The bleaching stage is followed by an anti-chlorine treatment in order to completely eliminate the hypochlorite and decompose the chloroamines generated during bleaching. Bleaching with sodium hypochlorite can be carried out in batch (e.g. overflow, jet, jigger, winch beck), semi-continuous (pad-batch) or continuous mode. A two-stage process is also in use in which hypochlorite and hydrogen peroxide are used.
The use of hypochlorite as a bleaching agent is in decline for ecological reasons. It is still applied for yarn and knitted fabric when a high degree of whiteness is required, for articles that need to remain white (e.g. linen), or require a white background or in processes where the ground initial dye is discharged removed with a bleach treatment (see also Section 4.4.7.1 for alternative techniques).

**Bleaching with sodium chlorite/chlorate**

Chlorite/chlorate bleaching, although in decline, is still applied for synthetic fibres, cotton, flax and other cellulosic fibres, often in combination with hydrogen peroxide.

The bleaching agent is the chlorine dioxide gas (ClO₂), which follows a completely different working mechanism compared to hydrogen peroxide. Whereas the superoxide radical ion in hydrogen peroxide is hydrophilic and therefore works preferentially in the hydrophilic region of the fibre (attack of the fibre polymer), ClO₂ absorbs preferentially on the hydrophobic associated material, such as the woody part of bast fibres. For this reason, it is an excellent bleaching agent (ensuring a high degree of whiteness and no risk of damage of the fibre) especially for synthetic fibres and for bast fibres such as flax where, compared to cotton, there is a higher percentage of hydrophobic impurities.

Because chlorine dioxide is unstable as a gas and can only be stored as a solution of approximately 1% in water, it must be generated on site as an aqueous solution. There are two ClO₂ precursor chemicals currently in general industrial use, namely sodium chlorite and sodium chlorate. Although sodium chlorate is considerably less expensive than sodium chlorite, it is more difficult and expensive to convert to ClO₂, which explains why it is less commonly used.

Both sodium chlorite and sodium chlorate are used in strong acid conditions (pH 3.5-4 by formic or acetic acid). Chlorine dioxide solutions have a significant corrosive action on construction materials including stainless steel. Sodium nitrate is used as a corrosion inhibitor to protect the stainless steel parts of equipment. It is also necessary to select detergent/wetting agents that can resist acidic conditions. On the other hand, sequestering agents are not necessary because the oxalic acid used for acidification also serves for sequestering metals. The order of introduction of the different auxiliaries has to be controlled to avoid direct contact between the concentrated sodium chlorite/chlorate solution and acids.

The textile material is bleached by padding or in long bath processes. The temperature is normally kept at 95°C, but cold procedures have also been developed to diminish toxicity and corrosion problems, using formaldehyde as an activator for sodium chlorite.

The advantages of chlorine dioxide bleaching are the high degree of whiteness and the fact that there is no risk of damage to the fibre. The main disadvantages are the high stresses to which the equipment is subjected and the chlorine residues that may be left on the fibre, depending on the way chlorite (or chlorate) is produced and activated. Recent Technologies using hydrogen peroxide as the reducing agent of sodium chlorate are now available to produce ClO₂ without generation of AOX (see also Section 4.4.7.1).

**Bleaching with peracetic acid**

Peracetic acid is produced from acetic acid and hydrogen peroxide. It can be purchased as ready-made product or produced in situ. Its optimal bleaching action is reached only in a very narrow pH range between 7 and 8. Below pH 7 the degree of whiteness decreases sharply and above pH 9 depolymerisation of the fibre with consequent damage of the fibre occurs. Peracetic acid is sometimes applied for synthetic fibres (e.g. polyamide) where hydrogen peroxide cannot be used.

### 2.6.1.2 Environmental issues
The main environmental issues associated with cotton pretreatment arise from emissions to water.

The characteristics of the emissions vary according to a number of factors: the make-up, the sequence adopted, the fact that some treatments are often combined in a single step, etc.

The most relevant issues are highlighted below for the various operations involved in pretreatment.

2.6.1.2.1 Desizing and scouring

In a typical mill processing cotton or cotton-blend woven fabric, desizing represents the main emission source in the overall process. As already stated in Section 2.5.1.2, the washing water from desizing may contain up to 70% of the total COD load in the final effluent, especially in the case of native sizing agents. Neither enzymatic nor oxidative desizing allows size recovery, while for some synthetic sizing agents size recovery is technically feasible, but difficult to apply for commission-companies working on commission (see also Section 4.4.8.1).

Compared to woven cotton fabric, the removal of impurities from yarn and knitted fabric is less significant in terms of pollutant load. Nevertheless, consideration must be given to the two issues are the COD load associated with the removal of knitting oils (for knitted fabric), spinning oils and preparation agents (when cotton is in the blend with synthetic fibres) and as well as the biodegradability of these compounds. Substances such as synthetic ester oils are readily emulsified or soluble in water and easily biodegraded. More problems are posed by the presence of substances that are difficult to emulsify and poorly biodegradable such as silicone oils, which are found in elastane blends with cotton or polyamide.

2.6.1.2.2 Mercerising

Mercerising is responsible for a large amount of strong alkali that is discharged in waste water and needs to be neutralised. The corresponding salt is formed after neutralisation. In this respect, the cold process involves higher emission loads than the hot one. In order to allow the required retention time and make possible the cooling of the bath in continuous mode possible, a portion of the bath needs to be taken out removed and cooled down in continuous mode. This means that higher volumes of bath are necessary in cold mercerising, which also result in higher emissions if the caustic soda is not recovered. Mercerising baths are usually recovered and reused. When this is not possible, they are used as alkali in other preparation treatments (caustic soda recovery is discussed in Section 4.4.8.2).

2.6.1.2.3 Bleaching with hydrogen peroxide

The decomposition of hydrogen peroxide, which takes place during the bleaching reaction, forms only water and oxygen. However, environmental concerns associated with the use of stabilisers have to be taken into account (see Section 8.5). These products may contain complexing agents such as EDTA and DTPA with poor bio-eliminability, which may pass undegraded through the waste water treatment systems. Their ability to form very stable complexes with metal makes the problem even more serious because they can mobilise heavy metals present in the effluent and release them in the receiving water (see also Sections 4.1.6.8.2 and 4.4.7.2 for alternative techniques).

It has been reported ([77, EURATEX, 2000]) that, depending on concentration, pH, time and temperature, effluents containing inorganic chlorides (e.g. NaCl from dyeing and printing, MgCl₂ from finishing) can be oxidised to their chlorites/hypochlorites when they are mixed with hydrogen peroxide bleach waste water. In this way, AOX may be found in waste water even if
bleaching is carried out without chlorine-based bleaching agents. However, experimental measurements have shown that this does not play an important role, if any [7, UBA, 1994].

2.6.1.2.4 **Bleaching with sodium hypochlorite**

For ecological reasons the use of sodium hypochlorite is now limited in Europe to just a few particular cases, connected with knitted fabric and, in some cases, bleaching of yarn when a high degree of whiteness is required. Bleaching with sodium hypochlorite leads, in fact, to secondary reactions that form organic halogen compounds, commonly quantified as AOX.

Trichloromethane (which is suspected of being carcinogenic) accounts for the bulk of the compounds formed, but other chlorinating subsidiary reactions might occur, besides the haloform reaction (see also Section 4.4.7.1).

When bleaching with hypochlorite, emissions of chlorine to air may also occur (although only under strongly acidic conditions [281, Belgium, 2002]).

According to the Institute of Applied Environmental Research (Stockholm University), in 1991-1992 dioxins were found in sludge from a textile plant that bleached with sodium hypochlorite. Further investigations showed that pentachlorophenol was present in the hypochlorite [316, Sweden, 2001].

2.6.1.2.5 **Bleaching with sodium chlorite**

Sodium chlorite bleaching may also be responsible for AOX generation in the waste water. However, compared to sodium hypochlorite, the amount of AOX formed during chlorite bleaching is much lower (on average only 10% to a maximum of 20% of the amount of AOX generated by hypochlorite) and it is not correlated with sodium chlorite concentration or with temperature [7, UBA, 1994]. Recent investigations have shown that the formation of AOX is not originated by the sodium chlorite itself, but rather by the chlorine or hypochlorite that is present as an impurity or is used as the activating agent. Recent technologies (using hydrogen peroxide as the reducing agent of sodium chlorate) are now available to produce ClO₂ without generation of AOX (see also Section 4.4.7.1).

As already mentioned earlier, handling and storage of sodium chlorite need particular attention because of toxicity and corrosion risks. Mixtures of sodium chlorite with combustible substances or reducing agents can constitute an explosion hazard, especially when they are subject to heat, friction or impact. Sodium chlorite forms chlorine dioxide when brought into contact with acids. Moreover, sodium chlorite decomposition produces oxygen, which supports combustion.

2.6.2 **Wool preparation before colouring**

Typical preparation wet treatments applied on wool fibre before dyeing are:

- carbonising;
- washing (scouring);
- fulling;
- bleaching.

Other possible treatments are those that fall under the definition of anti-felt and stabilisation treatments. Although they are often carried out before dyeing, they are not obligatory
preparation steps. For this reason, they are described under finishing operations (Section 2.9.2.8).

2.6.2.1 Principal manufacturing processes

2.6.2.1.1 Carbonising

Sometimes scoured wool contains vegetable impurities that cannot be completely removed through mechanical operations. Sulphuric acid is the chemical substance used for destroying these vegetable particles and the process is called carbonising.

Carbonising can be carried out on floc/loose fibre or on fabric (this operation is not applied in the carpet sector).

*Loose fibre carbonising* is performed only on fibres that are later used to produce fine fabric for garments (worsted fabrics) and usually takes place at the scouring mill.

In typical equipment for carbonisation of loose fibre, the still damp scoured wool is soaked in a solution containing 6-9% mineral acid (generally sulphuric acid). Excess acid and water are removed by pressing or by centrifugation until on average 5-7.5% sulphuric acid and 50-65% water remain. The fibres are then dried at 65-90 °C to concentrate the acid and baked at 105-130 °C (carbonising).

As soon as the wool is dried, it is fed into a machine, which consists of two counter-rotating rolls. These rolls crush the carbonised particles into very small fragments, which are then easily removed. The addition of small quantities of detergent to the sulphuric acid improves the yield and reduces the attack on the wool. In order to prevent the fibre from being gradually degraded, the pH is finally set to 6 by neutralisation with sodium acetate or ammonia.

Sulphuric acid can be replaced by gaseous HCl or by aluminium chloride. The latter releases HCl when it is heated: this method is useful for the carbonisation of wool/synthetic fibre mixtures, such as wool/PES, that are too sensitive to sulphuric acid.

After carbonising, the fibre can be carded and then spun before being dyed or it can be dyed directly in floc form.

*Fabric carbonising* is typical for woollen fabrics. The operation can be carried out by either the traditional system (see Figure 2.13 below) or the solvent-based more modern ‘Carbosol’ system (see Figure 2.14).

The conventional procedure is substantially largely similar to that used for loose fibre. The fabric can be previously soaked in a water or solvent bath and squeezed, but this step is optional. Then it is impregnated in a concentrated sulphuric acid solution (acidification) and squeezed (hydroextraction) before passing through the carbonising chamber. The carbonised particles are then removed by mechanical action and subsequent washing. In modern carbonising plants, all these steps are carried out in continuous mode.

The ‘Carbosol’ process, licensed by SPEROTTO RIMAR, uses an organic solvent instead of water. The equipment consists of three units. In the first one the fabric is impregnated and scoured with perchloroethylene, in the second the material is soaked in the sulphuric acid solution and in the third carbonising and solvent evaporation take place. At this stage, the perchloroethylene is recovered by distillation in a closed loop.

The ‘Carbosol’ system is reported to have several technical advantages over the traditional process. Mainly, the level of acidity of the fabric after carbonising is much lower and the risk of
damage to the wool fibre is reduced. Thanks to full recovery of the organic solvent, the process can also be considered more efficient from the environmental point of view.

Source: [71, Bozzetto, 1997]

Figure 2.13: Representation of a conventional carbonising installation

Source: [71, Bozzetto, 1997]

Figure 2.14: ‘Carbosol’ system

2.6.2.1.2 Scouring

Both yarn and fabric contain, besides accidental impurities, a certain amount of spinning oils and in some cases also sizing agents such as CMC and PVA. All these substances are usually removed before dyeing in order to make the fibre more hydrophilic and allow the penetration of the fibre by dyestuffs. However, this operation is not always necessary. In some cases, if the preparation agents are applied in very small amounts and they do not interfere with the dyeing process, a separate scouring/washing step can be omitted.

As pointed out in Section 2.4.1, the percentage of spinning oils on woollen wool is quite relevant and it is always above 5 %, while on worsted wool it never reaches 2 %. Typical substances that have to be removed by scouring can be classified as follows:

- Soluble in water.
- Insoluble in water, but emulsifiable thanks to the action of surfactants.
• Insoluble in water and non-emulsifiable (or difficult to emulsify) with surfactants. These substances can be removed only by using organic solvents (in general, halogenated solvents like perchloroethylene).

As a result the material can be washed (scoured):

• with water; or
• with solvent (dry cleaning).

Water washing is carried out in neutral or weakly alkaline conditions (by sodium carbonate or bicarbonate) in the presence of detergents. Commonly used detergents are mixtures of anionic and non-ionic surfactants such as alkyl sulphates and fatty alcohols and alkylphenol ethoxylates. In wool carpet yarn production, the scouring process can include simultaneous chemical setting of yarn twist with reductive agents (sodium metabisulphite) and/or application of mothproofing (insect-resist) agents (see also Section 2.13.5.1).

Water scouring is normally a batch operation which is carried out in the equipment in which the textile material will be subsequently dyed. This means that an autoclave is the commonly used equipment for yarn, while jets and overflows are the machines typically applied for fabric. In this respect, the carpet sector is an exception. Wool yarn for carpet is scoured on a continuous or semi-continuous basis in tape scouring machines (hanks) or in ‘package to package’ scouring machines (package yarn), where the yarn is passed through a series of interconnected bowls (see Section 16.2).

Dry cleaning is less common and is applied when the fabric is heavily soiled and stained with oils from the weaving or knitting process. The most widely used solvent is perchloroethylene. In some cases, water and surfactants are added to the solvent to provide a softening effect.

Solvent washing can be carried out either in discontinuous mode in a tumbler (generally for knitted fabric) or in continuous mode in open-width (for woven and knitted fabric). Impurities are carried away by the solvent, which is continuously purified and recycled in a closed loop (see also Section 2.11.2).

2.6.2.1.3 Fulling

This treatment takes advantage of the typical felting tendency of wool fibre when it is submitted to friction under hot humid conditions and is a typical pretreatment for woollen fabric.

It is usually carried out after carbonising, but in some cases (e.g. heavy woollen fabrics) it can be done directly on raw fabric. The material is kept in circulation in a bath containing fulling auxiliaries. Both acids (pH < 4.5) and alkalis (pH > 8) speed up the fulling process. Fulling auxiliaries available on the market, however, also produce excellent results under neutral conditions. As a result, fulling either in acidic or alkaline conditions is becoming less common. After fulling, the fabric is washed.

Machines specially designed for this process are still in use. However, today they have been largely replaced by multifunctional machines, where both fulling and washing can be carried out by simply adjusting the set-up of the equipment.

2.6.2.1.4 Bleaching

Wool is bleached with hydrogen peroxide (sodium hypochlorite may discolour and damage the wool). An additional reductive bleaching is, however, indispensable for achieving high levels of whiteness (full bleach). A typical reductive bleaching agent is sodium dithionite...
(hydrosulphite), which is often used in combination with optical brighteners to enhance its effect.

In the oxidative bleaching step, hydrogen peroxide is applied in the presence of alkali and stabilisers, which slow down the decomposition of the hydrogen peroxide (see also Section 8.5).

When wool has been previously submitted subjected to an anti-felt treatment it is preferable to use hydrogen peroxide in weakly acidic conditions.

## 2.6.2.2 Environmental issues

Wool pretreatment gives rise mainly to water emissions, although there are also specific operations (e.g. carbonising with the ‘Carbosol’ system and dry cleaning) where halogenated (mainly perchloroethylene) solvents are employed. The use of halogenated organic solvents can produce not only emissions to air, but also contamination of soil and groundwater if they are not handled and stored using the necessary precautions. Preventive and end-of-pipe measures include closed-loop equipment and in-loop destruction of the pollutants by means of advanced oxidation processes (e.g. Fenton reaction). See Sections 4.2.1, 4.4.1 and 4.1.7.3.4.1 for more detailed information. The process also involves the generation of exhausted active carbon from the solvent recovery system. This solid waste has to be handled separately from other waste material and disposed of as hazardous waste or sent to specialised companies for regeneration.

Due to the predominantly batch nature of wool pretreatment operations for all types of make-ups, the resulting emissions will be discontinuous and with concentration levels largely influenced by the liquor ratios used. An exception is represented by carpet yarn which can be scoured/bleached and mothproofed on tape or ‘package to package’ scouring machines (see Section 16.2), giving rise to continuous flows.

The pollutants that can be found in the waste water originate in part from the impurities that are already present on the fibre when it enters the process sequence and in part from the chemicals and auxiliaries used in the process.

**Pollution originating from impurities present on the raw material**

Residues of pesticides used to prevent the sheep becoming infested with external parasites can still be found on scoured wool in amounts which depend on the efficiency of the scouring process. These are mainly organophosphates (OPs) and synthetic pyrethroid (SPs) insecticides and insect growth regulators (IGRs), but detectable residues of organochlorine pesticides (OCs) can be observed. They partition between the fibre and the water according to their stronger or weaker lipophilic character and, as a consequence, traces of these compounds are released in the waste water. More information about ectoparasiticides can be found in Sections 2.1.1.9 and 2.3.1.2. The partition factors of the different classes of pesticides are discussed in more detail for the carpet sector in Sections.

Note that because of their steam volatility some pesticides (OPs) end up in the emissions to air from open machines. This must be taken into account in input/output balances.

Spinning lubricants (see Section 8.2.3), knitting oils (see Section 8.2.5) and other preparation agents also represent an important issue in wool pretreatment. These substances are removed during the scouring process, contributing to the COD load and aquatic toxicity in the final effluent. The main concerns are about:

- poorly refined mineral oils (content of aromatic hydrocarbons);
- APEO (non-biodegradable and giving rise to toxic metabolites);
- silicones (non-biodegradable and difficult to remove without scouring assistants);
- biocides (toxic to aquatic life).
The dry spinning route in the carpet sector, described in Section 2.13.5.1, represents one exception because in this case spinning lubricants do not reach the water effluent.

Pollution originating from chemicals and auxiliaries used in the process

Considerable amounts of surfactants are used in pretreatment as detergents, wetting agents, etc. Surfactants with good biodegradability with an acceptable performance are now available (see Section 4.1.6.8). Nevertheless, the use of alkylphenol ethoxylates is still common in some companies due to their low cost. Alkylphenol ethoxylates (APEOs) and in particular nonylphenol ethoxylates (NPEs) are under pressure due to the reported negative effects of their metabolites on the reproduction system of aquatic species. The environmental issues arising from surfactants in common use are discussed in Section 8.1.

Other pollutants of concern that may be found in water effluent from pretreatment activities are:

- reducing agents from bleaching treatments and chemical setting of carpet wool yarn (sodium metabisulphite): they contribute to oxygen demand in the waste water;
- poorly bio-eliminable complexing agents (e.g. EDTA, DTPA, phosphonates) from hydrogen peroxide stabilisers, etc.;
- AOX from sodium hypochlorite bleaching
- insect-resist agents in wool carpet yarn production.

More details regarding environmental issues associated with the above-mentioned substances are given elsewhere in this document, in particular in Section 2.6.1.2 and Section 8.5.

2.6.3 Pretreatment of silk

The following information has been submitted by Italy [206, Italy, 2001]

2.6.3.1 Scouring

To prepare a silk yarn for dyeing and silk fabrics for dyeing and printing, it is necessary to partially or completely remove sericin, as well as natural oils and organic impurities. Depending on the percentage of sericin removed during scouring (sericin is present in raw silk in a ratio between 20% to 25%), the end-product is defined as unscoured (used only for shirts and suits), ‘souple’ or degummed.

Scouring can be carried out either on the yarn or on the fabric. It is easier to remove sericin more evenly by performing the operation on the yarn itself. Nevertheless, the operation is generally carried out on the fabric, in order to exploit the protective action of this ‘natural size’ against possible damage during weaving.

The scouring treatment can be carried out in a neutral, acidic or alkaline solution, depending on the desired results. At the industrial level, treatment in alkaline conditions is by far the most common. It is extremely important to control the temperature.

Scouring baths present a high total organic charge; the concentration of nitrogen organic components in particular is high.

‘Unscoured’ silk

The process to produce ‘unscoured’ silk consists of removing from raw silk fabrics all residual substances from previous operations, with a minimal elimination of sericin (1-2%), so that the fabric keeps the characteristic stiffness. The operation is carried out in a slightly alkaline soap bath at low temperature.

‘Souple’ silk
The process is carried out on weft yarns under acidic conditions. The loss of weight is approximately 10%.

**Degummed silk**

This treatment is carried out on both yarns and fabrics and ensures a complete elimination of sericin, as well as substances added in previous operations, without modifying the fibroin.

Hydrolytic degradation of the sericin protein macromolecule can be obtained by simply using soaps, by using synthetic surfactants or mixtures of soaps and synthetic surfactants, by means of an enzymatic treatment, or by treating the silk in water at high temperature and under pressure.

In the *degumming process with soap*, yarn and fabric are plunged into two baths (degumming baths). Each bath contains green soap at different concentrations. The treatment is followed by washing with ammonia and rinsing. The process temperature varies between 95 °C and 98 °C. The soap concentration in the degumming bath varies between 10 g/l and 15 g/l. On average, the entire treatment lasts for 2 hours. It is possible to reuse exhausted baths after appropriate addition of soap.

**Degumming with synthetic detergents** implies the partial or total replacement of soap with synthetic non-ionic surfactants (e.g. ethoxylate fatty alcohol). It is also possible to combine a degumming treatment with an oxidising or reducing bleaching and, in some cases, even with dyeing, thus improving water and energy saving. Generally, alkali and detergent mixtures are used at temperatures around 95-98 °C. Such a treatment is suited to continuous processing.

**Degumming under pressure at high temperature** is a specific treatment essentially used to degum yarns. It is necessary to prepare an aqueous bath without surfactants and the temperature should be between 110 °C and 140 °C. A post-treatment washing step is required to eliminate substances used in previous processes.

### 2.6.3.2 Weighting

The weighting operation is carried out mostly on yarns to promote recovery of the weight lost after the removal of the sericin. The treatment consists of the deposition of tin salts or of grafting polymer chains to the functional groups of the fibroin protein chain.

Weighting is defined as ‘equal’ if the final substrate weight is the same as it was before degumming, and as ‘higher’ if the weight is higher. Weighted silk is different in touch and in draping. The most frequently applied procedure is a ‘mix weighting’ process.

**Weighting with minerals**

The silk yarn undergoes a treatment using tin tetrachloride in baths at different concentrations (strong or weak baths) in an acidic medium. In a strong bath, silk can increase its weight by about 10 % simply by absorbing the salt. The procedure is followed by accurate washing cycles to eliminate unfixed salt and to hydrolyse the salt present on the fibre. Such operations can be repeated to further increase the silk weight. To ensure fixation of tin salts, weighting is completed with a treatment in a sodium phosphate bi-basic solution, followed by a second treatment in sodium silicate.

Disadvantages of this procedure are the long processing time and the high water and energy consumption. The high amount of tin in the waste water is an environmentally undesirable effect of this process.

**Weighting with vinyl monomers**

Grafting vinyl monomers onto silk represents an alternative to the traditional mineral weighting. Such a method not only allows the desired weight increase to be achieved, but also improves
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silk characteristics and performance. Co-polymerisation with vinyl monomers is carried out using radical activation methods (redox systems, UV, γ rays and so on).

Methacrylamide (MAA) is one of the most frequently applied monomers at the industrial level. MAA weighting is a simple application. Radical activation is obtained through ammonia or potassium persulphate. Other radical activators, which consist of redox systems described in the literature, are not currently applied at the industrial level.

Silk dyeing behaviour can be modified through the weighting treatment. Studies prove how the dyeing affinity of silk weighted with MAA towards the most widely used dyes changes according to the percentage of acquired weight. They also show that wet-fastness is reduced in dyeing after weighting.

For the weighting of silk for ties, methacrylamide is the only technique used by industry; at present no MAA substitute is available on the market.

Mix weighting
To achieve a hybrid of the final characteristics of compounds submitted subjected to mineral or MAA weighting, a fairly widely used weighting process at the industrial level is mix weighting with tin/MAA.

2.6.4 Pretreatment of synthetic material

2.6.4.1 Principal manufacturing processes

Typical operations before colouring are washing and thermofixing (heat-setting).

Washing is necessary to remove from the yarn the preparation agents that have been applied to its surface in the previous treatments (usually 2-3 %, but can be up to 4 % of the weight of the fibre). Most preparation agents (about 95 %) are removed at this stage (ethoxylated fatty alcohols are commonly used as emulsifying agents). Elastomeric fibres (elastan) are an exception because they contain preparation agents mainly made up of silicone oils in the order of 6-7 %. Silicones are more difficult to remove and partly still remain on the fibre (40 % of the initial add-on) after washing. To improve their removal it is common practice to use ethoxylated nonylphenols.

When pretreating woven fabric, the removal of sizing agents is a crucial step. The extraction of these substances is achieved thanks to the synergistic action of the following:

- Surfactants (non-ionic or mixtures of non-ionic and anionic): they act as wetting and emulsifying agents and promote the solubilisation of the size.
- Complexing agents (e.g. phosphonates): they are used when there is a risk of re-precipitation of the components of the sizing agents. An increase in hardness level can occur, particularly in continuous lines when processing synthetic blends with cellulose fibres (characterised by the presence of Ca, Fe and Mg salts as natural impurities).
- Alkali (caustic soda or sodium carbonate): the alkali is chosen according to the sizing agent employed (for example for the removal of sizing agents based on polyacrylate ammonium salts the use of caustic soda is obligatory, while a polyester sizing agent would precipitate in the same pH conditions).

Thermofixation is also another important operation in synthetic fibres pretreatment. Its position within the process can be different, depending on the make-up and the fibre. As a result, the following possible sequences are possible:

- thermofixation – washing – dyeing;
• washing – thermofixation – dyeing;
• washing – dyeing – thermofixation.

If white fabrics are to be produced, bleaching of the fabric may be necessary after thermofixation.

### 2.6.4.2 Environmental issues

Potentially harmful impurities and additives are already present on synthetic fibres before they are processed at the finishing mill and they account for a large fraction of the pollution load coming from pretreatment.

Some of these impurities are produced during the manufacture of the fibre. They are polymer synthesis by-products such as unreacted monomers (for example caprolactame, in the production of PA 6) low-molecular-weight oligomers, and residual catalysts and they are emitted to air during thermal treatments.

Other substances are intentionally added to the fibre to improve subsequent processing. These are the preparation agents used in fibre and yarn manufacturing and the sizing agents.

The average amount of preparation agents applied on man-made fibres (except for elastomeric, where the load can be much higher) ranges between 2% and 4% of the weight of the fibre (see also Section 8.2).

When the textile is washed, about 80% of these substances are released to the waste water and the remaining 20% can be emitted to exhaust air in the subsequent high-temperature treatments (drying and thermofixation). Conversely, when thermofixation is carried out on the grey material before washing (which is the case when fine woven and knitted fabrics are processed), the main percentage of the pollution load is found in the exhaust air.

During high-temperature treatments, the lower-molecular-weight components of the preparation agents (basically lubricants and surfactants) either decompose — resulting in smaller, more volatile molecules — or they react with each other, forming tar. Volatility and tar are undesirable effects because they lead to emissions to air and damage to the yarn.

However, thanks to considerable technological improvements achieved by the technology in the field of synthetic fibres, the fibres/filaments leaving the primary spinning process (fibre production) no longer cause fuming. The remaining problems today are connected with those cases where, after the fibre/filament production, lubricants such as coning oils are added to the fibre at a rate of over 2% or even 3% of the yarn weight [48, VITO, 2001].

The main concerns, as regards waste water, arise from the discharge of poorly or non-biodegradable substances such as mineral oils, ethylene oxide/propylene oxide adducts, silicone oils, hard surfactants, etc. Furthermore, biocides, which are normally contained in the aqueous formulations, contribute to the aquatic toxicity of the waste water.

Likewise for emissions to air, as for water emissions, the main charging load in waste water again also comes from the preparation agents (coning oils, overspray, etc.) that are applied to the fibre/filament after the primary spinning stage. These substances (secondary spinning agents) are applied in significantly higher amounts than primary spinning agents. Moreover, they usually have low affinity with water and are therefore difficult to remove.

For woven fabric, sizing agents also have to be considered. Sizing agents do not give rise to emissions to air during high-temperature treatments, but they may be responsible for poorly biodegradable substances and aquatic toxicity.
Information about alternative preparation agents for man-made fibres is given in Section 4.1.5.1.1.
2.7 Dyeing

In the following sections, the general principles of dyeing and the most commonly used dyeing techniques for the different fibres are described. For practical reasons, detailed information concerning dyeing auxiliaries, dyestuffs and dyeing equipment is given in specific annexes (namely Section 8.6, Chapter 9 and Chapter 10).

2.7.1 General principles of dyeing

Dyeing is a method for colouring a textile material in which a dye is applied to the substrate in a uniform manner to obtain an even shade with a performance and fastness appropriate to its final use. A dyestuff is a molecule which contains a chromophoric group (conjugated system) capable of interacting with light, thus giving the impression of colour.

Textile dyeing involves the use of a number of different chemicals and auxiliaries to assist the dyeing process. Some of them are process-specific, while others are also used in other operations. Some auxiliaries (e.g. dispersing agents) are already contained in the dyestuff formulation, but more commonly auxiliary agents are added at a later stage to the dye liquor. Since auxiliaries in general do not remain on the substrate after dyeing, they are ultimately found in the emissions.

Various dyeing techniques exist:

- mass dyeing/gel dyeing, in which a dye is incorporated in the synthetic fibre during its production (this technique is the most commonly applied process for PP fibres and is also of interest for PAC, but is not described in this document);
- pigment dyeing, in which an insoluble pigment, without affinity for the fibre, is deposited onto the textile substrate and then fixed with a binder;
- dyeing processes which involve the diffusion of a dissolved or at least partially dissolved dye into the fibre.

This last group of processes is the one that will be discussed in more detail in the following sections. From a molecular point of view, four different steps are involved:

- First, the dye, previously dissolved or dispersed in the dye liquor, diffuses from the liquor to the substrate.
- The second step consists of the accumulation of the dye on the surface of the textile material. This process is controlled by the affinity (substantivity) of the colourant for the fibre.
- The dye diffuses/migrates into the interior of the fibre until this is uniformly dyed. This step is much slower than the transport of the dissolved dye within the dye bath. The penetration of the dye into the fibre requires that the fibre itself is accessible. In the case of hydrophilic fibres the dye penetrates through the available micropores, while in hydrophobic fibres, whose molecular structure does not allow a continuous water phase, cavities need to be developed in order to make the penetration of the dye possible. In general, access to the fibre is enhanced by temperature. Hydrophobic fibres can only be penetrated by the dye above the glass transition temperature, which sometimes lies above 100 °C. During the diffusion into the micropores, an electrostatic barrier, which develops on the surface of the fibre, still has to be overcome. In some cases, large amounts of salt have to be added to the dye bath in order to reduce the electrostatic forces on the surface of the fibre and promote an even penetration of the dye.
- The dye must be anchored (fixed) to suitable places within the substrate. Different mechanisms of fixation are known, ranging from chemical reaction of the dye with the
fibre to form a covalent bond (reactive dyes) to formation of Van der Waals and other short-range forces between the fibre and the dye (direct dyes). An important role is also played by hydrogen bonding responsible for long-, medium- and short-distance interactions between fibre and dyestuff, dyestuff and dyestuff, water and fibre and water and soluble substances present in the liquor, such as surfactants. This is more fully explained in Chapter 9.

2.7.2 Dyeing processes

Textiles can be coloured at any of several stages of the manufacturing process so that the following colouring processes are possible:

- flock or stock dyeing;
- top dyeing: fibres are shaped in lightly twisted roving before dyeing;
- tow dyeing: it consists of dyeing the mono-filament material (called tow) produced during the manufacture of synthetic fibres;
- yarn dyeing;
- piece (e.g. woven, knitted and tufted cloths) dyeing;
- ready-made goods (finished garments, carpet rugs, bathroom sets, etc.).

Dyeing can be carried out in batch or in continuous/semi-continuous mode. The choice between the two processes depends on the type of make-up, the chosen class of dye, the equipment available and the cost involved. Both continuous and discontinuous dyeing involve the following steps:

- preparation of the dye;
- dyeing;
- fixation;
- washing and drying.

2.7.2.1 Batch dyeing

In batch dyeing (also called exhaustion dyeing), a certain amount of textile material is loaded into a dyeing machine and brought to equilibrium with a solution containing the dye and the auxiliaries over a period of minutes to hours.

The dyeing process starts with the absorption of the colourant onto the external surface of the fibre, then the diffusion and migration of the colourant through the fibre takes place. The use of chemicals and controlled temperatures accelerates and optimises exhaustion and fixation (rate/level) of the dye. When the dyeing is judged to be the right shade, the spent dye bath is drained and the textile material is washed to remove unfixed dyes and chemicals. Washing is usually carried out in the same equipment. However, separate washing machines can also be used in the case of fabric.

All these operations can be carried out with different degrees of automatisation. In fully automated dyehouses, all steps going from the preparation of recipes and laboratory trials to dyestuffs and chemicals feeding, material transportation, loading and unloading of the machines and control of dyeing parameters (e.g. level, heating, injection at selected speed, pH, temperature) are performed under computer guidance.
In a manual regime, the dyestuffs and chemicals are dosed and fed to the machines manually. A manual dyeing approach used for wool is to carry out trial laboratory dyeing on a sample of the particular fibre and then to apply 5-10% less dye in the full-scale dyeing. The final shade is achieved by adding additional dye in small portions quantities to achieve the final shade. Depending on the dyestuffs, it may be necessary to cool the dye bath for each of these additions in order to promote even migration of the added dye. Shade matching is carried out by eye, the dyer comparing the dyed material with a reference pattern under standard illumination.

Dyeings which are ‘overshade’ can be corrected by stripping dyestuff from the fibre using an excess of levelling agent or reducing conditions, and then by adding further colour to achieve the correct shade. This is a very costly and polluting practice and is only used as a last resort in most dyehouses.

An important parameter in discontinuous dyeing is the liquor ratio of the equipment. This is the weight ratio between the total dry material and the total liquor. So, for example, a liquor ratio of 1:10 means 10 litres of water for 1 kg of textile material.

This parameter not only influences the amount of water and energy consumed in the dyeing process, but also plays an important role in the level of exhaustion of the dye and in the consumption of chemicals and auxiliaries.

The liquor ratio is related to the exhaustion level of the bath through the equation: \[ E = \frac{K}{K+L} \], where:

- \( K \) (affinity) = 50 to 1 000 for various dye/fibre combinations;
- \( L \) (liquor ratio) = 5 to 50 for various machines;
- \( E \) (exhaustion) = 0.5 to 1 (50% to 100% exhaustion).

From this equation it can be inferred that when \( L \) increases, \( E \) decreases and less dye is absorbed onto the fibre when the equilibrium is reached. The effect is more pronounced on low-affinity dyes.

As stated earlier, the liquor ratio also has an influence on the levels of chemicals and auxiliaries consumption. Most chemicals and auxiliaries are dosed on the basis of the amount of bath (on the weight of the bath - o.w.b.) rather than the weight of the fibre (on the weight of the fibre - o.w.f.). For example, in a 1:5 bath liquor ratio, 50 g/l of salt will mean 250 g/kg of fibre, but at a 1:40 liquor ratio, the same 50 g/l of salt corresponds to 2 kg/kg of fibre.

Dyeing machines vary greatly in their liquor ratios, depending also on the type of substrate to be dyed and its hydrophilicity. Equipment manufacturers provide a range of nominal liquor ratios for each type of machine. This is defined as the range of liquor ratios at which the machine can be operated when it is loaded at its optimum/maximum capacity. In each range the lowest values normally refer to synthetic fibres (PES is usually taken as the reference), while the highest figures apply to cotton. This is due to the lower amount of liquor retained by synthetic fibres compared to cotton.
Table 2.5 shows typical ranges of nominal liquor ratios for each type of machine. It should also be noted that each type of machine has its own limitations and range of applicability.

The features of a number of typical machines are described in more detail in Sections 10.1 to 10.4.1.2, while the latest developments in selected types of machines are reported in Sections 4.5.1.6 to 4.5.1.6.2.2.
Table 2.5: Discontinuous dyeing equipment and liquor ratios

<table>
<thead>
<tr>
<th>Make-up</th>
<th>Process</th>
<th>Equipment</th>
<th>Liquor ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose/stock fibre (also card sliver and tow)</td>
<td>Loose stock dyeing</td>
<td>Autoclave (loose stock dyeing)</td>
<td>1:4 - 1:12 (1)</td>
</tr>
<tr>
<td>Yarn</td>
<td>Bobbins/cones</td>
<td>Yarn dyeing</td>
<td>1:8 - 1:15</td>
</tr>
<tr>
<td>Hank</td>
<td>Hank dyeing</td>
<td>Hank dyeing machines</td>
<td>1:12 - 1:25 (3)</td>
</tr>
<tr>
<td>Woven and knitted fabric, tufted carpet</td>
<td>Rope</td>
<td>Piece dyeing in rope form</td>
<td>1:15 - 1:40 (4)</td>
</tr>
<tr>
<td></td>
<td>Open-width</td>
<td>Piece dyeing in open-width form</td>
<td>1:15 - 1:30 (4)</td>
</tr>
<tr>
<td>Ready-made goods (e.g. garments, rugs, bathroom sets)</td>
<td>Piece dyeing</td>
<td>Winch beck</td>
<td>1:10 - 1:15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Beam dyeing</td>
<td>1:8 - 1:10 (6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Beam + washing machine</td>
<td>1:10 - 1:15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jig dyeing</td>
<td>1:3 - 1:6 (6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jigger + washing machine</td>
<td>1:10</td>
</tr>
<tr>
<td></td>
<td>Piece dyeing</td>
<td>Paddle</td>
<td>1:60 (not exceptional)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drum</td>
<td>Very variable</td>
</tr>
</tbody>
</table>

(1) [32, ENco, 2001]
(2) [204, ETAD, 2001]
(3) The typical range is 1:15 - 1:25 as reported in the Comment from BCMA [208, ENco, 2001]. A liquor ratio of 1:12 has been reported for hank carpet wool (semi-worsted) [281, Belgium, 2002].
(4) [161, GuT, 2001]
(5) [3, RIZA, 1998]
(6) [293, Spain, 2002]
Source: [91, TWG 2001]

2.7.2.2 Continuous and semi-continuous dyeing

In continuous and semi-continuous dyeing processes, the dye liquor is applied to the textile either by impregnation (by means of foulards) or by using other application systems. Most commonly, textiles are fed continuously in open-width through a dip trough filled with dye liquor. The substrate absorbs an amount of dye solution before leaving the dip trough through rollers that control the pick-up of the dye. Surplus stripped dye flows back into the dye bath. In the carpet industry (and for open goods that must pick up and retain large volumes of liquor), thickening agents are added to the pad liquor to prevent dye migration. Moreover, special application systems are also encountered, where the dyestuff is poured, jet-sprayed, injected or applied in the form of foamed liquor (see Section 10.4.2).

Dye fixation is usually achieved in a subsequent stage using chemicals or heat (steam or dry heat). The final operation is washing, which is usually carried out in washing machinery at the end of the same line.

The only difference between continuous and semi-continuous processes is the fact that in semi-continuous dyeing the application of the dye is performed continuously by padding, while fixation and washing are discontinuous.
In general, dyes with low affinity are favoured in continuous dyeing to prevent tailing (attributable to undesirable exhaustion of the padding solution) and to make washing-off of the unfixed dye easier.

In continuous and semi-continuous processes, the liquor ratio is not of practical importance and it is not used as a parameter. In these processes, the factor to be taken into account is the *wet pick-up %* (grams of liquor picked up by 100 grams of substrate) and the concentration of the dye.

An overview of the most common techniques and machinery utilised in continuous and semi-continuous processes is given in Table 2.6.

### Table 2.6: Semi-continuous and continuous dyeing processes and equipment

<table>
<thead>
<tr>
<th>Make-up</th>
<th>Process</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woven &amp; knitted fabric, tufted carpet</td>
<td>Rope</td>
<td>Continuous Padding machine for piece in rope form + J-box or conveyor + washing machine</td>
</tr>
<tr>
<td>Open-width</td>
<td>Semi-continuous Pad-batch (or Carp-O-Roll for carpet) Padding machine + washing machine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Semi-continuous Pad-roll (or Carp-O-Roll for carpet) Padding machine + washing machine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Semi-continuous Pad-jig Padding machine + jigger + washing machine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Continuous Pad-steam Padding machine (1) + steamer + washing machine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Continuous Pad-dry Padding machine (1) + stenter frame + washing machine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermosol</td>
<td>See Section 10.4.2.6</td>
</tr>
</tbody>
</table>

(1) Different applicators are used to dye carpets on continuous ranges (see also Section 10.4.2).

#### 2.7.3 Cellulose fibres dyeing

Cellulose fibres can be dyed with a wide range of dyestuffs, namely:

- reactive dyes;
- direct dyes;
- vat dyes;
- sulphur dyes;
- azoic (naphtol) dyes.

The most common dyestuffs and dyeing techniques for cellulose fibres are summarised in
Table 2.7 and are described in more detail further below.
<table>
<thead>
<tr>
<th>Dyestuff</th>
<th>Chemicals and auxiliaries / typical application conditions</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive</td>
<td>pH 9.5-11.5 by addition of sodium carbonate and/or sodium hydroxide. Salt is used to increase dye bath exhaustion: higher concentrations are used for low-affinity dyes and for deep shades. Application temperatures vary from 40 °C to 80 °C depending on the class of the dyestuff. In padding processes, urea or cyanoguanidine is usually added to the pad liquor (the Econtrol® process described in Section 4.5.2.6 does not need urea). After dyeing, the material is soaped and then washed off with addition of surfactants to remove unfixed dye.</td>
<td>Batch Pad-batch Pad-steam Pad-dry</td>
</tr>
<tr>
<td>Direct</td>
<td>Salt is used to increase bath exhaustion. Mixtures of non-ionic and anionic surfactants are used as wetting/dispersing agents. After-treatment is usually necessary to improve wet-fastness (possible use of fixative cationic agents, formaldehyde condensation products).</td>
<td>Batch Pad-batch Pad-jig Pad-steam</td>
</tr>
<tr>
<td>Vat</td>
<td>Alkali and reducing agents (sodium dithionite, sulphonylic acid derivatives, thiourea dioxide, and other organic reducing agents) are applied to convert the dye to the sodium leuco-form. Poorly degradable dispersants are present in the dye formulation and are further added in other steps of the process. Levelling agents are sometimes necessary. Temperature and the amount of salt and alkali required vary according to the nature of the dye (IK, IW, IN). Dye is fixed to the fibre by oxidation, generally using hydrogen peroxide, but halogen-containing oxidising agents can also be used. After-treatment takes place in a weakly alkaline detergent liquor at boiling temperature. In continuous processes, anti-migration and wetting agents are used.</td>
<td>Batch Pad-steam</td>
</tr>
<tr>
<td>Sulphur</td>
<td>Reducing agents (Na₂S, NaHS, glucose-based combination of reducing agents) and alkali are applied to convert the dye into soluble form, unless ready-for-use dyes are used. Dispersants and complexing agents are used in batch dyeing. In batch dyeing, the dye generally absorbs at 60-110 °C, while in the pad-steam process the material is padded at 20-30 °C and then subjected to steaming at 102-105 °C. Oxidation is carried out mainly with hydrogen peroxide, bromate and iodate.</td>
<td>Batch Pad-steam Pad-dry Pad-steam</td>
</tr>
<tr>
<td>Azoic</td>
<td>Preparation of the naphtholate (caustic soda and, in some cases, addition of formaldehyde is required to stabilise the naphthol on the fibre). Impregnation of the naphtholate by exhaustion or padding processes. Preparation of the diazoised base (with NaNO₃ and HCl). Developing stage (the textile is passed through the cold developing bath or the developing solution is circulated through the stationary textile in the dyeing machine).</td>
<td>Batch Padding methods</td>
</tr>
</tbody>
</table>
2.7.3.1 Reactive dyes

One third of dyes used for cellulose fibres today are reactive dyes. They are mostly applied in the pad-batch and continuous processes for woven fabric, while batch processes are the most common for knitted fabric, loose stock and yarn.

In batch dyeing, dye, alkali (sodium hydroxide or sodium carbonate or bicarbonate) and salt are added to the dye bath in one step, at the start of the process, or stepwise. In the stepwise process, the alkali is added only after the dye has absorbed into the fibre. Its amount is determined by the reactivity of the system and the desired depth of shade (cold dyes are applied at lower pH compared to warm and hot dyes). Salt is added to improve bath exhaustion: the concentration employed depends on the substantivity of the dye and on the intensity of the shade. Higher concentrations are required for deep shades and low-affinity dyes, as shown in the Table 2.8 below.

### Table 2.8: Salt concentration required for reactive dyes

<table>
<thead>
<tr>
<th>Shade</th>
<th>High-affinity dyes</th>
<th>Low-affinity dyes</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.5 %</td>
<td>10-30 g/l NaCl</td>
<td>Up to 60 g/l NaCl</td>
</tr>
<tr>
<td>&gt; 4 %</td>
<td>~ 50 g/l NaCl</td>
<td>Up to 80-100 g/l NaCl</td>
</tr>
</tbody>
</table>

Source: [186, Ullmann's, 2000], [11, US EPA, 1995]

After dyeing, the liquor is drained off and the material is rinsed and then washed off with the addition of auxiliaries.

In pad dyeing processes, dye and alkali can be added together to the dye liquor or in separate steps into two separate padders (or other types of application systems). When all the chemicals are applied in one step, the stability of the pad liquor is important. In fact, with increasing reactivity of the dye there is a risk that the dye, after a long dwell time in the pad box, will be hydrolysed by the alkali, before reacting with the fibre. For this reason, dye and alkali are commonly metered separately into the padder. In addition, pad boxes are now constructed so that the liquor volume is as low as possible, so that it and is replaced on average within 5 minutes [186, Ullmann's, 2000].

Among semi-continuous processes the cold pad-batch is by far the most important one for reactive dyes. After the textile has been padded with highly concentrated dye and alkali, it is rolled up into batches. Fixing takes place during storage. Scouring or dyeing actions are accomplished effectively during this low-temperature fixation. Compared with conventional processing, the cold pad-batch system reduces reliance on large volumes of heated water for application of chemicals and dyes. Furthermore, no salt is required for reactive dyeing. [162, Cotton Incorporated 2009]

In continuous processes, padding, fixing, washing-off and drying are carried out in the same process-line. Fixation is commonly achieved either by dry-heating or by steaming. The following processes are commonly used:

- pad-steam processes (one common method is the pad-dry-pad-steam process which includes dye application by padding - intermediate drying - alkali application by padding - dye fixation with saturated steam - washing - drying);
- pad-dry thermofix processes (dye and alkali are padded at the same time; then the material can be dried and fixed in a single step or it can be thermofixed after an intermediate drying stage).

In all cases, after fixation the material is always carefully washed off in open-width or in a rope washing machine to completely remove the hydrolysed colourant and is then dried.
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In pad-dry thermofix processes, urea is usually added to the padding liquor to act as a solvent for the dye during fixation. Urea melts at 115 °C and binds water above 100 °C. It can therefore be used as solvent for the dye in dry heat. A recently developed dyeing process is now available that does not require the addition of urea (see Section 4.5.2.6).

Urea is also sometimes used in pad-batch processes as dyeing solvent to increase the solubility of the dye. As early as 1992 the use of urea as dyeing solvent was already in decline [61, L. Bettens, 1999]. New highly soluble reactive dyes have been introduced in the market which do not need urea even for deep dyeing in with highly concentrated dye liquor.

2.7.3.2 Direct dyes

Direct dyes are also quite important in cellulose fibre dyeing: 75% of the total consumption of these colourants is used, in fact, to dye cotton or viscose substrates [186, Ullmann's, 2000].

Direct dyes are applied directly from the dye bath together with salt (sodium chloride or sodium sulphate) and auxiliary agents, which ensure a thorough wetting and dispersing effect. Mixtures of non-ionic and anionic surfactants are used for this purpose.

In the batch process the dye is made into paste, then dissolved in hot water and added to the dye bath. The electrolyte is then added to the dye bath. After the dye bath has been drained, the fabric is washed with cold water and generally subjected to after-treatment.

Pad processes encompass the following techniques:

- pad-steam;
- pad-roll;
- cold pad-batch;
- pad-jig process (the material is padded with the dye and then passed through a salt liquor in a jigger).

In all processes the material is rinsed at the end with cold water.

With increasing depth of colour the wet-fastness can decrease to such an extent that after-treatment must generally be carried out [186, Ullmann's, 2000]. Two methods exist:

- removing the unfixed dye by washing with complexing agents or surfactants with a dispersing effect;
- reducing the solubility of the dye by blocking the hydrophilic groups (‘enlargement of the molecule’).

Various techniques can be applied to achieve this enlargement of the molecule. Namely, the dyed textile can be treated with the following:

- Fixative cationic agents: these are complex substances that form with the anionic dye a salt-like compound less soluble than the original dye. Quaternary ammonium compounds with long hydrocarbon chains, polyamines and polyethylenimine derivatives can be used for this purpose.
- Metal salts: copper sulphate and potassium dichromate can form with certain azo dyes metal complexes with higher light-fastness.
- Agents based on formaldehyde condensation products with amines, polynuclear aromatic phenols, cyanamide or dicyandiamide (the use of these condensation products leads to the formation of sparingly soluble adducts with the dye molecules).
Diazotised bases: after dyeing, the material is subjected to diazotisation and is then coupled with aromatic amines or phenols that do not contain hydrosolubilising groups [186, Ullmann's, 2000]. Environmental concerns arise when after-treating with formaldehyde condensation products or metal salts. The method using fixative cationic agents is, therefore, the most frequently applied. However, quaternary ammonium compounds are often non-biodegradable, fish-toxic to fish and contain nitrogen.

2.7.3.3 Vat dyes

Vat dyes have excellent fastness properties when properly selected and are often used for fabrics that will be subjected to severe washing and bleaching conditions (towelling, industrial and military uniforms, etc.).

Vat dyes are normally insoluble in water, but they become water-soluble and substantive for the fibre after reduction in alkaline conditions (vatting). They are then converted again to the original insoluble form by oxidation and in this way they remain fixed into the fibre.

When applying vat dyes in batch processes, the textile is dyed very rapidly and unevenly due to the high affinity of the dye. Nevertheless, level dyeing can be achieved by:

- adding levelling agents;
- increase of the temperature under a controlled profile (‘high-temperature’ process and ‘semi-pigmentation’ method);
- impregnation of the textile with the dye as water-insoluble dispersion, followed by addition of the reductive agent in a subsequent step (pre-pigmentation process).

In all cases, oxidation and after-treatment follow. After-treatment consists of washing the material in a weakly alkaline bath with a detergent at boiling temperature.

Continuous processes are used almost exclusively for dyeing woven fabrics and to only a small extent for knitwear. The most commonly applied continuous process is the pad-steam process. The textile is padded with the aqueous dye dispersion in the presence of anti-migrant (polyacrylates, alginates, etc.) and dispersing/wetting agents, if required. After drying, the fabric is passed through a chemical padder, which contains the required amount of alkali and reducing agent, and is fed immediately to a steamer. The material is finally rinsed, oxidised and soaped in an open-width washing machine.

A more rapid, one-step process is also possible (see Section 4.5.4.2), but only for pastel to pale shades.

Voluminous open fabrics can be dyed according to a wet-steam process. Unlike the pad-steam process, this process does not require intermediate drying before steaming.

The following chemicals and auxiliaries are applied in vat dyeing:

- Reducing agents: mainly sodium dithionite (hydrosulphite) and sulphoxylic acid derivatives (zinc sulphoxylate). The latter, in particular, is used when the pad-steam process is applied. Sulphur-free organic reducing agents such as hydroxyacetone are also now available for some applications.
- Oxidising agents, such as hydrogen peroxide, perborate, or 3-nitrobenzenesulphonic acid.
- Alkali (caustic soda).
- Salt.
Dispersing agents: they are already present in the dye formulation and are further added in the subsequent steps of the dyeing process.

Levelling agents: they form adducts with the dye, thus retarding its absorption into the fibre.

2.7.3.4 Sulphur dyes

Sulphur dyes are used in piece dyeing (cellulose and cellulose-polyester blends), yarn dyeing (sewing thread, warp yarn for denim fabric, yarn for coloured woven goods), dyeing of flock, card sliver (wool-man-made-fibre blends) [186, Ullmann's, 2000].

Like vat dyes, sulphur dyes are insoluble in water, and, under alkaline conditions, are converted into the leuco-form, which is water-soluble and has a high affinity for the fibre. After absorption into the fibre, the colourant is oxidised and converted to the original insoluble state. The reducing agent, salts, alkali and unfixed dye are finally removed from the fibre by rinsing and washing.

Mostly continuous dyeing methods are applied, although batch dyeing (jigger, jet, and winch beck) is also possible.

In continuous processes the material is impregnated with dye, reducing agent and wetting agent through a one-bath or a two-bath procedure. With the one-bath procedure (pad-steam process), the reducing agent and the dye are added at the same time. With the two-bath procedure (pad-dry/pad-steam), the material is padded in the liquor containing the dye and the wetting agent, while the reducing agent is applied, if necessary, in a second step, after intermediate drying. The material is then submitted to air-free steaming. After that, rinsing, oxidation and re-rinsing are carried out.

Because the exhaustion is not too high, it is possible to reuse dye baths in continuous processes.

Chemicals and auxiliaries applied to the substrate during the dyeing process are as follows:

- Reducing agents: sodium sulphide, sodium hydrosulphide and thiourea dioxide are the most commonly employed (although their use has decreased over the past decades [281, Belgium, 2002]). Binary systems made of glucose and sodium dithionite, hydroxyacetone and glucose or formamidine sulphonic acid and glucose are also used as alternative reducing agents (see Section 4.5.2.1).
- Alkali (caustic soda).
- Salt.
- Dispersing agents (they are necessary in the process steps in which the pigment has not yet been reduced or has been re-formed by oxidation).
- Complexing agents: EDTA or polyphosphates are used in some cases, especially in circulating liquor dyeing to avoid the negative effects of alkaline-earth ions on dyeing.
- Oxidising agents: mainly hydrogen peroxide and halogen-containing compounds such as bromate, iodate and chlorite.

2.7.3.5 Azoic dyes (naphthol dyes)

Naphthol AS-dyes allow colours with outstanding fastness, but their popularity has declined because of application costs and the complexity of the process for the preparation of the colourant [77, EURATEX, 2000].
Dyeing with azoic colourants is a complex process which involves a number of delicate steps:

- Preparation of the naphtholate solution by the hot solution process (the naphthol is dissolved by boiling with caustic soda) or by the cold solution process (the naphthol is solubilised with alcohol or cellosolve, caustic soda and cold water). For certain naphthols, the addition of formaldehyde is also necessary to prevent the formation of free naphthol.
- Application of the naphtholate to the fibre by batch or padding techniques.
- Preparation of the diazotised base by reaction with sodium nitrite and hydrochloric acid (this step can be avoided when using fast-colour-fast salts).
- Formation of the azoic dye into the fibre, by passing the textile, previously impregnated with the naphtholate solution, through a bath containing the diazotised base or the fast colour-fast salt (addition of buffering agents is necessary to control the pH, in order to increase the coupling capacity).
- After-treatment by rinsing the material to remove the excess naphthol from the fibre.

### 2.7.4 Wool dyeing

Wool can be dyed with the following dyestuffs:

- acid (metal-free) dyes;
- chrome dyes;
- 1:1 and 1:2 metal complex dyes;
- reactive dyes.

The most common dyestuffs and dyeing techniques for wool fibres are summarised in Table 2.9 and are described in more detail further below.
Table 2.9: Summary of the most common dyestuffs and dyeing techniques for wool fibres

<table>
<thead>
<tr>
<th>Dyestuff</th>
<th>Chemicals and auxiliaries / typical application conditions</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid dyes (metal-free)</td>
<td>Strongly acidic conditions for equalising dyes (by formic acid). Moderately acidic conditions for half-milling dyes (by acetic acid). More neutral conditions for milling dyes (by acetic acid and sodium acetate or ammonium sulphate). Salt: sodium sulphate or ammonium sulphate. Levelling agents other than sulphate and formic acid are not necessary for level-dyeing colourants.</td>
<td>Batch dyeing</td>
</tr>
<tr>
<td>Chrome dyes (mordant)</td>
<td>pH 3 to 4.5. Sodium sulphate. Organic acids: acetic and formic acid (tartaric and lactic acids can also be used). Reducing agent: sodium thiosulphate. After-chrome with Na or K dichromate.</td>
<td>Batch dyeing (After-chrome method)</td>
</tr>
<tr>
<td>1:1 metal-complex dyes</td>
<td>pH 1.8 to 2.5 (pH 2.5 in the presence of auxiliary agents such as alkanolethoxylates). Sulphuric or formic acid. Salt: sodium sulphate. Ammonia or sodium acetate can be added to the last rinsing bath.</td>
<td>Batch dyeing</td>
</tr>
<tr>
<td>1:2 metal-complex dyes</td>
<td>pH 4.5 to 7. Ammonium sulphate or acetate. Levelling agents (non-ionic, ionic and amphoteric surfactants).</td>
<td>Batch dyeing</td>
</tr>
<tr>
<td>Reactive dyes</td>
<td>pH 4.5 to 7. Formic or acetic acid. Levelling agent. After-treatment with ammonia for highest fastness.</td>
<td>Batch dyeing</td>
</tr>
</tbody>
</table>

2.7.4.1 Acid dyes

Acid dyes are typically applied in acidic conditions, but the pH range used varies depending on the type of acid dye. The greater the affinity of the dyestuff for the fibre, the more the hydrophobic interaction must be repressed by applying the dye at higher pH.

Therefore level-dyeing colourants are applied under strongly acidic conditions (1-3 % formic acid) in the presence of sulphate ions (5-10 % sodium sulphate) to assist migration and levelling. HCOOH and HSO₄⁻ compete with the sulphonated dyes acting as levelling agents. As a result, other levelling agents are not generally required and the rate of dye uptake is controlled initially by increasing the temperature of the dye bath slowly (1 °C/min) and then extending the time at the boil to allow the dye to migrate from areas of high initial uptake.

Fast acid dyes (also known as half-milling dyes or perspiration-fast dyes) exhibit superior fastness properties to level-dyeing acid dyes, while retaining some of the migration properties. Application is from a moderately acidic dye bath (1-3 % acetic acid) in the presence of sodium sulphate (5-10 %) and levelling agent to assist migration.

Acid milling dyes (including 1:2 metal-complex dyes mentioned later) have good affinity for the fibre and do not migrate well at the boil. They are therefore applied at more neutral pH (5-7.5 with acetic acid) in the presence of sodium acetate (2 g/l) or ammonium sulphate (4 %) and levelling agent (1-2 %). Sodium sulphate is usually avoided as it has little effect on migration and can promote uneven dye adsorption.

Levelling agents play an important role in acid dyeing. A number of non-ionic, cationic, anionic and amphoteric surfactants belong to this category.
2.7.4.2 Chrome dyes

A number of techniques have been developed for the application of chrome dyes. The *Chrome mordant* process relies on chroming the fibre prior to dyeing with a chromable dye; the *Metachrome* process applies both dye and chromium salt simultaneously. Both processes have been largely superseded by the *Afterchrome* process in which the dye is applied first and the fibre is then chromed in a separate step, utilising the exhausted dye bath and thus conserving water.

Application of the dyestuff takes place from a moderately acidic dye bath (1% acetic acid), often with an addition of formic acid towards the end of the boiling period to promote exhaustion of the dye. The dye bath is then cooled back from the boil to approx. 80 °C, the pH is lowered to approximately 3.5 with formic acid and the pre-dissolved chromium salt added. The dye bath is then returned to the boil and boiling continued for 20-30 minutes. Chromium is added to the dye bath as either sodium or potassium dichromate. In solution the chroming species present vary according to pH, with the dichromate anion $\text{Cr}_2\text{O}_7^{2-}$ predominating at pH between 3 and 7. Although it is the chromium (VI) anion which is initially adsorbed by the wool, the dye complex is formed with chromium (III), formed by the action of reducing groups in the fibre itself. Strong acids have an activating effect on this process; organic acids (tartaric, lactic, formic acid) or thiosulphate can also be used to enhance the degree of conversion of Cr(VI) (see also Section 4.5.3.1).

It is to be noted that both sodium and potassium dichromate are listed in Annex XIV to REACH [79, EU 2006], which means that in the EU an authorisation is necessary to use these substances.

2.7.4.3 Metal-complex dyes

Application of *1:1 metal-complex dyes* (i.e. one metal ion is joined to one dye molecule) is carried out at pH 1.8-2.5 with sulphuric acid or at pH 3-4 with formic acid, in the presence of sodium sulphate (5-10%) and other organic levelling agents. Owing to these particular operating conditions, this class of dyestuffs is particularly suitable for piece-dyeing of carbonised wool.

*1:2 metal-complex dyes* (i.e. one metal ion is joined to two dye molecules) form the most important group in this class and may be divided into two subgroups: weakly polar and strongly polar 1:2 complexes. Application is usually carried out in moderately acidic conditions:

- pH range 4-7 (with acetic acid) in the presence of ammonium acetate, for weakly polar complexes;
- pH range 5-6 (with acetic acid) in the presence of ammonium sulphate, for strongly polar complexes.

The use of levelling agents is very common when dyeing with metal-complex dyes. The groups of substances used for acid dyes also apply in this case.

2.7.4.4 Reactive dyes

Reactive dyes are generally applied at pH values of between 5 and 6, depending on the depth of shade, in the presence of ammonium sulphate and specialised levelling agents (amphoteric substances, which form complexes with the dye at low dye bath temperatures and then break down as the dyeing temperature increases).
Chapter 2

The dyeing method may include a temperature hold step at 65-70 °C, during which the dye bath is maintained at this temperature for 30 minutes in order to allow the dye to migrate without fibre reaction. When dyeing of the very highest fastness is required, the fibre is rinsed under alkali conditions (pH 8-9 with ammonia) to remove unreacted dyestuff.

2.7.5 Silk dyeing

Silk is dyed with the same dyes as wool, excluding 1:1 metal complex dyes. In addition, direct dyes can be used. The dyeing pH is slightly higher than with wool. For reactive dyeing, 20-60 g/l of salt and 2-5g/l of soda ash is needed for fixation [294, ETAD, 2001].

For more a detailed description, reference is made to the “Wool dyeing” section.

2.7.6 Synthetic fibres dyeing

2.7.6.1 Polyamide fibres

Polyamide fibres (PA 6 and PA 6.6) are easily dyed with various types of dyes. Due to their hydrophobic characteristics, they can be dyed with disperse dyes (non-ionic), whereas thanks to the presence of the groups NH-CO- and NH2- in the polymer chain, acid, basic, reactive and 1:2 metal-complex dyes (ionic) can also be used. However, in practice, acid levelling dyes are increasingly used.

The most common dyestuffs and dyeing techniques for polyamide fibres are summarised in Table 2.10 and are described in more detail further below.

<table>
<thead>
<tr>
<th>Dyestuff</th>
<th>Chemicals and auxiliaries / typical application conditions</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disperse</td>
<td>PH 5 by acetic acid. Dispersing agents (sulphoaromatic condensation products or non-ionic surfactants). Dyeing is conducted at near-boiling temperature.</td>
<td>Batch</td>
</tr>
<tr>
<td>Acid dyes</td>
<td>pH conditions from acid to neutral depending on the affinity of the dye. Optimal bath exhaustion and level dyeing are achieved by either pH or temperature control methods (levelling agents are also used). In the acidic range, electrolytes retard the exhaustion. With levelling dyes, wet-fastness is often unsatisfactory and after-treatment with synthanes can be necessary.</td>
<td>Batch</td>
</tr>
<tr>
<td>1:2 metal-complex dyes</td>
<td>Dyes containing sulphonic groups are preferred because they are more water-soluble and produce better wet-fastness. To improve absorption of low-affinity dyes (especially for disulphonic), dyeing is carried out in weakly acidic conditions using acetic acid. High-affinity dyes are applied in a neutral or weakly alkaline medium using amphoteric or non-ionic levelling agents.</td>
<td>Batch</td>
</tr>
<tr>
<td>Reactive dyes</td>
<td>In principle the reactive dyes used for wool are also suitable for PA. Dyeing is conducted at near-boiling temperature in weakly acidic conditions. After-treatment is performed at 95 °C using a non-ionic surfactant and sodium bicarbonate or ammonia.</td>
<td>Batch</td>
</tr>
</tbody>
</table>
Before dyeing, fabrics must be pre-fixed to compensate for material-related differences in affinity and to reduce the sensitivity to creasing during the dyeing process. Prefixing can be performed in a stenter frame.

2.7.6.1.1 Disperse dyes

Disperse dyes used for polyamide fibres are mainly azo compounds and anthraquinones. They are applied especially for lighter shades.

The material is dyed in acidic conditions (pH 5) by acetic acid. A dispersing agent is always added to the liquor.

2.7.6.1.2 Acid dyes

As with acid dyeing of wool, with increasing dye affinity, the hydrophobic interaction in the initial phase must be repressed to achieve uniform absorption. This means that for high-affinity dyes the liquor must be sufficiently alkaline at the start and then slowly decreased to optimise exhaustion. The level of acidity of the liquor is regulated either by dosing with acids during dyeing or by adding acid donors (e.g. ammonium sulphate, sodium pyrophosphate or esters of organic acids) at the start of the process (see also Section 4.5.1.5).

Optimal exhaustion and uniform dyeing can also be achieved by controlling the temperature profile.

Auxiliary agents (anionic, cationic, non-ionic surfactants) are normally used to improve the levelling effect.

The wet-fastness of dyeing with acid dyes on polyamide fibres is often unsatisfactory. After-treatment with syntans (synthetic tanning agents) is often necessary. The syntans are added to the exhausted bath or to fresh liquor at pH 4.5 by formic or acetic acid. The material is treated at 70-80 °C and is then rinsed.

2.7.6.1.3 Metal-complex dyes

Among 1:2 metal-complex dyes, molecules containing sulphonic groups are the most suitable for polyamide fibres.

The absorption of the dye increases with decreasing pH. Dyeing conditions vary from weakly acidic by addition of ammonium sulphate and acetic acid to neutral or moderately alkaline for high-affinity dyes. For high-affinity dyes, amphoteric or non-ionic levelling agents are usually added.

2.7.6.1.4 Reactive dyes

In principle, the reactive dyes used for wool are also suitable for polyamide. The dyeing process is carried out in weakly acidic conditions (pH 4.5-5). The process is started at 20-45 °C and then the temperature is increased near to boiling. Non-ionic surfactants and sodium bicarbonate or ammonia are used in the after-treatment step.

2.7.6.2 Polyester fibres

Articles made of pure PES are dyed almost exclusively using batch dyeing techniques and, among these, dyeing under high-temperature conditions is the most commonly applied. The
most common dyestuffs and dyeing techniques for polyester fibres are summarised in Table 2.11 below.

Dyeing polyester fibres under atmospheric conditions (below 100 °C) was also frequently done in the past with the aid of carriers. Since these substances are ecologically harmful (see Section 2.7.8.1 and Section 8.6.7), dyeing below 100 °C is no longer in use today for pure PES fibres, unless carrier-free dyeable fibres are employed (see Section 4.5.4.1).

Concerning high-temperature dyeing, the process is usually carried out in acidic conditions (pH 4-5) with addition of acetic acid under pressure at 125-135 °C. In these conditions, levelling agents are necessary to prevent excessively rapid absorption.

Provided that alkali-stable dyes are used, dyeing in an alkaline medium (pH 9-9.5) is also possible. This technique has been developed in order to counteract the migration and deposition of oligomers typical of PES fibres (see Section 2.1.1.1). In fact, oligomeric components (cyclic trimers of ethylene terephthalate are especially harmful) tend to migrate out of the fibre during dyeing, thus forming with the dye agglomerates that can deposit on the textile or on the dyeing equipment. To achieve level effects, ethoxylated products are used as levelling agents.

The thermosol process is another applied technique, although it is primarily used for PES/cellulose blends. The dye is padded on the textile together with an anti-migration agent. A drying step at 100-140 °C is carried out. Then the dye is fixed (200-225 °C for 12-25 seconds).

For light shades, the material needs only to be rinsed or soaped after dyeing. For dark shades, in order to ensure high light-fastness, an after-clearing step is normally necessary. This usually consists of an alkaline reductive treatment followed by post-rinsing in weakly acidic conditions. Information about alternative processes is reported in Section 4.5.4.2.

PES fibres can be dyed with cationic dyestuffs, provided that acidic components (e.g. sulphated aromatic polycarboxylic acid) are used as co-monomers during the manufacturing of the fibre (creation of anionic sites).

<table>
<thead>
<tr>
<th>Table 2.11: Summary of the most common dyestuffs and dyeing techniques for polyester fibres</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dyestuff</strong></td>
</tr>
<tr>
<td>Disperse</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**2.7.6.3 Acrylic fibres**

So-called PAC fibres are hydrophobic and contain anionic groups in the molecule. As a result, they can be dyed with disperse and cationic dyes. With the introduction of cationic co-monomers in the polymer, the fibre can also be dyed with acid dyes.
The most common dyestuffs and dyeing techniques for polyamide fibres are summarised in Table 2.12 and are described in more detail further below.

### Table 2.12: Summary of the most common dyestuffs and dyeing techniques for polyacrylic fibres

<table>
<thead>
<tr>
<th>Dyestuff</th>
<th>Chemicals and auxiliaries / typical application conditions</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disperse</td>
<td>Dyeing conditions correspond to those used for polyester. Addition of carriers is not required.</td>
<td>See Table 2.11</td>
</tr>
<tr>
<td>Cationic</td>
<td>Acetic acid (pH 3.6-4.5). Salt (sodium sulphate or sodium acetate). Retardant auxiliaries (usually cationic agents). Non-ionic dispersing agents.</td>
<td>Batch</td>
</tr>
<tr>
<td></td>
<td>Acetic acid (pH 4.5). Dye solvent. Steam-resistant, readily-soluble dyes (usually liquid) are required.</td>
<td>Pad-steam process with pressurised steam</td>
</tr>
<tr>
<td></td>
<td>Dye solvent. Rapidly diffusing dyes are required.</td>
<td>Pad-steam process with saturated steam</td>
</tr>
</tbody>
</table>

*Batch dyeing* is commonly applied for cable or stock (package dyeing), yarn in hank form or packages and for fabric. Piece dyeing can be performed on beam, overflow, paddle (for knitwear, ready-made bath sets), or drum (for socks).

Stock, cable and top can also be dyed on special machines, using the pad-steam process, preferably with pressurised steam to obtain short fixing times. Piece goods, especially upholstery material (velour), are also dyed according to the pad-steam process, but in this case fixing is carried out with saturated steam. This implies longer fixing times, which means that rapidly diffusing cationic dyes and dye solvents are required.

#### 2.7.6.3.1 Disperse dyes

Disperse dyes are used to produce light to medium-deep shades. The dyeing techniques correspond to those used on polyester fibres. However, dyeing can be performed at temperatures < 100 °C without carriers. Furthermore, due to the good migration properties of disperse dyes, levelling agents are not required.

#### 2.7.6.3.2 Cationic dyes

Typical recipes used in *batch dyeing* include an electrolyte (sodium acetate or sodium sulphate), acetic acid, a non-ionic dispersant and a retarding agent. Dyeing is conducted by controlling the temperature in the optimum range for the treated fibre. Finally, the bath is cooled down and the material is rinsed and submitted to after-treatment.

*Continuous processes* commonly applied are as follows:

- Pad-steam process (fixation with pressurised steam at more than 100 °C) - this process has the advantage of reducing the fixing time. Pad liquor typically contains a steam-resistant cationic dye, acetic acid and a dye solvent.
- Pad-steam process (fixation with saturated steam at 100-102 °C) - this process requires a longer fixing time. Rapidly diffusing cationic dyes and dye solvents, which exhibit a carrier effect, are required.
When dyeing with basic dyes, special levelling agents (also called retarding agents) are widely used to control the absorption rate of the colourant on the fibre, thus improving level dyeing.

### 2.7.6.4 Cellulose acetate (CA) and cellulose triacetate (CT)

In contrast to the other regenerated cellulose fibres, CA and CT are hydrophobic and therefore they can be dyed with disperse dyes under conditions which are very similar to those applying to PES fibres.

Cellulose acetate is dyed by the exhaustion method with disperse dyes in the presence of non-ionic or anionic dispersing agents in weakly acidic conditions (pH 5-6). Dyeing is normally done at 80-85 °C. However, a series of less wet-fast dyes already absorb onto the fibre at 50-60 °C, whereas more wet-fast dyes require temperatures up to 90 °C.

Compared to CA, CT dyeing and finishing characteristics are more similar to purely synthetic fibres. CT, like CA, is dyed with disperse dyes in a weakly acidic medium in the presence of levelling auxiliaries. Applied dyeing techniques for CT are:

- batch dyeing process, usually at 120 °C, but if these conditions are not possible a dyeing accelerant (based on butyl benzoate or butyl salicylate) is required;
- thermosol process.

### 2.7.7 Fibre blends dyeing

Natural/synthetic fibre blends are becoming more and more important in the textile industry because this allows the favourable technological properties of synthetic fibres to be combined with the pleasant feel of natural fibres.

Of the worldwide consumption of PES fibres, 55-60 % is used in blends with cellulose fibres or wool. About 40 % of polyamide is used in blends, while 50 % of polyacrylic fibres is used especially in blends with wool for knitwear [186, Ullmann's, 2000].

Fibre blends can be produced according to three different methods:

- fibres of different types in the form of staple fibres are mixed at the yarn manufacturing stage, during spinning;
- fibres of different types are separately spun and the resulting yarns are wound together to give a mixed yarn;
- fibres of different types are separately spun and combined together only at the weaving stage where one or more fibre yarns are used as warp and the other ones as weft.

Dyeing of blend fibres is always longer and more difficult as an operation compared to pure fibre dyeing. Despite these disadvantages, dyeing tends to be placed as close as possible towards the end of the finishing process. In fact, this enables the dyer to satisfy the requests of the market without the need to store large amounts of material already dyed in flock or yarn form in all available shades.

When dyeing blend fibres, the following methods can be applied:

- the two fibres are dyed in the same tone ("tone on tone") or in two different shades using the same dyes;
- only one fibre is dyed (the colourant is not absorbed by the other ones);
- the different fibres are dyed in different tones.
For ‘tone on tone’ dyeing, it is sometimes possible to use the same dye for the different fibres. When dyes of different classes have to be employed, the dyeing process is easier to control when the selected colourants have affinity only for one fibre and not for the other one. In reality, however, this situation is exceptional and the dyeing of fibre blends remains a complex operation.

Blend fibre dyeing can be done in batch, semi-continuous and continuous processes. Batch processes include:

- dyeing in one bath and one step (all dyes are added in the same bath in one single step);
- dyeing in one bath and in two steps (dyes are added to the same bath in subsequent steps);
- dyeing in two baths (dyes are applied in two steps in two different baths).

The most common fibre blends will be discussed in the following sections.

2.7.7.1 Polyester-cellulose blends

A large part of the entire production of PES (circa 45%) is used to make this mixture. Polyester-cellulose blends are used for all types of clothing and for bed linen. The cellulose component is usually cotton, but viscose staple fibres and occasionally linen are also used. The preferred mixing ratio is 67:33 PES to cellulose (for textiles worn close to the skin), 50:50 and 20:80 [186, Ullmann’s, 2000].

In dyeing PES-cellulose mixtures, disperse dyes are used for the polyester component, while the cellulose portion is usually dyed with reactive, vat and direct dyes. Pigment dyeing is also commonly used for light shades.

Disperse dyes stain cellulose fibres only slightly and they can easily be removed by subsequent washing or, if necessary, by reductive after-treatment. Most of the dyes used for cellulose only stain PES slightly or not at all.

PES-cellulose blends are commonly dyed in continuous processes. Nevertheless, for yarn and knitwear, batch dyeing is of major importance.

In batch dyeing, the application of dyes can be done in one or two steps in one bath or in two different baths in subsequent stages. The disperse dye is generally applied at high-temperature (HT) conditions without the use of carriers.

In the one-bath/one-step procedure, special auxiliaries, so-called acid donors, are used, which lower the pH when the temperature is increased. In this way, it is possible to fix the reactive dyes in alkaline conditions and then reach the optimal dyeing conditions (pH 5-6) for disperse dyes by increasing the temperature. Alternatively, it is advantageous to operate at pH 8-10 using alkali-stable disperse dyestuffs, which also avoids oligomer problems.

The one-bath/one-step procedure is preferred, being more economical, but presents more difficulties. For example, the presence of salt increases the tendency of disperse dyes to stain the cotton fibre of the blend. Recently developed low-salt reactive dyes are claimed to show good performance and high reproducibility in this application (see Section 4.5.2.4).

In continuous processes the dyes are usually applied in one bath. The fabric is subsequently dried and disperse dye is fixed to the PES component by the thermosol process. Afterwards, the second dye is developed according to the procedure typical of each class of dye, using in general pad-steam, pad-jig or pad-batch processes.

Table 2.13 presents a summary of the most frequently applied processes. Dyes are applied according to application conditions typical of their class. More details regarding a given class of colourant, see the specific section.

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Table 2.13: Summary of the most common dyestuffs and dyeing techniques for polyester-cellulose blends

<table>
<thead>
<tr>
<th>Technique</th>
<th>Disperse /vat</th>
<th>Disperse/reactive</th>
<th>Disperse/direct</th>
<th>Pigment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch</td>
<td>NA</td>
<td>NA</td>
<td>Y K</td>
<td>W (1)</td>
</tr>
<tr>
<td>One-bath process</td>
<td>NA</td>
<td></td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Two-bath process</td>
<td>NA</td>
<td>Y K</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>One-bath two-step process</td>
<td>Y K</td>
<td>Y K</td>
<td>Y K</td>
<td>NA</td>
</tr>
<tr>
<td>Continuous</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I stage</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>II stage</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Application of all dyes in one bath by padding + drying followed by:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermosol + pad-jig</td>
<td>W</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Thermosol + pad-batch</td>
<td>NA</td>
<td>W</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Thermosol + pad-steam</td>
<td>W</td>
<td>W</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

(1) Pigment dyeing includes padding with the pigment, a binder and auxiliaries, drying and polymerisation at 140 °C for 5 min.

2.7.7.2 Polyester-wool blends

Polyester-wool blends are widely used, especially for woven goods and knitwear. The most frequently found ratio is 55:45 PES to wool. Wool cannot be dyed at the high temperatures typical of the HT dyeing process for PES fibres and PES-cellulose blends. The dyeing time should also be as short as possible so that the wool is not damaged. For large production volumes, it is therefore preferable to dye wool and PES separately in top, blending the two fibres at the yarn manufacturing stage. However, quick changes in fashion and short-term planning frequently do not allow separate dyeing.

When dyeing polyester-wool blends, disperse dyes are used for polyester and anionic (acid and metal-complex dyes) for wool.

Only disperse dyes that stain wool as slightly as possible or are easily removed by washing can be used for dyeing wool-polyester blends. Disperse dyes, in fact, tend to stain wool and a reductive after-treatment is not always possible (appropriately stable dyes are required).

PES/wool blends are typically dyed according to the following batch processes:

- at boiling temperature with carriers;
- at 103-106 °C with little carrier;
- at 110-120 °C with the addition of formaldehyde as a wool protective agent and with low amounts of carriers or none at all (HT conditions).

Because of the environmental concerns associated with the use of carriers (see Sections 8.6.7 and 0), the first dyeing technique is avoided when possible. In this respect, carrier-free dyeable fibres are also available, which can be dyed at boiling temperature without the use of carriers (see Section 4.5.4.1 for more information about carrier-free dyeable fibres and Section 4.5.4.1 for environmentally optimised carriers).

The one-bath process method is preferred in practice; the two-bath process is applied when deep shades and high fastness are required. The material is first dyed with disperse dyes. A reductive intermediate treatment may be applied before dyeing the wool part. In both dyeing methods, after dyeing, an after-treatment is applied to remove any disperse dye attached to the wool, if the
dye used for wool can withstand it. The material is treated with ethoxylated fatty amine in weakly acidic liquor at 60 °C.

### 2.7.7.3 Polyamide-cellulose blends

Since PA fibres have an affinity for almost all dyes used for cellulose, different possibilities are available for dyeing this blend:

- direct and disperse dyes (pH 8);
- acid or 1:2 metal-complex dyes (pH 5-8);
- vat dyes (exhaust and pad-steam process are used);
- reactive dyes.

Application conditions are those typical of each class of dye, as described in Sections 2.7.3 to 2.7.6. They have already been described in the specific sections.

### 2.7.7.4 Polyamide-wool blends

Blends with polyamide to wool ratios varying from 20:80 to 60:40 are used. This blend is particularly important in the carpet sector. More detailed information is therefore reported in the specific section dedicated to this sector (see Section 2.13.5).

As general information about the dyeing processes suitable for this type of blend, both fibres have affinity for acid and 1:2 metal-complex dyes. However, since PA is more accessible to the dye than wool, it is dyed more deeply, particularly in the case of light colours. To counteract this effect, special levelling agents (also called PA reserving/blocking agents) are used (mainly aromatic sulphonates). These auxiliaries have a relatively high affinity for the PA fibre and retard the absorption of the colourant into this part of the blend.

Dyeing is performed in the presence of acetic acid and sodium sulphate. Due to the limited fastness of acid dyes, 1:2 metal-complex dyes are required for dark shades [186, Ullmann's, 2000].

### 2.7.7.5 Acrylic-cellulose blends

PAC-cellulose blends are used for household textiles (drapery and table linen) and imitation fur (‘peluche’, in which the pile consists of PAC fibres and the back is made of cotton). The percentage of PAC in the mixtures varies between 30 % and 80 %.

PAC can be dyed with cationic or disperse dyes, while direct, vat or reactive dyes can be used for the cellulose component.

The following methods are the most commonly used for dyeing this blend:

- **continuous dyeing** with cationic and direct dyes according to the pad-steam process (to avoid precipitation of cationic and anionic dyes present in the pad liquor at relatively high concentration, a combination of anionic and non-ionic surfactants are added to the solution);
- **batch dyeing** (usually according to the one-bath two-step method) with cationic and vat dyes or with cationic and reactive dyes.
2.7.7.6 Acrylic-wool blends

Among synthetic fibres, PAC fibres are the most suitable for obtaining blends with wool that keep a wool-like character. This makes this blend widely used, especially for knitwear and household textiles. The blending ratio of PAC to wool varies from 20:80 to 80:20.

Metal-complex, acid and reactive dyes are the dyestuffs typically used for the wool part, while PAC is dyed with cationic dyes.

Cationic dyes stain wool fibre. As a matter of fact, cationic dyes attach first to wool and then migrate to PAC fibre at higher temperature. Even if well-reserving dyes (i.e. dyeing only PAC fibres) are selected, dyeing must be conducted for a sufficiently long time (from 60 to 90 minutes) in order to obtain a good wool reserve (i.e. undyed wool) [186, Ullmann's, 2000].

PAC-wool blends can be dyed using the following exhaustion methods:

- one-bath one-step;
- one-bath two-step;
- two-bath.

The first one allows shorter dyeing times and lower consumption of water. However, it is not always applicable because the simultaneous presence in the dye bath of anionic and cationic compounds can produce the precipitation of the formed adducts on the fibre. Precipitation can be prevented using dispersing agents and selecting adequate dyes.

When dyeing with the one-bath two-step method, the use of reserve agents is not necessary. In fact, wool absorbs the cationic dye and slowly releases it, acting as a retarding agent (exerting a retardant effect on PAC).

2.7.8 Environmental issues

Potential sources and types of emissions associated with dyeing processes are summarised in Table 2.14 below.
### Table 2.14: Overview of the typical emissions generated in dyeing processes

<table>
<thead>
<tr>
<th>Operations</th>
<th>Emission sources</th>
<th>Type of emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour kitchen operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dye preparation</td>
<td>Discontinuous, low-concentration water emissions to water at the end of each batch (cleaning step)</td>
<td></td>
</tr>
<tr>
<td>Auxiliaries preparation</td>
<td>Discontinuous, low-concentration water emissions to water at the end of each batch (cleaning step)</td>
<td></td>
</tr>
<tr>
<td>Dispensing of dyes and auxiliaries (manual)</td>
<td>Indirect pollution from inaccurate dosing and handling of chemicals (spillage, poor shade repeats, etc.)</td>
<td></td>
</tr>
<tr>
<td>Dispensing of dyes and auxiliaries (automatic)</td>
<td>No emission, provided that the system is regularly calibrated and verified for accuracy</td>
<td></td>
</tr>
<tr>
<td>Batch dyeing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dyeing</td>
<td>Discontinuous, low-concentration water emissions to water at the end of each cycle</td>
<td></td>
</tr>
<tr>
<td>Washing and rinsing operations after dyeing</td>
<td>Discontinuous, low-concentration water emissions to water at the end of each cycle</td>
<td></td>
</tr>
<tr>
<td>Cleaning of equipment</td>
<td>Discontinuous, low-concentration water emissions to water</td>
<td></td>
</tr>
<tr>
<td>Semi-continuous and continuous dyeing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application of the colourant</td>
<td>No emission from the process unless the dye bath is drained</td>
<td></td>
</tr>
<tr>
<td>Fixation by steam or dry-heat</td>
<td>Continuous emission to air (generally not significant, except for specific situations such as the thermosol process, drying of carrier-dyed fabrics)</td>
<td></td>
</tr>
<tr>
<td>Washing and rinsing operations after dyeing</td>
<td>Continuous, low-concentration water emissions to water</td>
<td></td>
</tr>
<tr>
<td>Discharging of leftovers in the chassis and feed storage container</td>
<td>Discontinuous, concentrated water emissions to water at the end of each lot</td>
<td></td>
</tr>
<tr>
<td>Cleaning of equipment</td>
<td>Discontinuous, low-concentration water emissions to water (it can contain hazardous substances when reductive agents and hypochlorite are applied)</td>
<td></td>
</tr>
</tbody>
</table>

As the table shows, most of the emissions are emissions to water. Due to the low vapour pressure of the substances in the dye bath, emissions to air are generally not significant and can be regarded more as problems related to the workplace atmosphere (fugitive emissions from dosing/dispensing chemicals and dyeing processes in ‘open’ machines). A few exceptions are the thermosol process, pigment dyeing and those dyeing processes where carriers are employed. In pigment dyeing, the substrate is not washed after pigment application and therefore the pollutants are quantitatively released to air during drying. Emissions from carriers are to air and water.

In the first part of the following discussion the environmental issues related to the substances employed will be described, while in the second part the environmental issues related to the process will be mentioned.
Environmental issues related to the substances employed

Water-polluting substances in the above-mentioned emissions may originate from:

- the dyes themselves (e.g. toxicity, metals, colour);
- auxiliaries contained in the dye formulation;
- basic chemicals (e.g. alkali, salts, reducing and oxidising agents) and auxiliaries used in dyeing processes;
- contaminants present on the fibre when it enters the process sequence (residues of pesticides on wool are encountered in loose fibre and yarn dyeing and the same occurs with spin finishes present on synthetic fibres).

Dyes

Spent dye baths (discontinuous dyeing), residual dye liquors and water from washing operations always contain a percentage of unfixed dye. The rates of fixation vary considerably among the different classes of dyes and may be especially low for reactive dyes (in the case of cotton) and for sulphur dyes. Moreover, large variations are found even within a given class of colourants. This is particularly significant in the case of reactive dyes. Fixing rates above 60% cannot be achieved, for example, in the case of copper (sometimes nickel) phthalocyanine reactive dyes especially used for turquoise-green and some marine shades. In contrast, the so-called double anchor reactive dyes can achieve extremely high rates of fixation (see Sections 4.5.2.2 and 4.5.2.4).

The degree of fixation of an individual dye varies according to type of fibre, shade and dyeing parameters. Therefore fixation rate values can be given only as approximations. However, they are useful to give an idea of the amount of unfixed dyes that can be found in waste water. Information from different authors is given in Table 2.15, the table below.
Table 2.15: Percentage of non-fixed dye that may be discharged in the effluent for the principal classes of dyes

<table>
<thead>
<tr>
<th>Dyestuffs</th>
<th>EPA</th>
<th>OECD</th>
<th>ATV</th>
<th>Bayer (1)</th>
<th>Euratex</th>
<th>Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid dyes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>for wool</td>
<td>10</td>
<td>&gt; 7-20</td>
<td>&gt; 7-20</td>
<td>NI</td>
<td>&gt; 5-15</td>
<td>5-15</td>
</tr>
<tr>
<td>for polyamide</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic dyes</td>
<td>1</td>
<td>2-3</td>
<td>2-3</td>
<td>2</td>
<td>NI</td>
<td>0-2</td>
</tr>
<tr>
<td>Direct dyes</td>
<td>30</td>
<td>5-20</td>
<td>5-30</td>
<td>10</td>
<td>5-35</td>
<td>0-2</td>
</tr>
<tr>
<td>Disperse dyes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>for acetate</td>
<td>25</td>
<td>&gt; 8-20</td>
<td>&gt; 8-20</td>
<td>&gt; 5</td>
<td>&gt; 1-15</td>
<td>&gt; 0-10</td>
</tr>
<tr>
<td>for polyester 1 bar</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>for polyester HT</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Azoic dyes</td>
<td>25</td>
<td>5-10</td>
<td>5-10</td>
<td>NI</td>
<td>10-25</td>
<td>10-25</td>
</tr>
<tr>
<td>Reactive dyes (2) for cotton</td>
<td>&gt; 50-60</td>
<td>&gt; 20-50</td>
<td>&gt; 5-50</td>
<td>&gt; 5-50</td>
<td>20-45</td>
<td>&gt; 10-35</td>
</tr>
<tr>
<td>for wool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal-complex</td>
<td>10</td>
<td>2-5</td>
<td>2-5</td>
<td>5</td>
<td>2-15</td>
<td>5-15</td>
</tr>
<tr>
<td>Chrome dyes</td>
<td>NI</td>
<td>NI</td>
<td>1-2</td>
<td>NI</td>
<td>NI</td>
<td>5-10</td>
</tr>
<tr>
<td>Vat dyes</td>
<td>25</td>
<td>5-20</td>
<td>5-20</td>
<td>NI</td>
<td>5-30</td>
<td>5-30</td>
</tr>
<tr>
<td>Sulphur dyes</td>
<td>25</td>
<td>30-40</td>
<td>30-40</td>
<td>NI</td>
<td>10-40</td>
<td>15-40</td>
</tr>
</tbody>
</table>

(1) New Dystar (including BASF).
(2) New reactive dyestuffs with higher fixation rates are now available (see Sections 4.5.2.2 and 4.5.2.4).

As stated earlier, as a consequence of uncomplete fixation, a percentage of the dyestuff used in the process ends up in the waste water.

Dyestuffs are not biodegradable in oxidative conditions, although some of them may degrade under other conditions (e.g. azo dyes may cleave under anoxic and anaerobic conditions). Less water-soluble dyestuff molecules (typically, disperse, vat, sulphur, some direct dyestuffs and pigments) can be largely bio-eliminated from waste water by coagulation/precipitation or absorption/adsorption to the activated sludge. The quantity of activated sludge in the waste water treatment plant and the quantity of dyestuff to be eliminated are key factors in determining the efficiency of removal of a dyestuff from the effluent.

Another factor to take into consideration is the colour strength of the colourant. For example, with reactive dyestuffs a lower smaller amount of colourant is needed to achieve a given shade compared to other classes of dyes (e.g. direct, vat and sulphur dyes). As a result, a lower smaller amount of dyestuff will need to be removed from the waste water.

Dyestuffs that are poorly bio-eliminable (unless they are submitted subjected to destructive treatment techniques) will pass through a biological waste water treatment plant and will ultimately end up in the discharged effluent. The first noticeable effect in the receiving water is the colour. High doses of colour not only cause aesthetic impact, but can also interrupt photosynthesis, thus affecting aquatic life. Other effects are related to the organic content of the colourant (normally expressed as COD and BOD, but it could be better expressed as organic carbon, using TOC and DOC as parameters), its aquatic toxicity and the presence in the molecule of metals or halogens that can give rise to AOX emissions.

These issues are discussed in more detail for each class of dyestuff in Chapter 9. Only some general key issues are considered in this section.
**AOX emissions**

Vat, disperse and reactive dyes are more likely to contain halogens in their molecules.

The content of organically bound halogens can be up to 12 % by weight for some *vat dyes*. Vat dyes, however, usually show a very high degree of fixation. In addition, they are insoluble in water and the amount that reaches the effluent can be eliminated with high efficiency in the waste water treatment plant through adsorption on the activated sludge.

*Reactive dyes*, on the contrary, may have low fixation degrees (the lowest level of fixation is observed with phthalocyanine in batch dyeing) and their removal from waste water is difficult because of the low biodegradability and/or low level of adsorption of the dye onto activated sludge during treatment. The halogen in MCT (monochlorotriazines) reactive groups is converted into a harmless chloride during the dyeing process. In calculating the waste water burden, it is therefore assumed that the MCT reactive groups react completely by fixation or hydrolysis so that they do not contribute to AOX emissions. However, many commonly used polyhalogenated reactive dyes, such as DCT (dichlorotriazine), DFCP (difluorochloropyrimidine) and TCP (trichloropyrimidine), contain organically bound halogens even after fixation and hydrolysis. Bound halogens are also found in discharges of dye concentrate (pad, kitchen) and non-exhausted dye baths that may still contain unreacted dyestuff.

For the other classes of colourants the AOX issue is not relevant because, with few exceptions, the halogen content is usually below 0.1 %.

PARCOM 97/1 recommends strict limits for AOX. Even stricter limits are set by the EU-Ecolabel and German legislation. Extensive investigation of AOX in textile effluents was performed, but AOX as an indicator remains a matter of discussion.

Dyestuffs containing organically bound halogens (except fluorine) are measured as AOX. The only way to limit AOX from dyeing is by dye selection, by more efficient use of dyes or by treating the resulting effluent by decolouration. Effluent decolouration can be achieved using destructive techniques, such as the free radical oxidation or non-destructive techniques (e.g. coagulation, adsorption).

However, it should be noted that AOX from dyes do not have the same effect as the AOX derived from chlorine reactions (haloform reaction, in particular) arising from textile processes such as bleaching, wool shrink-resist treatments, etc.

Dyestuffs are not biodegradable compounds and the halogens in their molecules should not give rise to the haloform reaction (main cause of hazardous AOX).

In this respect it is interesting to consider that PARCOM 97/1 does not set a general discharge limit value for AOX, but rather allows discrimination between hazardous and non-hazardous AOX [50, OSPAR, 1997].

**Heavy metals emissions**

Metals can be present in dyes for two reasons. First, metals are used as catalysts during the manufacture of some dyes and can be present as impurities. Second, in some dyes the metal is chelated with the dye molecule, forming an integral structural element.

Dye manufacturers are now putting more effort into reducing the amount of metals present as impurities. This can be done by selection of starting products, removal of heavy metals and substitution of the solvent where the reaction takes place.

ETAD (Ecological and Toxicological Association of Dyes and Organic Pigments Manufacturers) has established limits for the content of heavy metals in dyestuffs. The values have been set to ensure that emission levels from a 2 % dyeing and a total dilution of the dye of 1:2 500 will meet the known waste water requirements [64, BASF, 1994].
Examples of dyes containing bound metals are copper and nickel in phthalocyanine groups, copper in blue copper-azo-complex reactive dyes and chromium in metal-complex dyes used for wool, silk and polyamide. The total amount of metallised dye used is decreasing, but there remain domains (certain shades such as greens, certain levels of fastness to light) where phthalocyanine dyes, for example, cannot be easily substituted.

The presence of the metal in these metallised dyes can be regarded as a less relevant problem compared to the presence of free metal impurities. Provided that high exhaustion and fixation levels are achieved and that measures are taken to minimise losses from handling, weighing, drum cleaning, etc., only a little unconsumed dye should end up in the waste water. Moreover, since the metal is an integral part of the dye molecules, which themselves are non-biodegradable, there is very little potential for them to become bio-available.

It is also important to take into account that treatment methods such as filtration and adsorption on activated sludge, which remove the dye from the waste water, also reduce almost proportionally the amount of bound metal in the final effluent. Conversely, other methods such as advanced oxidation may free the metal.

**Toxicity**

Dyestuffs showing aquatic toxicity and/or allergenic effects are highlighted in Chapter 9. Here it is also important to mention that about 60% to 70% of the dyes used nowadays are azo dyes [77, EURATEX, 2000]. Under reductive conditions, these dyes may produce amines and some of them are carcinogenic. A list of carcinogenic amines that can be formed by cleavage of certain azo dyes is shown in the Table 2.16.

<table>
<thead>
<tr>
<th>No.</th>
<th>Aromatic amine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4-aminodiphenyl</td>
</tr>
<tr>
<td>2</td>
<td>Benzidine</td>
</tr>
<tr>
<td>3</td>
<td>4-chloro-o-toluidine</td>
</tr>
<tr>
<td>4</td>
<td>2-naphthylamine</td>
</tr>
<tr>
<td>5</td>
<td>o-aminazotoluene</td>
</tr>
<tr>
<td>6</td>
<td>2-amin-4-nitrotoluene</td>
</tr>
<tr>
<td>7</td>
<td>p-chloroaniline</td>
</tr>
<tr>
<td>8</td>
<td>2,4-diaminoanisol</td>
</tr>
<tr>
<td>9</td>
<td>4,4’-diaminodiphenylmethane</td>
</tr>
<tr>
<td>10</td>
<td>3,3’-dichlorobenzidine</td>
</tr>
<tr>
<td>11</td>
<td>3,3’-dimethoxybenzidine</td>
</tr>
<tr>
<td>12</td>
<td>3,3’-dimethylbenzidine</td>
</tr>
<tr>
<td>13</td>
<td>3,3’-dimethyl-1,4-diaminodiphenylmethane</td>
</tr>
<tr>
<td>14</td>
<td>p-cresidine</td>
</tr>
<tr>
<td>15</td>
<td>4,4’-methylene-bis-(2-chloraniline)</td>
</tr>
<tr>
<td>16</td>
<td>4,4’-oxydianiline</td>
</tr>
<tr>
<td>17</td>
<td>4,4’-thiodianiline</td>
</tr>
<tr>
<td>18</td>
<td>o-toluidine</td>
</tr>
<tr>
<td>19</td>
<td>2,4-diaminotoluene</td>
</tr>
<tr>
<td>20</td>
<td>2,4,5-trimethylaniline</td>
</tr>
<tr>
<td>21</td>
<td>4-aminoaazobenzene</td>
</tr>
<tr>
<td>22</td>
<td>o-anisidine</td>
</tr>
</tbody>
</table>

The use of azo dyes that may cleave to one of the 22 potentially carcinogenic aromatic amines listed above is banned according to the 19th amendment of Directive 76/769/EWG on dangerous substances.

However, more than 100 dyes with the potential to form carcinogenic amines are still available on the market [77, EURATEX, 2000].
Auxiliaries contained in dye formulations

Depending on the dye class and the application method employed (e.g. batch or continuous dyeing, printing), different additives are present in the dye formulations. Since these substances are not absorbed/fixed by the fibres, they are completely discharged in the waste water. Typical additives are listed in the Table 2.17 below.

### Table 2.17: Ecological properties of dye formulations additives

<table>
<thead>
<tr>
<th>Additive</th>
<th>Chemical composition</th>
<th>COD (mg O₂/kg)</th>
<th>BOD₅ (mg O₂/kg)</th>
<th>TOC elimination (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispersants</td>
<td>- Lignin sulphonates</td>
<td>1 200</td>
<td>50</td>
<td>15 %</td>
</tr>
<tr>
<td></td>
<td>- Naphthalene sulphonates condensation products with formaldehyde</td>
<td>650</td>
<td>50</td>
<td>15 %</td>
</tr>
<tr>
<td></td>
<td>- Ethylene oxide / propylene oxide copolymers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salts</td>
<td>Sodium sulphate, sodium chloride</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Powder binding agents</td>
<td>Mineral- or paraffin oils (+ additives)</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Anti-foaming agents</td>
<td>Acetyl glycols</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Anti-freeze agents</td>
<td>Glycerine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glycols</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickening agents</td>
<td>Carboxymethyl cellulose</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Polyacrylates</td>
<td>1 000</td>
<td>0</td>
<td>30 %</td>
</tr>
<tr>
<td>Buffer systems</td>
<td>Phosphate, Acetate</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
</tbody>
</table>

(^1) Statistical elimination test (Zahn-Wellens Test).
Blank cells mean that data are not available.
NB: NI: No information.
Source: [18, VITO, 1998]

While these additives are not toxic to aquatic life, they are in general poorly biodegradable and not readily bioeliminable. This applies in particular to the dispersants present in the formulations of vat, disperse and sulphur dyes. These dyes are water-insoluble and need these special auxiliaries in order to be applied to the textile in the form of aqueous dispersions. These dispersants consist mainly of naphthalene sulphonate-formaldehyde condensation products and lignin sulphonates, but sulphonmethylation products derived from the condensation of phenols with formaldehyde and sodium sulphite can also be found. Other not readily eliminable additives are acrylate and CMC-based thickeners and anti-foaming agents.

The difference between liquid and powder formulations should also be mentioned. Dyes supplied in liquid form contain only one third of the amount of dispersing agent normally contained in powder dyes (see Table 2.18). The reason for this difference stems from the manufacturing process of powder dyes: the very small particles generated during grinding must be protected during the subsequent drying process and this is possible only by adding high proportions of dispersing agents.
Table 2.18: Proportion of additives and dye in powder and liquid dyes

<table>
<thead>
<tr>
<th>Formulation component</th>
<th>Powder formulation</th>
<th>Liquid formulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dye</td>
<td>30-50 %</td>
<td>20-40 %</td>
</tr>
<tr>
<td>Dispersing agent</td>
<td>40-60 %</td>
<td>10-30 %</td>
</tr>
<tr>
<td>Salts</td>
<td>0-20 %</td>
<td>NA</td>
</tr>
<tr>
<td>Powder binding agents</td>
<td>0-5 %</td>
<td>NA</td>
</tr>
<tr>
<td>Anti-foaming agents</td>
<td>0-5 %</td>
<td>0-5 %</td>
</tr>
<tr>
<td>Anti-freeze agent</td>
<td>NA</td>
<td>10-15 %</td>
</tr>
<tr>
<td>Thickening agent</td>
<td>NA</td>
<td>0-5 %</td>
</tr>
<tr>
<td>Water</td>
<td>5-10 %</td>
<td>40-60 %</td>
</tr>
</tbody>
</table>

NB: NA: Not applicable.
Source: [18, VITO, 1998]

Note that liquid formulations include liquid dispersions and true solutions (solutions without solubilising aids), whereas powder dyes can be supplied as dusting, free-flowing, non-dusting powders or granulates.

Basic chemicals and auxiliaries used in the dyeing process

Regarding the environmental concerns associated with the chemicals and auxiliaries used in dyeing processes, it is worth mentioning the following key issues.

Sulphur-containing reducing agents

In some cases the sulphide is already contained in the dye formulation and in other cases it is added to the dye bath before dyeing. In the end, however, the excess sulphide ends up in the waste water. Sulphides are toxic to aquatic organisms and contribute to increasing COD load. In addition, sulphide anions are converted into hydrogen sulphide under acidic conditions, thereby giving rise to problems of odour and corrosivity.

Sodium hydrosulphite (also called sodium dithionite) is another sulphur-containing reducing agent, which is commonly used not only in sulphur and vat dyeing processes, but also as a reductive after-cleaning agent in PES dyeing. Sodium hydrosulphite is less critical than sodium sulphide. However, during the dyeing process sodium dithionite is converted into sulphite (toxic to fish and bacteria) and in some cases this is further oxidised into sulphate.

In the waste water treatment plant sulphite is normally oxidised into sulphate, but this can still cause problems. Sulphate, in fact, may cause corrosion of concrete pipes or may be reduced under anaerobic conditions into hydrogen sulphide.

Hydroxyacetone, although it produces an increase in COD load, is recommended to lower the sulphur content in waste water, but it cannot replace hydrosulphite in all applications. New Organic reducing agents with improved reducing effects have been developed (see Section 9.10 and Section 4.5.2.1 for further details).

Consumption of the reducing agent by the oxygen present in the machine (partially flooded dyeing machines) needs also to be taken into account. Instead of applying only the amount of reducing agent required for the reduction of the dyestuff, a significant extra amount of reducing agent often needs to be added to compensate for the amount consumed by the oxygen contained in the machine. This obviously increases the oxygen demand of the effluent.

Oxidising agents

Dichromate should no longer be used in Europe as an oxidising agent when dyeing with vat and sulphur dyes, but it is still widely used for the fixation of chrome dyes in wool dyeing. Chromium III exhibits low acute toxicity, while chromium VI is acutely toxic and has been shown to be carcinogenic towards animals.
Sodium and potassium dichromate are listed in Annex XIV to REACH and their use is therefore subject to authorisation. At the time of drafting of this document, only one authorisation was granted to use sodium dichromate as mordant in wool dyeing.

During the dyeing processes with chrome dyes, Cr(VI) is reduced to Cr(III) if the process is under control. Nevertheless, emissions of Cr(VI) may still occur due to inappropriate handling of dichromate during dye preparation (care must be taken as dichromate is carcinogenic and may cause health problems for workers handling it). Emissions of trivalent chromium in the waste water can be minimised (see Section 4.5.3.1), but cannot be avoided, unless alternative dyestuffs are applied (see Section 4.5.3.1).

The use of bromate, iodate and chlorite as oxidising agents in vat and sulphur dyeing processes and the use of hypochlorite as a stripping agent for decolouring faulty goods or for cleaning dyeing machines (e.g. before subsequent lighter-coloured dyeing) may produce AOX emissions. However, only hypochlorite and elemental-chlorine-containing compounds (e.g. certain chlorite products that contain Cl₂ or use chlorine as an activator for formation of chlorine dioxide gas) are likely to give rise to hazardous AOX.

Salt
Salts of various types are used in dyeing processes for different purposes (e.g. to promote level dyeing or increase dye exhaustion). In particular, large amounts of salt are used in cotton batch dyeing processes with reactive dyes. The amount of salt employed is relatively significant compared to other classes of dyestuffs, for example direct dyes (see Table 2.19), and efforts have been made by dye manufacturers to solve this problem (see Section 4.5.2.4).

<table>
<thead>
<tr>
<th>Shade</th>
<th>Dye o.w.f.</th>
<th>Amount of salt applied with direct dyes</th>
<th>Amount of salt applied with reactive dyes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paste/light</td>
<td>&lt; 1.5 %</td>
<td>2.5-7.5 g/l</td>
<td>30-60 g/l</td>
</tr>
<tr>
<td>Medium</td>
<td>1.0-2.5 %</td>
<td>7.5-12.5 g/l</td>
<td>70-80 g/l</td>
</tr>
<tr>
<td>Dark</td>
<td>&gt; 2.5 %</td>
<td>12.5-20 g/l</td>
<td>80-100 g/l</td>
</tr>
</tbody>
</table>


In addition to the use of salt as a raw material, neutralisation of commonly employed acids and alkalis produces salts as by-products.

Salts are not removed in conventional waste water treatment systems and they are therefore ultimately discharged in the receiving water. Although the mammalian and aquatic toxicity of the commonly employed salts are very low, in arid or semi-arid regions their large-scale use can produce concentrations above the toxic limit and increase the salinity of the groundwater.

Countries have set emission limits at 2000 ppm or below. River quality standards must also be taken into account.

Carriers
The use of these auxiliaries, which were widely employed in the past, has now been reduced due to ecological and health problems. They are still an issue in dyeing of polyester-wool blends.

Carriers may already be added to the dyes by manufacturers. In this case textile finishers will have little knowledge of the loads discharged ([4, Tebodin, 1991] and [61, L. Bettens, 1999]).
Carriers (see Section 8.6.7) include a wide group of organic compounds, many of them steam-volatile, poorly biodegradable and toxic to humans and aquatic life. However, as the active substances usually have high affinity for the fibre (hydrophobic types), 75-90% are absorbed by the textile and only the emulsifiers and the hydrophilic-type carriers such as phenols and benzoate derivatives are found in the waste water. The carriers that remain on the fibre after dyeing and washing are partially volatilised during drying and fixing operations and can give rise to emissions to air. Traces can still be found on the finished product, thus representing a potential problem for the consumer.

Alternative options are described in Sections 4.5.4.1 and 4.5.4.1.

**Other auxiliaries of environmental interest**

Other substances that may be encountered in the dyeing auxiliaries and that may give rise to water pollution are shown in Table 2.20.

### Table 2.20: Substances of environmental interest in the dyeing auxiliaries

<table>
<thead>
<tr>
<th>Substance</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatty amine ethoxylates</td>
<td>Levelling agent</td>
</tr>
<tr>
<td>Alkylphenol ethoxylates</td>
<td></td>
</tr>
<tr>
<td>Quaternary ammonium compounds</td>
<td>Retarders for cationic dyes</td>
</tr>
<tr>
<td>Polynonylpyrolidone</td>
<td>Levelling agent for vat, sulphur and direct dyes</td>
</tr>
<tr>
<td>Cyanamide-ammonia salt condensation products</td>
<td>Auxiliaries for fastness improvement</td>
</tr>
<tr>
<td>Acrylic acid-maleic acid copolymers</td>
<td>Dispersing agent</td>
</tr>
<tr>
<td>Ethylenediamine tetraacetate (EDTA)</td>
<td></td>
</tr>
<tr>
<td>Diethylenetriaminepentaacetate (DTPA)</td>
<td>Complexing agent</td>
</tr>
<tr>
<td>Ethylenediaminetetra(methylene phosphonic acid) (EDTMP)</td>
<td></td>
</tr>
<tr>
<td>Diethylenetriaminepenta(methylene phosphonic acid) (DTPMP)</td>
<td></td>
</tr>
</tbody>
</table>

These are water-soluble hard-to-biodegrade compounds which can pass untransformed or only partially degraded through waste water treatment systems.

In addition, some of them are toxic (e.g. quaternary amines) or can give rise to metabolites which may affect reproduction in the aquatic environment (APEO).

#### 2.7.8.2 Environmental issues related to the process

Both water and energy consumption in dyeing processes are a function of the dyeing technique, operating practices and machinery employed.

**Batch dyeing processes** generally require higher water and energy consumption than continuous processes. This is due to a number of different factors.

The higher *liquor ratios* involved in batch dyeing represent one of these factors. As previously mentioned in Section 2.7.2, higher liquor ratios mean not only higher water and energy use, but also a higher consumption of those chemicals and auxiliaries that are dosed based on the volume of the bath.

Consistently with the quality of the different types of substrates, all equipment manufacturers can now offer machines with reduced liquor ratios. Terms like ‘low liquor ratio’ and ‘ultra-low liquor ratio’ are now commonly used to define the performance/features of modern machines.
Chapter 2

For dyeing fabric in rope form, nominal reference values for ‘low liquor ratio machines’ are in the range of 1:5-1:8 for cotton and correspondingly 1:3-1:4 for PES. The liquor ratio can be higher for other types of substrates/fibres.

The term ‘ultra-low liquor ratio’ is used to define machines that can be operated at liquor ratios as low as the minimum volume required to completely wet out the substrate and avoid cavitation of the pumps. This term applies only to machines for dyeing fabric in rope form.

It is important to show the difference between the nominal and the real liquor ratio. As already stated in Section 2.7.2, the nominal liquor ratio is the liquor ratio at which a machine can be operated when it is loaded at its maximum/optimal capacity. It is often the case that the machine is underloaded compared to its optimal capacity. This often occurs in commission companies where a high production flexibility is required to serve variable lot sizes according to customer demand. Modern machines can still be operated at approximately constant liquor ratio whilst being loaded at a level as low as 60 % of their nominal capacity (or even 30 % of their nominal capacity with yarn dyeing machines - see Section 4.5.1.6). In this way, the same benefits achievable with low liquor ratios can be kept even with reduced loading. It is obvious, however, that when a machine is loaded far below its optimal capacity (e.g. below 60 % of its nominal capacity for fabric dyeing machines) the real liquor ratio will differ greatly from the nominal liquor ratio. This will result not only in lower environmental performances (higher water, energy and chemical consumption), but also in higher operating costs.

In conclusion, the use of low liquor ratio machinery, or selection of the most adequate machine for the size of the lot to be processed, is fundamental to the resultant environmental performance of the process.

Having said that, high energy and water consumption in batch dyeing is not only the result of high liquor ratios.

Another factor to take into consideration is the discontinuous nature of the batch dyeing operating mode, especially with regard to operations such as cooling, heating, washing and rinsing.

Furthermore, shade matching can be responsible for higher water and energy consumption, especially when dyeing is carried out without the benefit of laboratory instruments. In a manual regime, the bulk of the dyestuff is normally applied in the first phase to obtain a shade which is close to that required in the final product. This is followed by a number of matching operations, during which small quantities of dye are applied to achieve the final shade. Shades which are difficult to match may require repeated shade additions with cooling and reheating between each addition [32, ENço, 2001].

Increased energy and water consumption may also be caused by inappropriate handling techniques and/or poorly performing process control systems. For example, in some cases displacement spillage may occur during immersion of the fibre in the machine, while the potential for overfilling and spillage exists where the machines are only equipped with manual control valves, which fail to control the liquor level and temperature correctly (see also Section 4.1.3.1).

Continuous and semi-continuous dyeing processes consume less water, but this also means a higher dyestuff concentration in the dye liquor. In discontinuous dyeing the dye concentration varies from 0.1 g/l to 1 g/l, while in continuous processes this value is in the range of 10 g/l to 100 g/l. The residual padding liquor in the padders, pumps and pipes must be is discarded when a new colour is started. The discharge of this concentrated effluent can result in a higher pollution load compared with discontinuous dyeing, especially when small quantities lots of material are processed. However, modern continuous dyeing ranges have steadily improved in recent years. The use of small pipes and pumps and small pad-bath troughs help to reduce the amount of concentrated liquor to be discharged. In addition, it is possible to minimise the
discard of leftovers, by using automated dosing systems, which meter the dye solution ingredients and deliver the exact amount needed (see also Sections 4.1.6.6 and 4.5.1.1 for more detailed information about recent improvements).

In both continuous and batch dyeing processes, final washing and rinsing operations are water-intensive steps that need to be taken into consideration. Washing and rinsing operations actually consume greater quantities of water than dyeing itself (see Sections 4.1.3.3 and 4.1.3.3.2 for water and energy conservation techniques in batch and continuous processing and Sections 4.1.3.1 and 4.5.1.6 for equipment optimisation in batch processing).
Chapter 2

2.8 Printing

2.8.1 Printing processes

Printing, like dyeing, is a process for applying colour to a substrate. However, instead of colouring the whole substrate (cloth, carpet or yarn) as in dyeing, print colour is applied only to defined areas to obtain the desired pattern. This involves different techniques and different machinery with respect to dyeing, but the physical and chemical processes that take place between the dye and the fibre are analogous to dyeing.

A typical printing process involves the following steps:

- Colour paste preparation: when printing textiles, the dye or pigment is not in an aqueous liquor. Instead, it is usually finely dispersed in a printing paste, in high concentration.
- Printing: the dye or pigment paste is applied to the substrate using different techniques, which are discussed below.
- Fixation: immediately after printing, the fabric is dried and then the prints are fixed mainly with steam or hot air (for pigments). Note that intermediate drying is not carried out when printing carpets (too much energy would be needed for removing the highly viscous liquor).
- After-treatment: this final operation consists of washing and drying the fabric (it is not necessary when printing with pigments or with other particular techniques such as transfer printing).

When describing the different printing techniques, a distinction should be made between printing with pigments, which have no affinity for the fibre, and printing with dyes (reactive, vat, disperse, etc.).

2.8.1.1 Printing with pigments

Pigment printing has gained in importance today and for some fibres (e.g. cellulose fibres) it is by far the most commonly applied technique. Pigments can be used on almost all types of textile substrates and, thanks to the increased performance of modern auxiliaries, it is now possible to obtain high-quality printing using this technique.

Pigment printing pastes contain a thickening agent, a binder and, if necessary, other auxiliaries such as fixing agents, plasticisers, anti-foaming agents, etc.

White spirit-based emulsions, used in the past as thickening systems, are used only occasionally today (mainly half-emulsion thickeners). More information regarding the characteristics of the auxiliaries used can be found in Section 8.7.2

After applying the printing paste, the fabric is dried and then the pigment is normally fixed with hot air (depending on the type of binder in the formulation, fixation can also be achieved by storage at 20 °C for a few days). The advantage of pigment printing is that the process can be done without subsequent washing (which, in turn on the other hand, is needed for most of the other printing techniques).

2.8.1.2 Printing with dyes

Printing paste preparation

The process traditionally starts with the preparation of the paste. Compared to pigment printing, the composition of the pastes is more complex and variable, being determined not by the dye
used, but by the printing technique, the substrate, the application and the fixation methods applied.

Apart from the dye, printing pastes contain a thickening agent (see also Section 8.7.1) and various other auxiliaries, which can be classified according to their function as follows:

- oxidising agents (e.g. m-nitrobenzenesulphonate, sodium chlorate, hydrogen peroxide);
- reducing agents (e.g. sodium dithionite, formaldehyde sulphonylates, thiourea dioxide, tin(II) chloride);
- discharging agents for discharge printing (e.g. anthraquinone);
- substances with a hydrotrropic effect, like urea;
- dye solubilisers, which are polar organic solvents like glycerine, ethylen glycol, butyl glycol, thiodiglycol, etc.;
- ‘resists’ for reactive resist printing (e.g. sulphonated alkanes);
- defoamers (e.g. silicon compounds, organic and inorganic esters, aliphatic esters, etc.).

All the necessary ingredients are metered (dosed) and mixed together in a mixing station. Since between 5 and 10 different printing pastes are usually necessary to print a single pattern (in some cases up to 20 different pastes are applied), in order to reduce losses due to incorrect measurement, the preparation of the pastes is done in automatic stations in order to reduce losses due to incorrect measurement. In modern plants, with the help of special devices, the exact amount of printing paste required is determined and prepared in continuous mode for each printing position, thus reducing leftovers at the end of the run.

It is common practice in many print houses to filter the printing pastes before application, using for example a filter cloth. This operation is especially important for thickeners to prevent free particles from blocking the openings of the screens.

**Printing (paste application)**

After preparation, the paste is applied to specific areas of the textile using one of the following techniques:

- direct printing (which also includes digital and transfer printing);
- discharge printing;
- resist printing.

In the case of direct printing the dye is applied to specific areas of a pretreated textile substrate, which can be white or pre-dyed (in light colours).

It is possible to speak of known as discharge printing if in the fixation process that follows the application of the printing paste there is local destruction of a dye applied previously. If the etched (discharge), previously dyed area becomes white, then the process is called white discharge. If, on the contrary, a coloured pattern has to be obtained in the etched area after the destruction of the previously applied dye, then the process is called coloured discharge. In this case, the printing paste must contains a reduction-resistant dye along with the chemicals needed to destroy the previous one. As a result, the pre-dyed background is destroyed according to a pattern and the dye, which is resistant to reduction, takes its place. Figure 2.15 below shows a representation of discharge printing.
In the case of resist printing, a special printing paste (called ‘resist’) is printed onto certain areas of the fabric to prevent dye fixation (see a schematic representation in Figure 2.16 below). In the case of physical resist, the material is printed with a difficult-to-wet resin that inhibits the penetration of a dye applied in a second stage. On the other hand, with a chemical resist, dye fixation is prevented by a chemical reaction. Depending on the way the process is carried out, one can speak of the resists are referred to as pre-printing, intermediate or over-printing resists. One common procedure is the wet-on-wet process in which the resist paste is initially printed, then the material is overprinted with full cover screen and finally fixed and washed. Over-printing resists can be applied only if the dye, already present in the previously dyed and dried fabric, is still in its unfixed form, as in the case of developing dyes.

The difference between transfer printing and the techniques described earlier is that with this technique the surface of the fabric is not directly printed on. Instead, the pattern is first created on an intermediate carrier (e.g. paper) using selected disperse dyes and then it is transferred from there to the fabric. The dye is usually fixed by placing the printed paper in contact with the fabric into a thermal pressure system. Under the influence of the heat, the dye sublimates and diffuses from the carrier into the fibre of the textile substrate. There is no need for further treatment such as steaming, washing, etc. This technique is applied for polyester, polyamide and some acrylic fibres, using selected disperse dyestuffs according to the specific type of fibre.
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Fixation
After printing, the fabric is dried. Water evaporation leads to an increase in dye concentration and at the same time prevents the colours from smearing when the fabric is transported over the guide rollers. At this stage the dye is not yet fixed.

The aim of the subsequent fixation step is to transport as much as possible of the dye, which is retained by the thickener, into the fibres. This is especially important with dyes, such as vat dyes, for example, that are printed in the insoluble form and are converted into the corresponding soluble state only after reaction with the reducing agents during the fixation process.

Fixation is usually carried out with steam. Water vapour condenses on the printed material, swells up, causes the thickener to swell, heats the print and provides the necessary transport medium for the diffusion of the dye. The distribution of the dye between fibre and thickener is an important factor in determining the degree of fixation of the dye, which is called the ‘retaining power’ of the thickener. The thickener, in fact, is often composed of polysaccharides and therefore competes with cellulose in retaining the dye. This is the main reason why the fixation rate of a given dye is 10% lower in printing than in dyeing.

After-treatment
The last step of the printing process consists of washing and drying the fabric. When printing with insoluble dyes such as vat dyes this operation also serves as a means to reconvert the dye to the original oxidised state. In this case, after an initial rinsing with cold water, the printed material is treated with hydrogen peroxide. The process is completed with a soap treatment with sodium carbonate at the boiling point.

As already explained, washing is not necessary with pigment printing and transfer printing. This holds for any dyeing/printing system where thickeners are not needed and where the dyestuff is (nearly) completely fixed (e.g. printing carpet tiles with digital jet printing techniques, see Section 4.6.1.2).

Ancillary operations
At the end of each batch and at each colour change various cleaning operations are carried out:

- The rubber belt, to which the fabric is glued during printing (see description below), is cleaned in continuous mode with water to remove excess adhesive and printing paste. Some machines are equipped with water recirculation systems.
- The printing gears (all systems responsible for feeding and applying the paste to the substrate) are cleaned by first removing as much as possible of the paste residues and then rinsing with water. In some companies the paste residues are directed back to the appropriate printing paste batch containers for reuse (see Section 4.6.1.7).
- The remaining paste in the containers, in which the paste is prepared (paste vats), is in general previously cleaned up by means of sucking systems before being washed out with water. The residual printing paste collected in this manner is then disposed of.
2.8.2 Printing technology

A variety of different machines can be used for printing fabrics. The most commonly used are described below.

2.8.2.1 Flat-screen printing

Flat-screen and rotary-screen printing are both characterised by the fact that the printing paste is transferred to the fabric through openings in specially designed screens. The openings on each screen correspond to a pattern and, when the printing paste is forced through by means of a squeegee, the desired pattern is reproduced on the fabric. A separate screen is made for each colour in the pattern. Figure 2.17 below shows an example of a flat-screen printing machine.

![Flat-screen printing machine](source: [69, Corbani, 1994])

**Figure 2.17:** Flat-screen printing with automatic squeegee system

Flat-screen printing machines can be manual, semi-automatic or completely automatic. One type of machine, which is still commonly found in print houses, can be described as follows. The fabric is first glued to a moving endless belt. A stationary screen at the front of the machine is lowered onto the area that has to be printed and the printing paste is wiped with a squeegee. Afterwards the belt, with the fabric glued onto it, is advanced to the pattern-repeat point and the screen is lowered again. The printed fabric moves forward step by step and passes through a dryer. The machine prints only one colour at a time. When the first colour is printed on the whole length of the fabric, the dried fabric is ready for the second cycle and so on until the pattern is completed. Figure 2.18 below shows a representation of a flat-screen printing machine.
In other fully mechanised machines all the colours are printed at the same time (see Figure 2.19 below). A number of stationary screens (from 8 to 12, but some machines are equipped with up to 24 different screens) are placed along the printing machine. The screens are simultaneously lifted, while the textile, which is glued to a moving endless rubber belt, is advanced to the pattern-repeat point. Then the screens are lowered again and the paste is squeezed through the screens onto the fabric. The printed material moves forward one frame at each application and as it leaves the last frame it is finally dried and ready for fixation.
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After printing, the screens and the application system are washed out. It is common practice to squeeze the colour from the screens back into the printing paste mixing containers before washing them.

2.8.2.2 Rotary-screen printing

Rotary-screen printing machines use the same principle described earlier, but, instead of flat screens, the colour is transferred to the fabric through lightweight metal foil screens, which are made in the form of cylinder rollers (see Figure 2.20 and Figure 2.21 below). The fabric moves along in continuous mode under a set of cylinder screens while at each position the printing paste is automatically fed to the inside of the screen from a tank and is then pressed through onto the fabric. A separate cylinder roller is required for each colour in the design.

Figure 2.20: Representation of the rotary-screen printing process

Source: [63, GuT/ ECA, 2000]
A conventional paste feeding system for rotary-screen printing machines is represented in Figure 2.22. A suction pipe leads from the paste vat to a pump, from where a printing hose leads to the squeegee (dye pipe with squeegee). From here the paste is directed inside the cylinder roller. The fill volume of this so-called printing paste input system is quite high and as a consequence the amount of paste residue that has to be removed at each colour change is also fairly significant. Various systems have been introduced in order to lower the volume configuration of this equipment, which also reduces the amount of such wastes (see Section 4.6.1.5). Another possibility, which has also already been implemented in some companies, is to recover and reuse these residues for making up new recipes (see Sections 4.6.1.6 and 4.6.1.7).
Rotary-screen printing machines are equipped with both gluing and washing devices analogous to those described earlier for flat-screen printing. The belt is washed in order to remove the residues of paste and adhesive. Not only the belt, but also the screens and the paste input systems (hoses, pipes, pumps, squeegees, etc.) have to be cleaned at each colour change.

2.8.2.3 **Roller printing**

In roller printing, the printing paste is supplied from reservoirs to rotating copper rollers, which are engraved with the desired design (see Figure 2.23 and Figure 2.24 below). These rollers are brought into contact with a main cylinder roller that transports the fabric. By the contact between the rollers and the fabric, the design is transferred to the fabric. As many as 16 rollers can be available per print machine, each roller imprints one repeat of the design. As the roller spins, a doctor blade in continuous mode scrapes the excess paste back to the colour trough. At the end of each batch, the paste reservoirs are manually emptied into appropriate printing paste batch containers and squeezed out. The belt and the printing gear (roller brushes or doctor blades, squeegees and ladles) are cleaned with water.
Jet printing is a non-contact application system originally developed for printing carpets, but now increasingly used in the textile sector.

The first commercial jet printing machine for carpets was the Elektrocolor, followed by the first Millitron machine. In the Millitron printing system, the injection of the dye into the substrate is accomplished by switching on and off a dye jet by means of a controlled air stream. As the carpet fabric moves along, no parts of the machine are in contact with the face of the substrate. Air streams are used to keep continuously flowing dye jets, deflected into a catcher or drain tray. This dye is drained back to the surge tank, filtered and recirculated. When a jet is requested to fire, the air jet is momentarily switched off, allowing the correct amount of dye to be injected into the textile substrate. The dye is supplied in continuous mode to the main storage tank to compensate for the amount of dye consumed. A schematic representation of a jet printing machine is given in Figure 2.25 below.
Figure 2.25: Schematic representation of the Millitron system a jet printing machine

Spray printing systems and first-generation jet printing methods cannot be controlled to produce a pre-specified pattern. Thus the equipment must first be employed to produce a wide range of effects and only then can selections be made from these by the designer or marketing staff.

An early improvement was made by the first digital carpet printers (Chromotronic and Titan by Zimmer and Tybar Engineering, respectively). These machines are based on the so-called ‘drop on demand principle’, namely the use of switchable electromagnetic valves placed in the dye liquor feed tubes to allow the jetting of discrete drops of dye liquor in a predetermined sequence according to the desired pattern.

In these machines, although the amount of dye applied can be digitally controlled at each point of the substrate, further penetration of the dye into the substrate is still dependent on capillary action of the fibre and fibre surface wetting forces. This can lead to problems of reproducibility (e.g. when the substrate is too wet) and means that it is still necessary to use thickeners to control the rheology of the dye liquor.

The latest improvement in jet printing of carpet and bulky fabrics is now represented by machines in which the colour is injected with surgical precision deep into the face of the fabric without any machine parts touching the substrate. Here, the control of the quantity of liquor applied to the substrate (which may vary for example from lightweight articles to heavy quality fabrics) is achieved by varying not only the ‘firing time’ but also the pumping pressure.

This system can be likened to an “injection dyeing” process. The name “injection dyeing” is used as a commercial name to define the technology applied on the latest Milliken’s Millitron machine. Another digital jet printing machine commercially available is Zimmer’s Chromojet. In the Chromojet system, the printing head is equipped with 512 nozzles. These are
magnetically controlled and can open and close up to 400 times a second (see also Section 4.7.8).

The carpet is accumulated into a J-shaped box ("J-box"), and is then steamed and brushed. When it reaches the printing table, it is stopped. The jets are mounted on a sliding frame that can itself be moved in the direction of the warp while the carpet remains stationary during the printing process.

Ink-jet printing is another digital printing technique with its origins in paper printing technology that is now also increasingly used in the textile industry. In ink-jet printing, colour is applied to the surface of the substrate without variation in firing time, pressure or velocity. For this reason, it can only be applied for flat, light fabrics, especially silk (see also Section 4.6.1.3).

The TAK printing system can still be found in the carpet industry (see Figure 2.26). With this technique, irregular patterns can be produced. The carpet, previously dyed with a ground shade, is provided with coloured spots through dripping. The size and the frequency of the coloured spots can be varied by adjusting the overflow groove placed along the carpet width.

![Schematic representation of the TAK system](source: [63, GuT/ECA, 2000])

Figure 2.26: Schematic representation of the TAK system

### 2.8.2.5 Transfer printing

The pattern is first created on an intermediate carrier (e.g. paper) using selected disperse dyes and then it is transferred from there to the fabric by applying high temperature and pressure (using a heat press or a calender). Transfer printing is used for synthetic fibres.

See also Section 4.6.1.4.

[135, RICARDO 2019] [147, Sinocolor 2019]

### 2.8.3 Environmental issues

Emission sources typical of printing processes are:

- printing paste residues;
- waste water from wash-off and cleaning operations;
- volatile organic compounds from drying and fixing.
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2.8.3.1 Printing paste residues

Printing paste residues are produced for different reasons during the printing process and the amount can be particularly relevant (Section 3.7.5 provides information about consumption and emission levels). Two main causes are, for example, incorrect measurements and the common practice of preparing excess paste to prevent a shortfall.

Moreover, at each colour change, printing equipment and containers (dippers, mixers, homogenisers, drums, screens, stirrers, squeegees, etc.) are have to be cleaned. Printing pastes adhere to every implement due to their high viscosity and it is common practice to use dry capture systems to remove them before rinsing with water. In this way these residues can at least be disposed of in segregated form, thus minimising water contamination.

Another significant but often forgotten source of printing paste residues is the preparation of sample patterns. Sometimes they are produced on series production machines, which means high specific amounts of residues are produced.

There are techniques available that can help to reduce paste residues (see Section 4.6.1.5) and techniques for recovery/reuse of the surplus paste (see Sections 4.6.1.6 and 4.6.1.7). Their efficiency success is, however, limited due to a number of inherent technological deficiencies of analogue printing technology. Most of these deficiencies are related to the analogue transfer of the pattern, the unavoidable contact between the surface of the substrate and the applicator (screen) and the need for thickeners in the formulation (paste rheology), which limits the ultimate potential for paste reuse.

Digital printing offers a solution to these problems (see Sections 4.6.1.2 and 4.6.1.3).

2.8.3.2 Waste water from wash-off and cleaning operations

Waste water in printing processes is generated primarily from final washing of the fabric after fixation, cleaning of application systems in the printing machines, cleaning of colour kitchen equipment and cleaning of belts.

Waste water from cleaning-up operations accounts for a large share of the total pollution load, even more than water from wash-off operations.

Emission loads to water are mainly attributable to dyestuff printing processes because in the case of pigment printing, although considerable amounts of waste water arise from cleaning operations, pigments are completely fixed on the fibre without need for washing off.

Pollutants that are likely to be encountered in waste water are listed in Table 2.21 below.
Table 2.21: Pollutants that are more likely to be encountered in waste water from printing processes

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Source</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic dyestuff</td>
<td>Unfixed dye</td>
<td>The related environmental problems depend on the type of dyestuff concerned (these are discussed in Section 9)</td>
</tr>
<tr>
<td>Urea</td>
<td>Hydrotropic agent</td>
<td>High levels of nitrogen contribute to eutrophication</td>
</tr>
<tr>
<td>Ammonia</td>
<td>In pigment printing pastes</td>
<td>High levels of nitrogen contribute to eutrophication</td>
</tr>
<tr>
<td>Sulphates and sulphites</td>
<td>Reducing agent by-products</td>
<td>Sulphites are toxic to aquatic life and sulphates may cause corrosion problems when the concentration is &gt; 500 mg/l</td>
</tr>
<tr>
<td>Polysaccharides</td>
<td>Thickeners</td>
<td>High COD, but easily biodegradable</td>
</tr>
<tr>
<td>CMC derivatives</td>
<td>Thickeners</td>
<td>Hardly biodegradable and hardly bioeliminable</td>
</tr>
<tr>
<td>Polyacrylates</td>
<td>Thickeners</td>
<td>Hardly biodegradable, but &gt; 70 % bioeliminable (OECD 302B test method)</td>
</tr>
<tr>
<td>Glycerin and polyols</td>
<td>Anti-freeze additives in dye formulation Solubilising agents in printing pastes</td>
<td>Hardly biodegradable and water-soluble</td>
</tr>
<tr>
<td>m-Nitrobenzene sulphonate and its corresponding amino derivative</td>
<td>In discharge printing of vat dyes as oxidising agent In direct printing with reactive dyes, it inhibits chemical reduction of the dyes</td>
<td>Hardly biodegradable and water-soluble</td>
</tr>
<tr>
<td>Polyvinyl alcohol</td>
<td>Blanket adhesive</td>
<td>Hardly biodegradable, but &gt; 90 % bioeliminable (OECD 302B test method)</td>
</tr>
<tr>
<td>Multiple-substituted aromatic amines</td>
<td>Reductive cleavage of azo dyestuff in discharge printing</td>
<td>Hardly biodegradable and hardly bioeliminable</td>
</tr>
<tr>
<td>Mineral oils / aliphatic hydrocarbons</td>
<td>Printing paste thickeners (half-emulsion pigment printing pastes are still occasionally used)</td>
<td>Aliphatic alcohols and hydrocarbons are readily biodegradable Aromatic hydrocarbons are hardly biodegradable and hardly bioeliminable</td>
</tr>
</tbody>
</table>

2.8.3.3 Volatile organic compounds from drying and fixing

Drying and fixing are another important emission source in printing processes. The following pollutants may be encountered in the exhaust air [179, UBA, 2001]:

- aliphatic hydrocarbons (C_{10}-C_{20}) from binders;
- monomers such as acrylates, vinylacetates, styrene, acrylonitrile, acrylamide, butadiene;
- methanol from fixation agents;
- other alcohols, esters, polyglycols from emulsifiers;
- formaldehyde from fixation agents;
- ammonia (from urea decomposition and from ammonia present, for example, in pigment printing pastes);
- N-methylpyrrolidone from emulsifiers;
- phosphoric acid esters;
- phenylcyclohexene from thickeners and binders.
A more comprehensive list of pollutants potentially present in the exhaust air from heat treatment after printing, with an indication of the potential source, is given in Chapter 12.
2.9 Finishing (functional finishing)

2.9.1 Finishing processes

The term ‘finishing’ covers all those treatments that serve to impart to the textile the desired end-use properties. These can include properties relating to visual effect, handle and special characteristics such as waterproofing and non-flammability.

Finishing may involve mechanical/physical and chemical treatments. Moreover, among chemical treatments, one can further distinguish between treatments that involve a chemical reaction of the finishing agent with the fibre and chemical treatments where this is not necessary (e.g. softening treatments).

Some finishing treatments are more typical for certain types of fibre (for example, easy-care finishes for cotton, antistatic treatment for synthetic fibres and mothproofing and anti-felt treatments for wool). Other finishes have a more general application (e.g. softening).

In this document, particular attention is given to chemical finishes because these are the processes with the most significant polluting potential.

In the case of fabric (including carpets in piece form), the finishing treatment often takes place as a separate operation after dyeing. However, this is not a rule: in carpets, for example, mothproofing can be carried out during dyeing and, in pigment dyeing, resin finishing and pigment dyeing are combined in the same step by applying the pigment and the film-forming polymer in the dyeing liquor.

In more than 80% of cases, the finishing liquor, in the form of an aqueous solution/dispersion, is applied by means of padding techniques. The dry fabric is passed through the finishing bath containing all the required ingredients, and is then passed between rollers to squeeze out as much as possible of the treating solution before being dried and finally cured. Washing as final step tends to be avoided unless absolutely necessary.

In order to reduce the pick-up, other so-called minimum application techniques are gaining importance. These are topical application methods like:

- kiss-roll (or slop-padding) application (the textile is wetted by means of a roller, which is immersed in a trough and which applies a controlled amount of liquor on only one side of the textile);
- spray application;
- foam application.

In the case of foulard application the pick-up is approximately 70%, while with minimum application systems this can be about 30%. In the minimum application techniques, however, the liquors are more concentrated by a factor of 2 to 3 in order to allow the same amount of active ingredient to be applied.

In the wool yarn carpet sector, the functional finishes are applied to the yarn or to the loose fibre either during the dyeing process or in the subsequent rinsing or finishing bath.

Apart from particular cases where there are problems of incompatibility between the different auxiliaries, both with padding and long liquor application techniques (batch processes), all the finishing agents necessary to give the textile material the desired properties are applied in a single bath rather than in different steps.
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2.9.2 Chemical finishing treatments

2.9.2.1 Easy-care treatments

Easy-care finishings are applied to cellulose-containing fibres to impart characteristics such as easy-to-wash, creasing resistance during wash and wear, no ironing or minimum ironing. These properties are now required for cellulose fibres to allow them to compete with synthetic fibres such as polyamide and polyester.

Easy-care recipes consist of various ingredients:

- cross-linking agent;
- catalyst;
- additives (softeners, hand builder most commonly, but also water-repellents, hydrophilising agents, etc.);
- surfactants as wetting agent.

Information about the typical substances used can be found in Section 8.8.1. In the easy-care process, the fabric, after being padded, is dried in open-width in a stenter frame and is finally cured. The most common curing method is the dry cross-linking process, in which the fabric is cured in a dry state in a curing apparatus or on the stenter immediately after drying.

2.9.2.2 Water- and oil-repellent treatments (hydrophobic and oleophobic treatments)

Water-repellent treatments are applied to fabrics for which waterproofing properties are required but which also need air and water-vapour permeability.

This may be obtained by:

- precipitation of hydrophobic substances such as paraffin emulsions together with aluminium salts (e.g. wax-based repellents);
- chemical transformation of the surface of the fibre by addition of polymers that form a cross-linked water-repellent film (e.g. silicone repellents, resin-based repellents, fluorochemical repellents).

Oil-repellent treatments are applied to fabrics for which oil-proofing is required. This may be obtained by chemical transformation of the surface of the fibre by addition of polymers that form a cross-linked oil-repellent film (mainly fluorochemical-based repellents). [121, Manich et al., 2018]

In addition to providing protection against water, oil and soil, these finishes also extend the life of products and keep them looking newer for longer. Water and oil repellence has historically been achieved with textile finishes that contain a polymer to which long-chain perfluoroalkyl groups have been attached. These long-chain fluorinated polymers often contain residual raw materials and trace levels of long-chain perfluoroalkyl acids (PFAAs) as impurities. The residual raw materials and the product themselves may degrade in the environment to form long-chain PFAAs.

Since the 1950s, long-chain PFAAs as well as polymers and surfactants containing long-chain perfluoroalkyl functionality that may degrade to form long-chain PFAAs have been widely used in numerous industries and commercial applications. As a result of the widespread use, long-chain PFAAs including PFOA and PFOS have been detected globally in the environment, wildlife and humans. PFOA and PFOS, the most widely known and studied long-chain PFAAs,
have been shown to be persistent in the environment, have long elimination half-life in wildlife and humans, and have toxicological properties of concern. Due to these properties, regulatory actions have been put in place or are being considered to manage these substances [121, Manich et al. 2018]. In the EU, PFOA and its salts have been listed in Annex XVII to REACH [79, EU 2006] since 2017 and PFOS are priority hazardous substances [112, EC 2008] and prohibited by the POPs Regulation (EC/850/2004) [90, EU 2004].

Section 4.7.5.1 gives some examples of alternatives to fluorochemical-based repellents.

The characteristics of the substances used as water repellents are described in Section 8.8.5.

### 2.9.2.3 Softening treatments

Softeners are used not only in finishing processes, but also in batch dyeing processes, where they are applied in the dye baths or in the subsequent washing baths.

The application of softening agents does not involve curing processes. In continuous or semi-continuous processes, the impregnated fabric is dried in the stenter frame.

The substances used as softening agents are described in Section 8.8.6.

### 2.9.2.4 Flame-retardant treatments

Flame-retardant finishing has become more and more important and is compulsory for some articles. Flame-retardant treatments should protect the fibre from burning, without modifying the handle, the colour or the look of the fabric.

They are generally applied to cotton and synthetic fibres (e.g. they are important in the furniture sector for upholstery fabric). In some specific cases, in particular in the carpet sector (e.g. contract market, aviation), they can also be required for wool, even though this fibre is already inherently flame-resistant.

Flame-retardant properties are achieved by the application of a wide range of chemicals, which either react with the textile or are used as additives. Substances that are usually used as flame-retardant finishing treatments are described in Section 8.8.4.

There are other approaches available to produce textile products with flame-retardant properties including:

- the addition of specific chemicals in the spinning solution during fibre manufacturing;
- the development of modified fibres with inherent flame-retardant properties;
- back-coating of finished textile-covered articles (e.g. furniture, mattresses), whereby a fire-resistant layer is attached to one side of the finished textile.

### 2.9.2.5 Antistatic treatments

The process consists of treating the fabric with hygroscopic substances (antistatic agents) which increase the electrical conductivity of the fibre, thus avoiding the accumulation of electrostatic charge.

These finishing treatments are very common for synthetic fibres, but they are also applied to wool in the carpet sector for floor coverings that have to be used in static-sensitive environments.
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The substances commonly used as antistatic agents are described in Section 8.8.3.

2.9.2.6 Mothproofing treatments

The mothproofing of wool and wool blends is mainly restricted to the production of textile floor coverings, but some high-risk apparel is also treated (for example military uniforms). For apparel application, mothproofing is usually carried out in dyeing. Floor coverings may be mothproofed at different stages of the production processes, such as during raw wool scouring, spinning, yarn scouring, dyeing, finishing or later in the backing line.

The biocides used in the mothproofing treatments are described in Section 8.8.2.

2.9.2.7 Bactericidal and fungicidal treatments

These finishes may be applied to chemicals (to preserve auxiliaries and dye formulations) and to apparel, for example in odour suppressant for socks and for the treatment of floor coverings for the healthcare sector and to provide anti-dust-mite finishes. Close analysis shows that more and more textile products (clothing and underwear) are being treated with anti-microbial agents.

The products used are biocides: they are mentioned in Section 8.8.2.

2.9.2.8 Anti-UV treatments

The anti-UV protection consists of nano-dispersion of titanium dioxide and is applied on the fabrics by padding. Dosing of chemicals is done automatically, in a closed-circuit system connected to the bath of the pad to avoid possible human contact. During the drying process, the temperature is controlled in order to avoid migration to air of non-fixed nanoparticles.

The most relevant environmental impacts associated with the product used are related to the potential waste water pollution by nano-TiO$_2$ coming from the liquid bath of the padding process, since the nano-TiO$_2$ could disrupt aquatic ecosystems’ carbon and nitrogen cycles. However, this impact is minimised by the automated control of the dosing and dispensing of chemicals and the reduction of the volume of the padding liquor. [151, LEITAT 2016]

2.9.2.9 Anti-felt treatments

Anti-felt finishing is applied in order to provide anti-felt properties to the good. This will prevent shrinking of the finished product when it is repetitively washed in a laundry machine.

Two treatments, which are also complementary, are applied:

- oxidising treatment (subtractive treatment);
- treatment with resins (additive treatment).

These treatments can be applied at any stage of the process and on all different make-ups. They are most commonly applied on combed tops for specific end-products (e.g. underwear).

2.9.2.9.1 Oxidising treatments
In the oxidising treatment, the specific chemicals used attack the scales of the cuticles and chemically change the external structure of the fibre.

This treatment has traditionally been carried out using one of the following chlorine-releasing agents:

- sodium hypochlorite;
- sodium salt dichloroisocyanurate;
- active chlorine (no longer used).

The oldest process is the one using sodium hypochlorite. However, since the development of active chlorine is difficult to control, wool fibre characteristics can be deeply changed, also giving irregular results. Dichloroisocyanurate is more advantageous here because it has the ability to release chlorine gradually, thereby reducing the risk of fibre damage.

The process with dichloroisocyanurate (Basolan process licensed by BASF) consists of impregnating the material in a bath (35 °C) containing the oxidant, sodium sulphate and an auxiliary (surfactant). After 20-30 minutes the material is rinsed, then it is submitted to an anti-chlorine treatment with 2-3 % sodium bisulphite and rinsed again.

All these chlorine-based agents have recently encountered restrictions because they react with components and impurities (soluble or converted into soluble substances) in the wool, to form absorbable organic chlorine compounds (AOX).

Alternative oxidising treatments have therefore been developed. In particular, peroxysulphate, permanganate, enzymes and corona discharge come into consideration. However, the only alternative to chlorine-based agents readily available today is peroxysulphate.

The process with peroxysulphate compounds is quite similar to the chlorine treatment, but does not involve the use of chlorine and does not generate chloroamines. The material is treated with the oxidising agent in acid liquor at room temperature until the active oxygen has been largely consumed.

Both with chlorine-based agents and peroxysulphate, sodium sulphite is then added as an antioxidant to the same liquor at slightly alkaline pH. This is a reductive after-treatment to avoid damage and yellowing of the wool fibre at alkaline pH.

The goods are subsequently rinsed. If necessary, they are treated with a polymer (see treatments with resins below).

### 2.9.2.9.2 Treatments with resins (additive processes)

In additive processes, polymers are applied to the surface of the fibre with the aim of covering the scales with a ‘film’. However, this treatment must be regarded as a pseudo felt-free finishing process, as it is not the felting propensity that is reduced, but merely the effect thereof.

The polymer must have a high substantivity for wool. Cationic polymers are the most suitable for this treatment because, after the previous oxidative and reductive pretreatment, the wool surface becomes anionic.

The polymer may, in some case, be sufficiently effective on its own to make pretreatment unnecessary. However, the combination of subtractive and additive processes has the greatest technical effect.
Combined treatments: Hercosett process

The oldest combination process is the so-called Hercosett process (by C.S.I.R.O.), which consists of chlorine pretreatment followed by application of a polyamide-epichlorohydrin resin.

Whilst the Hercosett process can be carried out in batch or continuous mode, the latter is predominant nowadays.

The continuous process consists of the following steps (see Figure 2.27):

- chlorine treatment in an acid medium (using chlorine gas or sodium hypochlorite);
- reduction of chlorine using sulphite in the same bath;
- rinsing;
- neutralisation with sodium carbonate;
- rinsing;
- resin application;
- softener application;
- drying and polymerisation.

![Figure 2.27: Schematic representation of the Hercosett process](image)

The Hercosett process has been widely used for years as anti-felt finishing of wool in different states (loose fibre, combed top, yarn, knitted and woven fabric) due to its low cost and high quality effects. However, the effluent shows high concentrations of COD and AOX. The formation of AOX is attributable not only to the oxidant, but also to the resin. In fact, the typical resin applied in the Hercosett process is a cationic polyamide whose manufacturing process involves the use of epichlorohydrin, which is another source of the chlorinated hydrocarbons in the effluent.

Alternative resins have been developed, based on polyethers, cationic aminopolysiloxanes, synergic mixtures of polyurethanes and polydimethylsiloxanes, but they all have some limitations concerning their applicability.

New processes have also been developed, but so far the results achieved with the Hercosett process cannot be fully matched by any alternative, which is why it is still the preferred process particularly for treatments such as the anti-felt finishing of combed tops.

It should also be noted that a more environmentally friendly chlorine-free Hercosett process has been developed (see Section 4.7.6.1).
2.9.3 Environmental issues

Among textile finishing processes, the chemical ones are those that are more significant from the point of view of the emissions generated. As in dyeing, the emissions are relatively different between continuous and discontinuous processes. Therefore this distinction will be used in the discussion of the main environmental issues associated with finishing. Anti-felt treatments represent a peculiar type of finishing both in terms of applied techniques and emissions. The environmental issues related to this process are therefore discussed in Section 2.9.2.8 together with the description of the process itself.

Environmental issues associated with continuous finishing processes

With some exceptions (e.g. application of phosphor-organic flame retardant), continuous finishing processes do not require washing operations after curing. This means that the possible emissions of relevance to water pollution are restricted to the system losses and to the water used to clean all the equipment. In a conventional foulard, potential system losses at the end of each batch are:

- the residual liquor in the chassis;
- the residual liquor in the pipes;
- the leftovers in the batch storage container from which the finishing formulation is fed to the chassis.

Normally these losses are in the range of 1-5 %, based on the total amount of liquor consumed; it is also in the finisher’s interest not to pour away expensive auxiliaries. However, in some cases, within small commission finishers, losses of up to 35 % or even 50 % may be observed. This depends on the application system (e.g. size of foulard chassis) and the size of the lots to be finished. In this respect, with application techniques such as spraying, foam application and slop-padding (to a lesser extent due to the high volume of residues in the system) system losses are much lower in terms of volume (although more concentrated in terms of active substances).

Residues of concentrated liquors are reused, if the finishing auxiliaries applied show sufficient stability, or otherwise disposed of separately as waste destined for incineration (see Section 4.1.7.2). However, too often these liquors are drained and mixed with other effluents.

Although the volumes involved are quite small when compared with the overall waste water volume produced by a textile mill, the concentration levels are very high, with active substances contents in the range of 5-25 % and COD of 10 g/litre to 200 g/litre. In the case of commission finishing mills working mainly on short batches, the system losses can make up a considerable amount of the overall organic load. In addition, many substances are difficult to biodegrade or are not biodegradable at all and sometimes they are also toxic (e.g. biocides have a very low COD, but are highly toxic).

The range of pollutants that can be found in the waste water varies widely depending on the type of finish applied. The typical pollutants and the environmental concerns associated with the use of the most common finishing agents are discussed in Section 8.8. In particular, the release of the following substances in the environment gives rise to significant concerns:

- ethylene urea and melamine derivatives in their ‘not cross-linked form’ (cross-linking agents in easy-care finishes);
- organo-phosphorous and polybrominated organic compounds (flame-retardant agents);
- polysiloxanes and derivatives (softening agents);
- alkylyphosphates and alkyetherphosphates (antistatic agents);
- fluorochemical repellents.
Concerning the anti-UV treatment with TiO₂ (see Section 2.9.2.8), waste water treatment plants are capable of removing the majority of TiO₂ nanomaterials but TiO₂ particles measuring between 4 nm and 30 nm have still been found in the treated effluent. These nanomaterials are then released to the surface waters where they can interact with living organisms. TiO₂ nanomaterials that are absorbed in the treatment plants may still end up in the environment if the biomass is landspread. Though the release of TiO₂ nanomaterials to the environment has been shown, it is difficult to quantify how much is released. Once in the environment, even less is known about how organisms are affected by nano-TiO₂. [151, LEITAT 2016]

In the drying and curing operation, emissions to air are produced due to the volatility of the active substances themselves as well as that of their constituents (e.g. monomers, oligomers, impurities and decomposition by-products). Furthermore, emissions to air (sometimes accompanied by odours) are associated with the residues of preparations and fabric carry-over from upstream processes (for example, polychlorinated dioxins/furans may arise from the thermal treatment of textiles that have been previously treated with chlorinated carriers or perchloroethylene).

The emission loads depend on the drying or curing temperature, the quantity of volatile substances in the finishing liquor, the substrate and the potential reagents in the formulation. The range of pollutants is very wide and depends on the active substances present in the formulation and again on the curing and drying parameters. In most cases, however, the emissions produced by the single components of the finishing recipes are additive. As a result, the total amount of organic emissions in the exhaust air (total organic carbon and specific problematic compounds such as carcinogenic and toxic substances) can easily be calculated by means of emission factors given for the finishing recipes by manufacturers (see also Section 4.1.2.4). Note, however, that Germany is the only Member State where there is a fully developed system in which the manufacturers provide the finisher with such information on the products supplied.

Another important factor to consider regarding emissions to air is that the directly heated (methane, propane, butane) stenters themselves may produce relevant emissions (non-combusted organic compounds, CO, NOX, formaldehyde). Emissions, for example, of formaldehyde up to 300 g/h (2-60 mg/m³) have been observed in some cases, which were attributable to inefficient combustion of the gas in the stenter frame [179, UBA, 2001]. It is therefore obvious – when speaking about emissions to air – that the environmental benefit obtained by the use of formaldehyde-free finishing recipes is totally lost if the burners in the stenter frames are poorly adjusted and produce high formaldehyde emissions.

The active substances in the most common finishing agents and the possible associated emissions to air are discussed in Section 8.8. Moreover, a more comprehensive list of pollutants that can be found in the exhaust air from heat treatments in general is reported in Chapter 12.

Environmental issues associated with discontinuous processes
The application of functional finishes in "long liquor" (liquor used in the preceding process, e.g. dyeing or rinsing) by means of batch processes is used mainly in yarn finishing and in the wool carpet yarn industry in particular. Since the functional finishes are generally applied either in the dye baths or in the rinsing baths after dyeing, this operation does not entail additional water consumption with respect to dyeing. For the resulting emissions to water, as with batch dyeing, the efficiency of the transfer of the active substance from the liquor to the fibre is the key factor which influences the emission loads. The efficiency depends on the liquor ratio and on many other parameters such as pH, temperature and the type of emulsion (micro- or macro-emulsion). Maximising the efficiency is particularly important when biocides are applied in mothproofing finishing. As mothproofing agents are not water-soluble, they are applied from emulsions. The degree of emulsification and the pH are critical in the application of mothproofing agents (i.e. the efficiency of the process is higher when the active substance is applied from micro-emulsions and at acidic pH). Note here that the finishing agents are dosed based on the weight of the fibre and not on the amount of bath (in g/litre).
The pollutants that may be encountered in waste water vary depending on the finishing agents applied; Section 8.8 gives more details. The main issues worth mentioning are the application of mothproofing agents (emissions of biocides) and the low level of exhaustion of softeners (emissions of poorly biodegradable substances).
Chapter 2

2.10 Coating and laminating

2.10.1 Coating and laminating processes

Usually, coated and laminated textiles consist of a textile substrate - typically a woven, knitted, or non-woven textile fabric - combined with a thin, flexible film of natural or synthetic polymeric substances.

A coated fabric usually consists of a textile substrate on which the polymer is applied directly as a viscous liquid. The thickness of the film is controlled by applying it via a blade or similar aperture.

A laminated fabric usually consists of one or more textile substrates, which are combined with a pre-prepared polymer film or membrane by adhesives or heat and pressure.

The basic techniques for coating/laminating fabrics require the following conditions:

- the fabric to be coated/laminated is supplied full width on a roll;
- the fabric is fed under careful tension control to a coating or laminating heat zone;
- after application of the coating auxiliaries, the fabric is passed through an oven to cure the composite and remove volatile solvents before cooling and rolling up.

Flame lamination

In the textile industry, the flame lamination of foams is a widely used technique: a pre-prepared thin, thermoplastic foam sheet is exposed to a wide slot flame burner located before the laminating rolls. No drying or curing oven is required in this process. Emissions to air produced during this treatment are highly irritant and may trigger an allergic reaction in susceptible persons.

In principle, the main characteristic of flame lamination is the generation of thermal plasma which generates a surface modification of the joining materials. The joining materials (mainly foamed plastic) are used to build up adhesive strength between the media. No additional adhesives are necessary. [36, ÖKOPOL 2011]

Hot-melt lamination

[36, ÖKOPOL 2011] [175, Weydts et al. 2019]

Generally, lamination is defined as the production of composite materials by the adhesion of different substrates. In hot-melt lamination, melted solvent-free polymers are applied to textile fabrics by appropriate aggregates.

Thermoplastic or reactive adhesives e.g. reactive polyurethanes (PUR), thermoplastic copolyester, copolyamide, EVA (ethylene-vinylacetate copolymer) polymers as well as non-cross-linking polyurethanes are used.

In a first step, the hot-melt adhesives must be melted. Normally, non-reactive thermoplastics like EVA are melted at temperatures between 150 °C and 180 °C in a melting tank. An extruder is used for copolyester and copolyamide (the operational temperature range is approximately 190 °C to 230 °C), although some polyamide can be used in a melting tank too. Reactive PUR adhesives are melted in drums with a drum-melter, in hobbocks or in tanks under an inert gas atmosphere, as cross-linking of the PUR adhesives is initiated by moisture. The operational temperature of moisture-reactive adhesives is between 80 °C and 150 °C.

Technologies for coating and laminating of textile fabrics are roller coating, spray-on coating and slot die coating.
Multi-roller and gravure roller technology as well as hot-melt screen printing coating are part of contact coating methods. When using the multi-roller equipment, the adhesive is charged between the first two rollers, metered out by the second roller and then applied to the substrate on the counter-pressure roller. In embossing cylinder processing, the melted mass is carried by rollers or doctor finishing machines into the indentation of the cylinder and transferred to the textile fabric via the counter-pressure roller. The polymer melt in hot-melt screen printing coating is applied through a heat-resistant screen with a doctor blade, resulting in dot coating.

Figure 2.28 below shows a representation of the multi-roller, the embossing cylinder process and a third method, the disperse powder coating.

Compact or open breathable adhesive layers can also be applied with the help of slot dies (see Figure 2.29 below). Heat treatment (infrared) of reactive PUR or adhesives with sufficiently long operating times before roll laminating is not necessary.

As an alternative to contact coating, spray-on coating can be used for fleecy substrates or substrates with low density. Spray-on coating and slot die coating are closed systems, i.e. the adhesive has no contact with the environment between melting and application. This prevents input of particles like dust or fibres leading to breakdowns during processing.

To prevent the cooling of the thermoplastic adhesives, an infrared radiator (80-160 °C) can be installed in front of the laminating calendar or nip roller.

In continuous operation, cleaning of feeding tubes and application advices using reactive adhesives is not necessary. If the adhesives have no contact with air, they can be reused at any time. For thermoplastic adhesives, cleaning of feeding systems is not necessary at all.
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Contamination of the application equipment during operation is possible. Cleaning intervals depend on the adhesives used and the textile substrates. During longer production stoppages, for reactive polyurethanes, the whole amount of adhesive is rinsed with a non-reactive product to avoid curing. For this purpose, adhesive producers offer solvent-free, liquid, surface-active cleaning products.

The typical coating compounds and auxiliaries used are described in Section 8.9.

2.10.2 Carpet back-coating

The backing process is an important production step which is applied to improve the stability of textile floor coverings. Moreover, backing may have a positive influence on properties such as soundproofing, stepping elasticity and heat insulation.

One can distinguish the following types of coatings:

- pre-coating;
- foam coating;
- textile back-coating;
- heavy coating;
- reinforcement;
- back finish.

Pre-coating

A common feature of tufted carpets is that they are pre-coated after tufting to permanently anchor the needled pile loops in the carrier layer (Figure 2.30). The pre-coating material used consists of:

- x-SBR latex, which is a dispersion containing a copolymer produced from styrene, butadiene and carbonic acid;
- fillers;
- water;
- additives (e.g. thickeners, anti-foaming agents, foam stabilisers).

![Pre-coated tufted carpet](source: [63, GuT/ECA, 2000])

Figure 2.30: Pre-coated tufted carpet
The pre-coating can be applied:

- unfoamed, by means of slop-padding (Figure 2.31);
- foamed, by means of the doctor-blade technique (Figure 2.32).

Figure 2.31: Pre-coating application by slop-padding

During the subsequent drying stage, thanks to the formation of hydrogen bonds, the polymer chains are woven into a three-dimensional web and an elastic plastic layer is produced.

**SBR foam coating**

Foam coating methods consist of the application of a foam layer onto a pre-coated carpet, as the following figure Figure 2.33 shows.

The foam finish is achieved in two steps: foam application and foam solidification through drying. The lattice is foamed with air and then applied by means of a doctor blade onto the pre-coated carpet.

The SBR foam must be stabilised until it is solidified in the vulcanisation oven. For this stabilisation, two methods are used:
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- the non-gel process, which uses surfactants as foam stabilisers;
- the gel process, which uses ammonium acetate (AA gel system) or silicium fluoride (SF gel system) as gelling agents.

The overall process is schematised in Figure 2.34.

![Figure 2.34: Representation of the SBR foam coating process](image)

Source: [63, GuT/ ECA, 2000]

The foam is composed of:

- the SBR colloidal dispersion;
- a paste, which contains a number of active additives;
- inactive fillers (mainly chalk, which is added to the ready-compounded paste);
- water;
- thickeners (e.g. polyvinyl alcohol, methyl cellulose, polyacrylates);
- colourants and pigments;
- anti-oxidants and ozone stabilisers.

Some of the active components of the paste are responsible for the environmental impact of this coating method. In order to better identify the emission sources, they can be divided as follows shown in Table 2.22 below.

**Polymerisation additives:**

<table>
<thead>
<tr>
<th>Type of additives</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam stabilisers</td>
<td></td>
</tr>
<tr>
<td>Cross-linkers</td>
<td>Usually sulphur, but also peroxides</td>
</tr>
<tr>
<td>Vulcanisation accelerators</td>
<td>Mercaptobenzothiazoles (e.g. zinc mercaptobenzothiazole)</td>
</tr>
<tr>
<td></td>
<td>Dithiocarbamates, such as zinc diethyldithiocarbamate or zinc dibenzylidithiocarbamate or zinc dibutyldithiocarbamate (the most commonly used one)</td>
</tr>
<tr>
<td>Activators</td>
<td>Usually combination of ZnO and stearic acid (one source reports that ZnO is not necessary for non-gel and some SF applications [281, Belgium, 2002])</td>
</tr>
</tbody>
</table>

**Processing additives:**

<table>
<thead>
<tr>
<th>Type of additives</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foaming agents and stabilisers</td>
<td>Surfactants</td>
</tr>
<tr>
<td>Gelling agent</td>
<td>e.g. Ammonium acetate (AA gel system) or silicium fluoride</td>
</tr>
</tbody>
</table>
Hydrophobic substances in order to improve the foam surface and the water-repellent properties | Paraffin dispersions and silicon emulsions
---|---
Complexing agents, to chelate metal ions (they behave as catalysts for ageing the foam layer) | e.g. EDTA, DTPA, polyphosphates
Antioxidants | 
Thickeners | Organic polymers based on polyacrylates and cellulose (e.g. CMC)

Functional additives:

- UV stabilisers;
- Antistatic agents;
- Flame retarding agents (e.g. Al₂O₃).
<table>
<thead>
<tr>
<th>Type of additives</th>
<th>Additives</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymerisation</td>
<td>Foam stabilisers</td>
<td>Usually sulphur, but also peroxides</td>
</tr>
<tr>
<td>additives</td>
<td>Cross-linkers</td>
<td>Mercaptobenzothiazoles (e.g. zinc mercaptobenzothiazole)</td>
</tr>
<tr>
<td></td>
<td>Vulcanisation accelerators</td>
<td>Dithiocarbamates (e.g. zinc diethylldithiocarbamate or zinc dibenzylidithiocarbamate or zinc dibutyldithiocarbamate (the most commonly used one))</td>
</tr>
<tr>
<td></td>
<td>Activators</td>
<td>Usually a combination of ZnO and stearic acid (one source reports that ZnO is not necessary for non-gel and some SF applications [281, Belgium, 2002])</td>
</tr>
<tr>
<td>Processing</td>
<td>Foaming agents and stabilisers</td>
<td>Surfactants</td>
</tr>
<tr>
<td>additives</td>
<td>Gelling agents</td>
<td>e.g. Ammonium acetate (AA gel system) or silicium fluoride (SF gel system)</td>
</tr>
<tr>
<td></td>
<td>Hydrophobic substances in order to improve the foam surface and the water-repellent properties</td>
<td>Paraffin dispersions and silicon emulsions</td>
</tr>
<tr>
<td></td>
<td>Complexing agents, to chelate metal ions (they behave as catalysts for ageing the foam layer)</td>
<td>e.g. EDTA, DTPA, polyphosphates</td>
</tr>
<tr>
<td></td>
<td>Antioxidants</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thickeners</td>
<td>Organic polymers based on polyacrylates and cellulose (e.g. CMC)</td>
</tr>
<tr>
<td>Functional</td>
<td>UV stabilisers</td>
<td></td>
</tr>
<tr>
<td>additives</td>
<td>Antistatic agents</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flame-retardant agents (e.g. Al2O3)</td>
<td></td>
</tr>
</tbody>
</table>

**PU foam coating**

Polyurethane is another method for foam coating. The ICI polyurethane coating process is the most commonly applied. The carpet is prepared by steaming and then reaches the spray chamber where the components of the polyurethane (diisocyanate and an alcohol) are sprayed. The CO2 produced during the chemical reaction is embedded into the foam. The coating is reinforced in an infrared heating field and in a subsequent reaction field. The process is schematically represented in the following diagram Figure 2.35.
Textile back-coating

Textile backing consists of the application of a textile fabric onto the pre-coated carpet (see Figure 2.36). The connection between the carpet and the textile fabric is obtained through the application of a layer of laminating glue and melting glue.

- laminating glue;
- melting glue.

Laminating glue

In this process, an x-SBR latex is applied to the carpet by slop-padding. After the application of the textile fabric, the final reinforcement of the latex is carried out by means of heat treatment (Figure 2.37). The latex composition is similar to that used for pre-coating, with a higher share of polymer dispersion in order to allow a higher adhesive power.
Melting glue

This system uses thermoplastic polymers (mainly polyethylene) which are meltable by means of heat. In powder lamination (and in particular in powder scattering lamination), polyethylene powder is evenly sprinkled onto the back of the carpet. Subsequently the polymer is melted in an infrared field. In the next stage, the fabric is pressed into the melting glue. Through subsequent cooling, the melting glue becomes permanently connected between the textile fabric and to the back of the carpet. The process is represented in Figure 2.38.

Another textile backing process by means of melting glue is the so-called AdBac process. In this case, the carpet is constructed using a primary cloth (carrier layer) with low-melting-point additives. In the next stage, the secondary cloth (also with a low melting point) is brought into contact with the back of the carpet before this enters the heating zone. The higher temperature melts the cloths, which are then forced together by nip rolls at the exit of the heating zone. The carpet is then cooled. A scheme of a carpet produced with the AdBac process is reported in Figure 2.39.
Heavy coating

Heavy coating is mainly used for the coating of self-laying (SL) tiles. The coating process consists of the application of the coating material by means of slop-padding or a doctor blade and subsequent reinforcement. In most cases, the coating material is applied in layers (two-coat technique). After the first layer, which may also serve as a pre-coating layer, a glass-fibre web may be added. The second coating application follows. The following coating materials are used:

- APO (abbreviation for ‘atactical polyolefin’);
- bitumen (enriched with inorganic and organic additives);
- PVC (polyvinylchloride);
- EVA (ethylen vinylacetate).

The process principle is schematised in Figure 2.40.

---

**Figure 2.39:** Carpet manufactured with the AdBac process

**Figure 2.40:** Representation of the heavy coating process


2.10.3 Environmental issues

The main environmental concerns in coating/laminating operations relate to emissions to air arising from solvents, additives and by-products contained in the formulations of the coating compounds. A distinction must therefore be made between the various products available (the following information is taken from [179, UBA, 2001]).

Coating powders

The emission potential of coating powders is in most cases negligible, with the exception of polyamide 6 and its copolymers (the residual monomer epsilon-caprolactam is released at standard process temperatures). In some cases, softeners (often phthalates) can be found in the emissions.

Coating pastes

The emissions from the coating pastes result mainly from the additives (except in the case of PA 6, which is mentioned above). These are mainly:

- fatty alcohols, fatty acids, fatty amines from surfactants;
- glycols from emulsifiers;
- alkylphenols from dispersants;
- glycol, aliphatic hydrocarbons, N-methylpyrrolidone from hydrotropic agents;
- aliphatic hydrocarbons, fatty acids/salts, ammonia from foaming agents;
- phthalates, sulphonamides/esters e.g. softeners/plasticisers;
- acrylic acid, acrylates, ammonia, aliphatic hydrocarbons from thickeners.

Polymer dispersions (aqueous formulations)

The emission potential of polymer dispersions is quite low compared to coating pastes. Components that are responsible for emissions to air are the dispersing agents, residual compounds from the polymerisation (especially tert-butanol used as catalyst in radically initialised polymerisation reactions) and monomers arising from incomplete reaction during polymerisation. The latter are particularly relevant to the workplace atmosphere and odour nuisances. They include:

- acrylates such as acrylic acid, butylacrylate, ethylacrylate, methylacrylate, ethylhexylacrylate and vinylacetate;
- carcinogenic monomers like acrylonitrile, vinylchloride, acrylamide, 1,3-butadiene and vinylcyclohexene.

Vinylcyclohexene is not often identified in the exhaust air. However, it is always formed (2 + 2 cycloaddition product) if 1,3-butadiene is used.

Acrylamide in the exhaust air is often related to formaldehyde emissions (reaction products of methylolacrylamide).

Melamine resins

Melamine resins are widely applied. Melamine resins are produced by the reaction of melamine and formaldehyde and subsequent etherification mostly with methanol in an aqueous medium. The products can contain considerable amounts of free formaldehyde and methanol. During their application, the cross-linking reaction of the resin with itself or with the fabric (e.g. cotton) is initiated by an acid catalyst and/or temperature, releasing stoichiometric amounts of methanol and formaldehyde.

Polymer dispersions (organic solvent-based formulations)

Solvent coating is not very common in the textile finishing industry. When this technique is applied, exhaust air cleaning equipment based on thermal incineration or adsorption on active carbon is normally installed.
2.11 Washing

2.11.1 Washing with water

Important factors in washing are:

- water characteristics;
- choice of soaps and detergents;
- hydromechanical action;
- temperature and pH;
- rinsing stage.

Washing is normally carried out in hot water (40-100 °C) in the presence of a wetting agent and a detergent. The detergent emulsifies the mineral oils and disperses the undissolved pigments. The choice of the surfactants may also vary depending on the type of fibre. Mixtures of anionic and non-ionic surfactants are commonly used. An important factor in the selection of a surfactant is its effectiveness in strong alkaline conditions.

Washing always involves a final rinsing step to remove the emulsified impurities.

Fabric washing can be carried out in rope form or open-width, and in either discontinuous or continuous mode. The most commonly used technique is continuous mode in open-width.

2.11.2 Dry cleaning

Industrial solvent washing is sometimes necessary, especially for delicate fabrics. In this case, the impurities are carried away by the solvent, which is usually perchloroethylene. In the same step, softening treatments may also be carried out. In this case, water and surfactant-based chemicals are added to the solvent.

Solvent washing may be carried out continuously in full-open-width (for woven or knitted fabric) or discontinuously with yarn or fabrics in rope form (generally for knitted fabric).

Solvent plants have a built-in solvent treatment and recovery system in which the solvent is purified by distillation and reused for the next washing process. Residual sludge from distillation must be disposed of as hazardous waste in the event of a high concentration of solvent.

After distillation, the solvent must be cooled before reuse and thus large amounts of cooling water are required. This water is never contaminated by solvent and can therefore be reused. In mills with both solvent and water washing facilities, warm water from the cooling plant may be used for water washing treatments, allowing water and energy savings. In many cases, however, this water is not reused and it is discharged together with the other effluents.

Both closed and open airflow circuits can be used for the removal of solvent from fabric.

In open-circuit machines, when the washing cycle is over, large amounts of air are taken from the external environment, warmed up with a steam heat exchanger and introduced into the machine, thus obtaining the evaporation of the organic solvent. This process goes on until the solvent is almost completely eliminated from clean fabrics. Solvent-rich air is then sent to a centralised activated charcoal filtering system. Filters require regular regeneration to ensure optimal cleaning performance. Most modern filters allow discharge into the atmosphere below 3-4 mg/Nm³.
Chapter 2

In closed-circuit machines, the volume of air used to carry out the drying process, instead of being filtered and released into the atmosphere, is internally treated. Such treatment consists of recovering the solvent by adsorption or condensation using a chiller. When the solvent has been removed from the air and recovered, solvent-poor air is heated by a heat exchanger and then sent into the machine again. Recovered solvent is sent to a centralised plant, where it is distilled and purified. Closed-circuit machines do not require an active carbon filter. See Section 4.4.5 for more details.

Apart from the above-mentioned emissions to air in open-circuit machines, possible emissions during washing operations may result from machine losses (which can be eliminated or reduced by hermetic sealing of the machinery) and from solvent attached to the dried fabric and ultimately released into the atmosphere. Most modern machines have a built-in control system which makes it impossible to open the machine hatch if the solvent concentration in the machine is greater than values established by national regulations.

Other potential sources of emissions are represented by the solvent contained in the residual sludges and active carbon filters.

Figure 2.41, Figure 2.42 and Figure 2.43 show the solvent and the air circuits in open-loop and closed-loop solvent washing machines (the solvent circuit is always closed).

Source: [66, CRIT, 1999]
Figure 2.42: Solvent washing: representation of the air circuit in an open-loop washing machine

Source: [66, CRIT, 1999], [318, Sperotto Rimar, 2002]

Figure 2.43: Solvent washing: representation of the air circuit in a closed-loop washing machine

Source: [66, CRIT, 1999], [318, Sperotto Rimar, 2002]
Chapter 2

2.12 Drying

Drying is necessary to eliminate or reduce the water content of the fibres, yarns and fabrics following wet processes. Drying, in particular by water evaporation, is a highly energy-intensive step (although overall consumption may be reduced if reuse/recycling options are adopted).

Drying techniques may be classified as mechanical or thermal. Mechanical processes are used in general to remove the water which is mechanically bound to the fibre. This is aimed at improving the efficiency of the following step. Thermal processes consist of heating the water and converting it into steam. Heat can be transferred by means of:

- convection;
- infrared radiation;
- direct contact;
- radio-frequency.

In general, drying is never carried out in a single machine; normally drying involves at least two different techniques.

2.12.1 Loose fibre drying

The water content of the fibre is initially reduced by either centrifugal extraction or by mangles before evaporative drying.

2.12.1.1 Centrifugal extraction

Textile centrifugal extractors (hydroextractors) are essentially a more robust version of the familiar domestic spin dryer, and normally operate on a batch principal, although machines capable of continuous operation may be used in very large installations.

When using conventional batch hydroextractors, fibre is unloaded from the dyeing machine into specially designed fabric bags which allow direct crane loading of the centrifuge. An extraction cycle of 3-5 minutes reduces the residual moisture content to approximately 8-10% dry fibre (in the case of wool).

2.12.1.2 Mangling

Pneumatically loaded mangles may be used to reduce the water content of dyed loose fibre. Such equipment is often associated with a fibre-opening hopper which is designed to break up the dyepack and present the fibre to a continuous dryer as an even mat. Mangling is invariably less efficient than centrifugal extraction.

2.12.1.3 Evaporative drying

All hot air evaporative dryers are of essentially similar design consisting of a number of chambers through which hot air is circulated by fans. Consecutive chambers operate at different temperatures, fibre passing from the hottest into progressively cooler chambers. Fibre may be transported on a brattice or conveyer belt or may be carried through the machine on the surface of a series of ‘suction drums’. High-efficiency dryers with perforated steel conveyer belts have been developed which even out the air pressure drop across the fibre mat. This design results in more even drying and lower thermal energy requirements.
While the majority of dryers are steam-heated, a number of manufacturers supply radio-frequency dryers. Fibre is conveyed on a perforated polypropylene belt through the radio-frequency field and airflow is fan-assisted. With these machines the fibre is not subjected to such high temperatures and the moisture content of the dried material can be controlled within fine-precise limits.

Radio-frequency dryers are reported to be significantly more energy-efficient than steam-heated chamber dryers. However, the higher efficiency is not always gained if a more global analysis is made, comparing the primary energy needed for production of electric power with methane gas consumed for thermal energy production. Radio-frequency dryers are mainly used where the cost of electricity is low.

### 2.12.2 Hank drying

#### 2.12.2.1 Centrifugal extraction

Drained hanks from the dyeing machine can contain (in the case of wool) up to 0.75 kg water per kg of dry fibre (or higher depending on the hydrophilicity of the fibre). Moisture content is normally reduced by centrifugal extraction prior to evaporative drying using equipment identical to that described for loose fibre, above. Yarn is normally unloaded from the dyeing machine into fabric bags held in round carts to facilitate direct crane loading of the centrifuge. Hydroextraction reduces the moisture content to approximately 0.4 litres/kg of dry weight.

#### 2.12.2.2 Evaporative drying

Evaporative dryers consist of a number of heated chambers with fan-assisted air circulation, through which the hanks pass suspended on hangers or poles or supported on a conveyer.

The hank sizes employed in carpet yarn processing require a slow passage through the dryer to ensure an even final moisture content, and a residence time of up to 4 hours is not uncommon. Air temperature is maintained below 120 °C to prevent yellowing (wool yellows above the boiling temperature).

All designs are capable of continuous operation. Thermal input is normally provided by a steam-heated exchanger and many designs incorporate air-to-air heat exchangers on the dryer exhaust to recover heat.

Less commonly, hanks may be dried by employing a dehumidifying chamber. Moisture is recovered by condensation, using conventional dehumidification equipment. In comparison to evaporative dryers, yarn residence time tends to be longer, but energy consumption is lower.

### 2.12.3 Yarn package drying

The moisture content of dyed packages is initially reduced by centrifugal extraction. Specially designed centrifuges, compatible with the design of the dyeing vessel and yarn carriers, are employed.

Traditionally packages were oven-dried, very long residence times being required to ensure adequate drying of the yarn on the inside of the package. Two methods are currently used, rapid (forced) air drying and radio-frequency drying, the latter sometimes being combined with initial vacuum extraction. Forced air dryers generally operate by circulating hot air from the inside of the package to the outside at a temperature of 100 °C, followed by conditioning, in which remaining residual moisture is redistributed in a stream of air passing from the outside to the inside of the package. Radio-frequency dryers operate on the conveyer principle and are perhaps
more flexible than the types mentioned above. Lower temperatures can be used and energy efficiency is said to be high (comments made for evaporative drying of loose fibre apply in this case too).

2.12.4 Fabric drying

The drying process for fabric usually involves two steps: the first one is intended to remove water which is mechanically bound to fibres, while the second one is necessary to completely dry the fabric.

2.12.4.1 Hydroextraction by squeezing

The fabric is squeezed by means of a padding machine through two or three rollers covered with rubber. This process cannot be applied to delicate fabric.

2.12.4.2 Hydroextraction by suction

The fabric is transported flat over a ‘suction drum’ which is linked to a pump. The external air is sucked through the fabric and thereby removes the excess water (see the principles shown in Figure 2.44). The resulting residual humidity is still about 90%.
Figure 2.44: Principle of dewatering by vacuum extraction

2.12.4.3 Centrifugal hydroextractor

The design of this machine is similar to the one described earlier for loose fibre and yarn hydroextraction. With heavy fabric, a horizontal axis machine may be used.

This is the most efficient method for mechanical water removal, but it cannot be applied to delicate fabrics prone to forming permanent creases.

2.12.4.4 Stenter

This machine is used for full drying of the fabric. The fabric is conveyed through the machine in open width. A hot current of air is blown across the fabric, thereby producing evaporation of the water.
The fabric is sustained and moved by two parallel endless chains. The fabric is hooked undulating and not taut to allow it to shrink during drying.

Most common stenter designs are horizontal and multi-layer, but many new designs exist. In the horizontal stenter machine, the fabric enters wet from one side and exits dried from the other. In the multi-layer type, it enters and exists from the same side. While in the first one the fabric moves horizontally without direction changes, in the second it is deviated many times, which makes this equipment unsuitable for delicate fabrics. On the other hand, horizontal stenter frames occupy more space and are less efficient (in terms of energy consumption).

### 2.12.4.5 Hot-flue dryer

This machine is composed of a large metallic box in which many rolls divert the fabric (in full width) so that it runs a long distance (about 250 m) inside the machine. The internal air is heated by means of heat exchangers and ventilated.

### 2.12.4.6 Contact dryer (heated cylinder)

In this type of machinery the fabric is dried by direct contact with a hot surface. The fabric is longitudinally stretched on the surface of a set of metallic cylinders. The cylinders are heated internally by means of steam or a direct flame.

### 2.12.4.7 Conveyor fabric dryer

The fabric is transported within two blankets through a set of drying modules. Inside each module the fabric is dried by means of a hot airflow.

This equipment is normally used for combined finishing operations on knitted and woven fabrics when, along with drying, a shrinking effect is also required in order to give the fabric a soft handle and good dimensional stability.

### 2.12.4.8 Airo dryer

This machine can be used for washing, softening and drying operations for woven and knitted fabrics in rope form.

During the drying phase, the fabric in rope form is recirculated in the machine by means of a highly turbulent airflow. Water is thus partly mechanically extracted and partly evaporated.

Thanks to the particular design of this machine, it is possible to carry out in the same machine wet treatments such as washing. In this case, the bottom of the machine is filled up with water and the required chemicals and the fabric is continuously soaked and squeezed.

The capacity of this machine is determined by the number of channels (from two to four).
2.13  [Textiles industry categories]-Examples of textile mills

Note to the TWG: please confirm this Section should be kept in the revised BREF.

Up to this point, this chapter has described the fundamental unit processes in the textiles industry that are within the scope of this document. The information given has been structured by fibre type, which has made it possible to explain those issues that are determined by the physico-chemical behaviour of the fibre. From a practical point of view, however, a subdivision of the textile industry activities into subsectors based on the type of the fibre offers little practical aid.

In practice, there are established patterns of activity, with finishing mills tending to concentrate on particular kinds of make-up or end-product (e.g. yarn, woven fabric, carpet), because this is defined by the specialist machinery used. This degree of specialisation does not apply to the same extent to the fibre. Although in the past the predominance of natural fibres made it possible to identify separate sectors based on the fibre (mainly cotton and wool), nowadays the proliferation of man-made fibres means that finishers almost always process a wide variety of fibres, even if one type is dominant within a particular mill (e.g. wool, cotton).

As an aid to the application use of this BREF, therefore, the rest of this chapter gives practical information on examples of the main configurations (i.e. combinations of processes and fibre types) that may be found at actual mills main categories of mills that are actually found in this sector (integrated mills should be seen as a combination of these main categories) and which are summarised in Table 2.23 below.

The typical mill categories listed below also prepare the ground for the presentation of the emission and consumption levels in Chapter 3.

Table 2.23:  Main types of textile mills

<table>
<thead>
<tr>
<th>Main types of mill</th>
<th>Main fibre types and/or activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wool scouring mills</td>
<td>Mainly CV, PES, PAC and/or CO floc material</td>
</tr>
<tr>
<td></td>
<td>Mainly WO floc/tops/yarn</td>
</tr>
<tr>
<td>Mills finishing yarn and/or floc</td>
<td>Mainly CO floc</td>
</tr>
<tr>
<td></td>
<td>Mainly PES yarn</td>
</tr>
<tr>
<td></td>
<td>Mainly WO, PAC and/or CV floc</td>
</tr>
<tr>
<td>Mills finishing knitted fabric</td>
<td>Mainly CO</td>
</tr>
<tr>
<td></td>
<td>Mainly CO with a significant proportion of printing</td>
</tr>
<tr>
<td></td>
<td>Mainly synthetic fibres</td>
</tr>
<tr>
<td></td>
<td>Mainly WO</td>
</tr>
<tr>
<td>Mills finishing woven fabric</td>
<td>Mainly CO and/or CV</td>
</tr>
<tr>
<td></td>
<td>Mainly CO and/or CV with a significant proportion of printing</td>
</tr>
<tr>
<td></td>
<td>Mainly WO</td>
</tr>
<tr>
<td></td>
<td>Mainly PA</td>
</tr>
<tr>
<td>Carpet industry manufacturing mills</td>
<td>Wool and wool-blend carpet yarn / loose fibre dyehouses</td>
</tr>
<tr>
<td></td>
<td>Piece carpet dyeing and printing mills</td>
</tr>
<tr>
<td></td>
<td>Integrated carpet manufacturing companies</td>
</tr>
</tbody>
</table>

The carpet industry manufacturing mills are is kept in a separate group from the other finishing mills. This is slightly inconsistent with the categorisation system adopted (based on the processing operations), in which a category of mills finishing yarn consisting mainly of wool is already identified in the list under the heading “Mills finishing yarn”. However, because the peculiarity of carpet as an end-product involves such specific requirements that companies tend to specialise in the processing of products that are suitable only for the carpet sector.
2.13.1 Wool scouring mills

Wool processed in Europe is mostly imported. Most of the wool produced in Europe is in fact coarse wool which is suitable for the manufacturing of carpets, but not for use in apparel. Merino wool (fine wool) is therefore imported mainly from Australia, New Zealand, South Africa, Argentina, Uruguay and Brazil.

The organisation of the scouring sector reflects the two main systems used to process wool: the woollen and the worsted system. Scourers tend to specialise in one or the other. Woollen system scourers normally only scour the wool (sometimes they may blend it before dispatching it to the customer). Worsted system scourers usually scour, card and comb the wool, thus producing a sliver of parallel fibres which is called top. Because of this difference, worsted system scourers are usually referred to as combers.

Within Europe, significant quantities of wool are also obtained from skins of slaughtered animals by a process called fellmongering in which the skins are treated chemically or biochemically to loosen the wool roots so that the wool can be readily easily separated from the skins.

The scouring process is usually the only wet process carried out in scouring mills and it has been described in detail in Section 2.3.1.1.

Most of the scourers have an on-site waste water treatment plant to treat their effluent. The majority discharge the treated effluent to sewer, but there are several scourers who discharge directly to surface waters. Those in the latter category have to treat their effluent to higher standards. Of the scourers who discharge to sewer, some treat only the heavily contaminated effluent from the scouring section and discharge the rinse water flowdown without treatment; others mix the two effluent streams before treatment.

Broadly speaking, there are four main types of effluent treatment process used by scourers:

- coagulation/flocculation;
- evaporation (sometimes combined with incineration with full closure of the water cycle);
- membrane filtration;
- anaerobic/aerobic biological treatment
- spreading to land or lagooning (after grease separation, in extensive wool producing areas).

Some scourers use combinations of the above processes. Neither the heavily contaminated effluent from the scouring section nor the mixed scouring and rinsing effluents can be treated directly by aerobic digestion, because their COD values are too high. It is normal to subject these effluent streams to anaerobic biological treatment or coagulation/flocculation before aerobic biological treatment (coagulation/ flocculation before aerobic treatment may result in huge amounts of sludge).

All of the effluent treatment processes employed by scourers produce a sludge or a concentrate which has to be disposed of safely. Sludge disposal routes used include landfill, composting, incineration, pyrolysis/gasification and brick manufacture.

2.13.2 Mills finishing yarn and/or floc

A common feature of floc and yarn finishing is that all process steps are normally carried out in the same equipment. The basic process sequence is:

- pretreatment (scouring/bleaching);
- dyeing;
- finishing (mainly softening by addition of softening agents in the last rinsing bath, but also flame-retardant or mothproofing treatments for carpet wool fibre).
Pretreatment can be carried out as a separate step, especially in the case of natural fibres, or together with dyeing by adding additional specific auxiliaries in the dye bath. The second option is common when the amount of impurities on the fibre is not significant and they are easy to remove, or when auxiliaries (e.g. preparation agents, spinning lubricants) are specially chosen not to interfere with the dyeing process.

Bleaching is normally not applied for synthetic fibres. With natural fibres, bleaching is commonly omitted for dark shades, whereas for light shades it is often combined with scouring. After washing, the material is dyed in the same machine and then submitted to final washing and rinsing.

For dyeing, it is common practice, in the case of floc and tops material, to achieve the desired final shade by thorough mixing of individual dyes. With yarn, on the other hand, the required shade has to be achieved with only one dye since, unlike floc and tops, the shade cannot be corrected by compensation. For this reason, a higher standard of accuracy is required in the development of the dye recipe in the laboratory.

As explained in other parts of this document, the dyes and auxiliaries applied vary with the fibres processed.

Mercerising treatment may be desired for cotton. If so, the material is processed in hank form. Mercerisation is carried out in a separate machine and is normally the first treatment applied.

Anti-felt treatment is another optional operation; it is applied only on wool and mainly on tops.

2.13.3 Mills finishing knitted fabric

Mills finishing knitted fabric consisting mainly of cotton
The typical process sequence for finishing knitted fabric consisting mainly of cotton is shown in Figure 2.45 (only the wet processes are reported). The dotted lines indicate processes that are not obligatory or are not common practice. Acidic demineralisation, for example, is applied only in a few mills. Mercerisation is also indicated with a dotted line because this additional treatment is only required for certain articles.
Scouring is generally a batch operation, but large installations often do it in continuous mode. Hydrogen peroxide is the most commonly applied bleaching agent in cotton mills today.

Cotton knitted fabric can be dyed with different classes of dyestuffs such as reactive, direct, sulphur and vat dyestuffs. Reactive dyestuffs are the most commonly used. Direct dyestuffs may be used for lighter shades and sulphur dyestuffs for dark shades. Vat dyestuffs may be used for very high light fastness requirements.

In printing, two further subclasses can be identified:

- mills finishing cotton knitted fabric without a printing section; and
- mills finishing cotton knitted fabric with a printing section.

Pigment printing is widely applied for knitted fabric and does not need the after-washing step required when printing with reactive, disperse and vat dyes (also relatively common techniques in this sector).

**Mills finishing knitted fabric consisting mainly of synthetic fibres or wool**

The typical process sequence for finishing knitted fabric consisting mainly of man-made fibres or wool is shown in Figure 2.46 (only the wet processes are indicated). Optional operations are indicated with dotted lines.
Figure 2.46: Typical process sequence for the finishing of knitted fabric consisting mainly of man-made fibres or wool

Before dyeing, the fabric is normally washed out in order to remove preparation agents and impurities. Heat-setting is not always needed, but when carried out this operation can take place either before washing (on the raw fabric) or after the washing step.

Depending on the required degree of white, bleaching may be needed.

**Mills finishing knitted fabric consisting mainly of WO**

The process sequence that is reported in Figure 2.46 is also applicable to this category of finishing mills.

**2.13.4 Mills finishing woven fabric**

Mills finishing woven fabric consisting mainly of cotton and/or cotton blends

The typical process sequence for the finishing of woven fabric consisting mainly of cotton or cotton blends is shown in Figure 2.47. Optional operations are indicated with dotted lines.
Woven fabric consisting mainly of cotton or cotton blends is finished on semi-continuous/continuous lines or in discontinuous mode, mainly depending on the size of the lot.

Pretreatment operations such as desizing, scouring and bleaching are very often combined in one single step in continuous lines. Pretreatment of viscose usually requires alkali treatment and washing only, provided that the sizing agents are water-soluble, which is normally the case.

In addition to the processes mentioned in Figure 2.47, further treatments may exceptionally be applied, such as pretreatment with liquid ammonia (carried out at very few sites in Europe only).

For printing, two further subclasses can be identified:

- mills finishing cotton woven fabric without a printing section; and
- mills finishing cotton woven fabric with a printing section.

**Mills finishing woven fabric consisting mainly of wool**

The typical process sequence for the finishing of woven fabric consisting mainly of wool (woollen and worsted wool) is shown in Figure 2.48.
Both water washing and solvent washing (dry cleaning) are common in the wool sector. Washing in an aqueous medium is carried out either in rope form (in batch) or in open-width (mostly in continuous, but also in batch). Heavy fabrics (woollen wool) are preferably treated in rope form, whereas washing in open-width is preferred for fine worsted fabric.

Carbonising and fulling are optional treatments in the basic process sequence. Carbonising is applied only on wollen wool fabric, which is also the most common application form of fabric for fulling treatments.

Crabbing can be carried out before or after dyeing, depending on the desired effect. Crabbing on raw fabric is done in order to set the dimensions of the fabric, so that they will not change during use or during the subsequent processes.

**Mills finishing woven fabric consisting mainly of synthetic fibres**
The process sequence for the finishing of woven fabric consisting mainly of man-made fibres is similar to the one illustrated in Figure 2.46 for knitted fabric. However, here the washing/desizing step is more important because all sizing agents need to be removed. Synthetic sizing agents are normally used, which are easily removed with water, often in continuous washing machines.
In fabric with a certain percentage of elastane, silicones are also present. The complete removal of these substances can be very difficult. In some cases, tetrachloroethylene solvent cleaning is applied; totally closed systems are mainly used for this purpose today, which severely limit losses of solvent.

Dyeing is carried out in continuous or in batch dyeing machines. The use of disperse dyes is predominant.

2.13.5 [The]-Carpet [industry] manufacturing mills

2.13.5.1 Wool and wool-blend carpet yarn dyehouse

The production of spun-dyed yarn can be regarded as a specific sector within the carpet manufacturing industry. Mills can be identified as dyehouses processing mainly wool and wool-blend fibres. Different treatments are carried out in order to convert white loose fibre into dyed carpet yarn. Wet processes essentially consist of dyeing and other ancillary operations carried out either in loose fibre or yarn form. Dry processes consist, in turn, of blending, carding, spinning, etc. These processes will not be considered here, since they have already been described in previous sections. Depending on when colouration takes place, raw fibre flows through some or all of these processes. As can be seen in Figure 2.49, three basic process sequences are possible.
The dry spinning route, so called because there is no wet processing after yarn formation, begins with colouration at the loose fibre stage. This is followed by yarn formation and finally twist setting. This process sequence is of relatively recent origin and requires the consistent use of wool with a low lanolin content and specialised spinning lubricants which can be left on the yarn without causing subsequent soiling of the carpet. The process is particularly useful in the production of yarn for large-volume plain-shade carpets and for effect yarns, obtained by blending together fibre dyed to different shades. While this production sequence is the most economical in terms of resource consumption, the selection of clean raw materials and the ongoing maintenance of the mill in a clean condition are essential.

The traditional loose stock dyeing route was originally used to produce large batches of yarn to the same shade for plain carpets. Loose fibre is first dyed and then converted to yarn using what is still sometimes referred to as the ‘oil spinning’ process; this terminology arose from the
practice of using spinning lubricants based on emulsions of mineral oil. Even small traces of residual mineral oil would lead to a marked propensity for the carpet to soil in service, and so yarns prepared by this route were thoroughly cleaned by scouring (washing) in hank form (see below). While the use of mineral-oil-based lubricants has been largely replaced with watersoluble synthetic products, the practice of scouring the yarn is still judged to be essential by many processors in order to avoid potential claims arising from soiling. Unlike the dry spinning process, this route allows greater flexibility in the purchase of raw materials, so that wool with a higher lanolin content can be used. See Chapter 16 for more details.

In the yarn dyeing route, clean fibre is first converted into yarn before dyeing. This process is particularly suitable for the production of the small coloured lots required for patterned carpet weaving or the bespoke trade, where white yarn can be held in stock and dyed as required to fill orders. The process is, however, by no means restricted to small batches, and dyeing machines with capacities of up to four tonnes are used to produce plain shades for both tufting and weaving. See Chapter 16 for more details.

In the case of integrated yarn manufacturers, it is common to find two or more of these process streams operating side by side and sharing common wet processing equipment. Since the dyeing and finishing techniques used apply equally to all three sequences, they are discussed in the following sections without further considering the different routes mentioned. Variants are described where they occur, and the relevance of any dry process segments is discussed where they have a significant impact on environmental performance or emissions.

Note for TWG: ex-Sections 2.14.5.1.1 and 2.14.5.1.2 were very detailed and have been moved to a new Annex. Please confirm this information should be kept in the revised BREF.

2.13.5.2 Integrated carpet manufacturing mills

Fully integrated carpet manufacturers carry out all the mechanical processes, wet processes (pretreatment, dyeing, printing and finishing operations) required to convert natural and synthetic fibres into finished carpet. Such companies may also produce their own synthetic fibres from raw polymer feedstock. Regarding the natural fibres processed, they can in some cases select and purchase natural fibres and operate the whole chain of processes from wool scouring to dyeing, yarn spinning and carpet weaving/tufting. However, usually not all of these operations are carried out at the same site.

The conversion of the fibre into finished carpet can follow different routes depending on the style of the carpet to be produced.

Tufted carpet

Yarn can be manufactured from:

- staple fibres, from both synthetic (PA, PP, PES, PAC) and natural (wool and cotton) fibres;
- continuous filaments, exclusively from synthetic fibres (mainly PA, PP and PES).

The carrier materials (primary backing) usually consist of:

- PP woven fabrics or webs;
- PES woven fabrics or webs;
- jute fabrics.

Finishing of tufted carpets involves:
• dyeing and/or printing;
• coating;
• mechanical finishing;
• chemical finishing.

Dyeing and chemical finishing can be applied on loose fibre, yarn or piece, while the other operations are carried out on the final carpet.

**Needle-felt carpet**
Almost all fibres may be used for the production of needle-felts (PP, PA, PES, PAC, wool, cotton jute/sisal, coconut fibre and viscose). However, mostly man-made fibres are used.

Needle-felt finishing involves:

• dyeing (rarely done);
• coating;
• mechanical finishing (rare);
• chemical finishing.

**Woven carpet**
Both natural and synthetic fibres are used in woven carpet production.

Carpets are woven using dyed yarns (so piece dyeing is not applied in woven carpet production). The final carpet is then subjected to mechanical and chemical finishing treatments.
3 EMISSION AND CONSUMPTION LEVELS

Note to the TWG: the majority of Chapter 3 (ex-Sections 3.2, 3.3 and 3.4) of the initial TXT BREF has been replaced by new information coming from the data collection. In order to improve readability, the deleted text does not appear in strikethrough.

3.1 Introduction

The main environmental issues relevant for the textile industry have been dealt with in detail, process by process, in Chapter 2.

The textiles industry has always been regarded as a water-intensive sector. The main environmental concern is therefore about the amount of water consumed and discharged and the chemical load it carries in the waste water. Other important issues are energy consumption, air emissions to air and solid wastes and odours, which can be a significant nuisance in certain treatments.

The emission and consumption levels presented in this chapter are based on data collected from 105 plants across the EU (see geographical distribution in Figure 3.1 below) over a reference period covering the years 2016, 2017 and 2018. The data was collected via 108 questionnaires (as some plants provided more than one questionnaire).

The plants from the data collection are listed in Annex VII PLANTS HAVING TAKEN PART IN THE DATA COLLECTION

![Geographical distribution of the plants](image)

Source: [196, TWG 2019]

Figure 3.1: Geographical distribution of the plants that participated in the data collection
3.2 Processes

Figure 3.2 below shows the IED activities carried out by each plant.

All plants of the data collection carry out activities listed in point 6.2 of IED Annex I.

The processes carried out at the plants are shown in Figure 3.3 and Figure 3.4 below for activities covered by point 6.2 of IED Annex I and for the directly associated activities (DAAs), respectively.
Figure 3.3: Number of plants performing 6.2 activities

Source: [196, TWG 2019]

Figure 3.4: Number of plants performing directly associated activities

Source: [196, TWG 2019]
No plants reported silk weighting as a directly associated activity.

In more detail, concerning fabric production, 5 plants carry out knitting, 12 sizing, 4 tufting, 14 warping, 3 waxing and 19 weaving. No plant reported carrying out needle-felting or production of non-woven fabric.

Out of the 89 plants performing dyeing, 39 carry out continuous dyeing and 68 batch dyeing.

Out of the 66 plants performing functional finishing, 56 carry out continuous finishing and 23 batch finishing.
3.3 Raw material and products

The composition and form of the main raw materials treated by the plants is given in Figure 3.5 and Figure 3.6 respectively.

Source: [196, TWG 2019]

Figure 3.5: Composition of the main raw materials treated
The main products of the plants of the data collection are shown in Figure 3.7.

**Figure 3.6: Form of the main raw materials treated**

**Figure 3.7: Main products of the plants of the data collection**
3.4 Emissions to water

3.4.1 Overview

The 108 questionnaires from 105 plants present a total of 112 monitored points of emissions to water. A total of 100 plants reported one monitored emission point, 11 plants reported two monitored emission points and 1 plant reported three monitored emission points.

In total, 3 plants reported no points of emissions to water (DK054, FR130 and FR133).

The 108 questionnaires present a total of 1213 data sets related to emissions of pollutants to water. These data sets correspond either to a combination of individual measurements, when the parameter is measured up to 12 times per year (periodic monitoring), or to a combination of minimum/average/maximum/97th percentile, when the parameter is measured more than 12 times per year (frequent monitoring).

The distribution of data sets according to the type of monitoring is as follows:

- periodic monitoring: 1041;
- frequent monitoring: 134.

Frequent monitoring

The distribution of the monitoring frequencies of the 134 data sets that were reported as frequent measurements can be seen in Figure 3.8.

![Figure 3.8: Distribution of the reported monitoring frequencies (number of data sets concerned) for the frequent measurements](image)

NB: The acronyms used for the pollutants are explained in the Glossary.

Source: [196, TWG 2019]
Periodic monitoring
The distribution of the monitoring frequencies of 1 041 data sets that were reported as periodic measurements can be seen in Figure 3.9.

![Bar chart showing the distribution of monitoring frequencies for different substances](image)

**NB:** The acronyms used for the pollutants are explained in the Glossary.

*Source: [196, TWG 2019]*

**Figure 3.9:** Distribution of the reported monitoring frequencies (number of data sets concerned) for the periodic measurements

Concerning the alkylphenols and alkylphenol ethoxylates, the perfluorocarbons, the pesticides, the brominated flame retardants and the surfactants, information about the individual substances or groups of substances measured is given in Sections 3.4.13 to 3.4.17.

**Type of discharge**
Out of 112 emission points, 24 correspond to direct discharge to the environment and 88 to indirect discharge.

Some particular cases are to be noted concerning the type of discharge:

- **Plant CZ016:** the waste water is not discharged but taken by truck to an external waste water treatment plant. It represents a small amount of about 1.5 m$^3$/t of textiles treated.
- **A number of plants located in the Prato district, Italy, discharge waste water to the same centralised industrial waste water treatment plant (Plants IT059, IT061, IT064, IT065, IT068, IT069, IT070, IT071, IT074, IT078, IT079, IT088, IT090 and IT094).** Some of the treated water is reused by these plants.
Abatement techniques
Out of 112 emission points that reported 1,213 data sets of emission measurements, Figure 3.10 shows the number of emission points and data sets related to each of the waste water treatment techniques.

![Graph showing the number of emission points and data sets related to each waste water treatment technique.](image)

Source: [196, TWG 2019]

Figure 3.10: Number of emission points (red) and data sets (blue) related to a given waste water treatment technique

‘No information’ was reported for 19 emission points and 199 data sets and for 5 emission points and 52 data sets it was reported that ‘No techniques’ were used. When no information was reported it was assumed that no technique is used.

The pollutant removal efficiency of these techniques was reported for only 16 out of 1,213 data sets.

3.4.2 Amount of waste water discharged
A total of 95 out of 112 emission points reported data related to the specific amount of waste water discharged.

The data about specific waste water discharged are shown in Figure 3.11 and Figure 3.12.

There is a great variability in the range of reported data, from 0.01 m$^3$/t of textiles treated to 696 m$^3$/t of textiles treated (median: 45.6 m$^3$/t of textiles treated, average: 79.6 m$^3$/t of textiles treated, 80th percentile: 115.4 m$^3$/t of textiles treated).
### 3.4.3 Presentation of data

In the following sections, each graph or table presents the minimum, average and maximum emission concentrations over the three-year reference period as well as the Emission Limit Value (ELV), the maximum emission load over the three-year reference period, the type of discharge (direct or indirect), the type of monitoring (periodic or frequent) and the abatement techniques applied at the emission points.

In the case of frequent monitoring, the minimum emission concentration corresponds to the maximum of the three minima reported. Likewise, the average and maximum concentrations correspond to the maximum of the three averages and three maxima reported, respectively. The maximum emission load corresponds to the maximum emission concentration multiplied by the average water flow.

The graphs and tables have been sorted in ascending order of the maximum emission concentration of all reported values (minimum, average and maximum).

### 3.4.4 Chemical oxygen demand (COD) and total organic carbon (TOC)

#### 3.4.4.1 Direct discharge to the environment

The direct discharges of COD to water are shown in Figure 3.13.

The COD concentrations from 24 emission points range from 39 mg/l to 776 mg/l.

It is to be noted that, out of the 20 emission points concerned, 19 are equipped with activated sludge treatment, 16 with equalisation, 14 with neutralisation, 13 with nitrification/denitrification, 7 with coagulation/flocculation, 6 with sand filtration, 3 with screening and 2 with grit separators. Some are also equipped with nano-filtration, chemical oxidation and/or reduction. The combination of these techniques effectively removes COD from the effluent.

Regarding the textile activities (activity 6.2 from Annex I to the IED), 19 plants carried out dyeing, 7 bleaching, and 4 desizing and washing of synthetic fibres. Regarding the activities directly associated with the activity 6.2 from Annex I of IED, 12 plants carried out functional finishing and 6 printing.

The higher concentration values are correlated to the treatment of synthetic fibres like washing and dyeing of synthetic fibres (UK124, DE025, BE009).

Out of the 20 emission points, the majority (18) are in plants processing fibre in the form of loose fibre, yarns or floc for example (of these, 5 produce wool fibre, 5 cotton fibre, 4 synthetic fibre, 2 cotton-synthetic blends and 4 all types of fibres).

The waste water discharge of these 20 emission points ranges from 0.05 m³/t to 494.2 m³/t of textiles treated, with a median value of 43.7 m³/t of textiles treated, average value of 101.8 m³/t of textiles treated and 80th percentile value of 182 m³/t of textiles treated. It is interesting to note that the majority of the plants with the highest COD concentrations typically discharge less than 25 m³/t of textiles treated, and the plants with the lowest COD concentrations more than 55 m³/t of textiles treated.

TOC emissions to water are shown in Figure 3.14. They are monitored at only 8 emission points of the data collection and range from 10.4 mg/l to 44 mg/l. All 8 emission points are equipped with activated sludge treatment. 7 plants also reported COD concentrations with COD/TOC average ratios from 1.9 (IT092_w{1}) to 06.0 (IT097_w{1}) (see Figure 3.15).
3.4.4.2 Indirect discharge to the environment

The indirect discharges of COD to water were reported for 71 emission points and are shown in Figure 3.16 and Figure 3.17. The COD concentration ranges from 54 mg/l to 29 200 mg/l.

A total of 12 data sets are available for indirect discharges of TOC emissions to water (see Figure 3.18). The emissions range from 51 mg/l to 1 600 mg/l. For emission points from Plants ES058 and DE031 no waste water treatment techniques were reported. Other plants report using primary treatments like neutralisation, equalisation, grit/oil separators and screening. Some plants also reported COD and in these cases the COD/TOC average ratios range from 4.2 (PT115_w{1}) to 11.1 (CZ015_w{1}) (see Figure 3.19).

3.4.5 Biological oxygen demand (BOD)

3.4.5.1 Direct discharge to the environment

BOD concentrations in direct emissions to water expressed as BOD$_5$ were reported for 24 emission points. They are shown in Figure 3.20 and range from 3 mg/l to 77 mg/l. In total, 22 emission points are equipped with the activated sludge process and 13 with nitrification/denitrification.

All the emission points that reported COD concentrations for direct discharge also reported BOD$_5$ concentrations. The BOD$_5$/COD average ratios range from 0.01 to 0.4. See Figure 3.21.

3.4.5.2 Indirect discharge to the environment

BOD concentrations in indirect emissions to water expressed as BOD$_5$ were reported for 55 emission points. They are shown in Figure 3.22 and Figure 3.23. The BOD$_5$ concentration ranges from 0.55 mg/l to 8 150 mg/l. Plants reporting the highest emissions (UK127, DE024 and CZ016) and the plant reporting the lowest emissions (IT061) do not have an appropriate waste water treatment to remove BOD (e.g. only equalisation and neutralisation). Of the plants using appropriate waste water treatment techniques it is worth noting that Plant IT084 is at the lower end of the spectrum with a maximum BOD$_5$ concentration of 25 mg/l, and Plant PT114 at the upper end of the spectrum with a maximum BOD$_5$ concentration of 460 mg/l.

It is to be noted that emissions of BOD expressed as BOD$_7$ were also reported in three instances.

All the emission points that reported COD concentrations for indirect discharge also reported BOD$_5$ concentrations (except emission point ES058_w {1} which did not report information about COD values). The BOD$_5$/COD average ratios range from 0.01 to 0.6. See Figure 3.24.

3.4.6 Total suspended solids (TSS)

3.4.6.1 Direct discharge to the environment

TSS concentrations in direct emissions to water were reported for 22 emission points. They are shown in Figure 3.25 and range from 1 mg/l to 107 mg/l. The plants apply various combinations of waste water treatment techniques: 17 are equipped with the activated sludge process, 13 with sedimentation, 7 with coagulation/flocculation, 6 with various forms of filtration (ultra-, micro- and nano-filtration) and 4 with screening. The plants at the upper end of the spectrum report low waste water discharges (e.g. BE009 and DE025 less than 25 m$^3$/t of treated textiles, IT067 less than 44 m$^3$/t of treated textiles), while the plants at the lower end of the spectrum report higher waste water discharges (e.g. BE011 and IT096 up to 65 m$^3$/t of treated textiles, IT097 up to 260 m$^3$/t of treated textiles).
It is to be noted that emissions of total dissolved solids were also reported in three instances.

### 3.4.6.2 Indirect discharge to the environment

The indirect discharges of TSS to water were reported for 62 emission points and are shown in Figure 3.26 and Figure 3.27. The TSS concentration ranges from 0.21 mg/l to 54 000 mg/l.

It is to be noted that emissions of total dissolved solids were also reported in four instances.

### 3.4.7 Nitrogen (expressed as Total N or ammonium)

#### 3.4.7.1 Direct discharge to the environment

Direct emissions of nitrogen to water expressed as Total N were reported for 18 emission points. They are shown in Figure 3.28 and range from 2.2 mg/l to 47 mg/l. The plant with the highest emission level (FR131) reported that the high concentration of nitrogen in the effluent may be due to the urea which is added in the WWTP for the operation of the biological treatment.

It is also to be noted that Plant BE014 uses ammonium sulphamate for flame-retardance finishing, which could explain the high level of nitrogen emissions (up to 29 mg/l) in spite of a nitrification/denitrification treatment.

Plant IT067 carries out printing with reactive dyes, which may explain the high emission levels in the event that urea is used.

Out of the 18 plants, 10 report using nitrification/denitrification.

A total of 13 data sets are also available for direct emissions of ammonium to water. They are shown in Figure 3.29 and range from 0.1 mg/l to 27.2 mg/l. In total, 11 of the emission points monitoring Total N are equipped with nitrification/denitrification, with the maximum concentration up to 19 mg/l.

#### 3.4.7.2 Indirect discharge to the environment

Indirect emissions of nitrogen to water expressed as Total N were reported from 47 emission points with the concentration ranging from 3.7 mg/l to 2 790 mg/l (see Figure 3.30). No plant uses nitrification/denitrification.

In total, 37 data sets are also available for indirect emissions of ammonium to water. They are shown in Figure 3.31 and range from 0.1 mg/l to 115 mg/l. The average value of SE120 seems to be a mistake in reporting (e.g. the maximum reported is 25 mg/l). Meanwhile, 2 plants report using the nitrification/denitrification technique (IT076 and IT075).

### 3.4.8 Phosphorus (expressed as Total P)

#### 3.4.8.1 Direct discharge to the environment

Direct emissions of phosphorus to water expressed as Total P were reported from 21 emission points. They are shown in Figure 3.32 and range from 0.35 mg/l to 52 mg/l. In total, 6 emission points are equipped with coagulation/flocculation and in that case the maximum concentration is up to 7 mg/l (and the majority of the concentrations are below 1.7 mg/l). One plant (BE010) reported using precipitation (with FeCl₃) to remove phosphorus, with a maximum concentration of 0.91 mg/l. One plant (DE025) reported using organophosphorus compounds as flame...
retardants (with a reported concentration of 0.41 mg/l) and two plants (FR131 and FR134) reported using phosphorus-based complexing agents (ATMP/NTMP and DTPMP) (with relatively high concentrations of 26 mg/l and 52 mg/l, respectively).

3.4.8.2 Indirect discharge to the environment

Indirect emissions of phosphorus to water expressed as Total P were reported from 37 emission points with the concentration ranging from 0.24 mg/l to 77 mg/l (see Figure 3.33). Only 3 plants are using coagulation/flocculation treatment prior to discharge. Effluent from these plants is discharged in a downstream waste water treatment plant (WWTP) – often an urban WWTP. These WWTPs would need to be equipped with appropriate tertiary treatment to also remove the non-biodegradable phosphorus compounds in the effluent (e.g. organophosphorus flame retardants or phosphorus-based complexing agents).

3.4.9 Metals

3.4.9.1 Antimony (Sb)

Emissions of antimony to water are generally associated with the presence of residues in polyester fibres because antimony oxide is used as catalyst for the production of these fibres. During pretreatment or dyeing of polyester, antimony is washed out into the waste water.

The presence of antimony in the waste water may also be due to the use of antimony trioxide as a synergist with halogen-containing compounds in flame-retardance finishing.

Antimony concentrations in direct and indirect emissions to water are shown in Figure 3.34 and range from 0.5 µg/l to 1.1 mg/l.

3.4.9.2 Copper (Cu)

The presence of copper in waste water may be connected to the use of reactive dyes but also possibly to the degradation over time of copper-containing equipment at the plant.

Copper concentrations in direct and indirect emissions to water are shown in Figure 3.35 and Figure 3.36, and range from 0 mg/l to 1.7 mg/l.

3.4.9.3 Chromium (Cr)

The presence of chromium in waste water may be connected to the use of dyes containing chromium such as chrome dyes for wool dyeing or metal-complex dyes.

Chromium concentrations in direct and indirect emissions to water are shown in Figure 3.37 and Figure 3.38, and range from 0 mg/l to 15.8 mg/l.

3.4.9.4 Nickel (Ni)

As with copper, the presence of nickel in waste water may be connected to the use of reactive dyes.

Nickel concentrations in direct and indirect emissions to water are shown in Figure 3.39, Figure 3.40 and Figure 3.41, and range from 0 mg/l to 2 mg/l.
3.4.9.5 Zinc (Zn)

Emissions of zinc to water are generally linked to the degradation over time of zinc-containing equipment at the plant.

Zinc concentrations in direct and indirect emissions to water are shown in Figure 3.42 and Figure 3.43, and range from 0 mg/l to 29.9 mg/l.

3.4.10 Adsorbable organically bound halogens (AOX)

AOX concentrations in direct and indirect emissions to water are shown in Figure 3.44 and Figure 3.45, and range from 0.02 mg/l to 200 mg/l. The highest emission concentrations correspond to Plant BE007 and may be a mistake.

Based on the information reported by Plants AT005 and BE013, the origin of the relatively high levels of AOX measured in the waste water by these two plants is not clear.

Plant IT063 carries out solvent scouring and reported AOX emissions between 0.01 mg/l and 1.64 mg/l. In this case, the amount of waste water released is small (8.5 m³/day) and AOX emissions are treated by adsorption.

Four plants performing chlorine-based bleaching (DE022, DE051, FR131 and FR132) reported AOX emissions to water with concentrations ranging between 0.4 mg/l and 0.7 mg/l.

Two plants carrying out chlorine-based shrink-proof finishing (Hercosett or Basolan processes) also reported AOX emissions, up to 0.35 mg/l for IT097. The other plant concerned (CZ016) does not discharge waste water but sends it by truck to a waste water treatment plant.

A total of 34 plants using dyes which are more likely to contain halogens in their molecules (vat, disperse and reactive dyes) reported AOX emissions to water, with concentrations ranging from 0.05 mg/l to 1 mg/l (excluding Plants AT005 and BE007).

3.4.11 Hydrocarbon oil index (HOI)

HOI concentrations in direct and indirect emissions to water are shown in Figure 3.46 and Figure 3.47, and range from 0 to 147.5 mg/l.

Oil in waste water may originate from residual knitting oil in knitted fabric, which is washed out during the treatment of the fabrics. In the case of plants treating knitted fabrics, the HOI concentrations range between 0 mg/l and 100 mg/l, and some of the plants concerned (such as IT059, IT064, IT068, IT070, IT074 and AT001) are amongst the plants with the highest emissions reported but do not apply waste water treatment.

Four plants treating knitted fabrics and applying abatement techniques show emission values of 0 mg/l (Plant DE025 applying the activated sludge process, sedimentation and coagulation and flocculation), 4 mg/l (Plant PT108 applying sand filtration), 7 mg/l (Plant PT104 applying ultrafiltration) and 18 mg/l (Plant DE022 applying evaporation and oil separation).
3.4.12 Sulphide

Sulphide concentrations in direct and indirect emissions to water are shown in Figure 3.48 and Figure 3.49, and range from 0 mg/l to 23.2 mg/l.

Emissions of sulphide to water are mostly relevant for plants using sulphur dyes, which is the case for 15 out of the 19 plants monitoring sulphide. Most of the reported values are below 1 mg/l, except for Plants AT005, IT065, PT102 and IT070 which are not equipped with waste water treatment.

3.4.13 Alkylphenols and alkylphenol ethoxylates

A total of 38 data sets were provided in relation to emissions to water of alkylphenols and alkylphenol ethoxylates but they do not necessarily all correspond to the same substance or group of substances. The monitored substances, type of discharge, minimum, average and maximum values reported over the 3 years, maximum load over the 3 years, ELV, techniques and associated monitoring standards reported are shown in Table 3.1.

3.4.14 Perfluorocarbons

In total, 30 data sets were reported in relation to emissions to water of perfluorocarbons but they do not necessarily all correspond to the same substance or group of substances. The monitored substances, type of discharge, minimum, average and maximum values reported over the 3 years, maximum load over the 3 years, ELV, techniques and associated monitoring standards reported are shown in Table 3.2.

3.4.15 Pesticides

A total of 15 data sets were reported in relation to emissions to water of pesticides but they do not necessarily all correspond to the same substance or group of substances. The monitored substances, type of discharge, minimum, average and maximum values reported over the 3 years, maximum load over the 3 years, ELV, techniques and associated monitoring standards reported are shown in Table 3.3.

3.4.16 Brominated flame retardants

In total, 10 data sets were reported in relation to emissions to water of brominated flame retardants but they do not necessarily all correspond to the same substance or group of substances. The monitored substances, type of discharge, minimum, average and maximum values reported over the 3 years, maximum load over the 3 years, ELV, techniques and associated monitoring standards reported are shown in Table 3.4.

3.4.17 Surfactants

A total of 100 data sets were reported in relation to emissions to water of surfactants but they do not necessarily all correspond to the same substance or group of substances. The monitored substances, type of discharge, minimum, average and maximum values reported over the 3 years, maximum load over the 3 years, ELV, techniques and associated monitoring standards reported are shown in Table 3.5.
Chapter 3

3.4.18 Toxicity

In total, 23 data sets (from 14 plants) are available for toxicity; of these, 6 were obtained by toxicity tests based on daphnia magna, 4 by toxicity tests based on Vibrio fisceri (bacteria), 4 by inhibition tests on microorganisms from active sludge, 3 on algae, 2 on fish, 1 on fish eggs and 1 by bacteria/daphnia magna/algae toxicity tests. For 2 data sets, it was not clear to which toxicity test (standard monitoring method) they refer. The available data sets are shown in Table 3.6.

3.4.19 Microplastics

Microplastics is a generic term for very small fragments of plastics with an approximate length of 1 nm to 5 mm. [131, ECHA 2019]

A number of studies were made available for the review of the BREF regarding the presence of microplastics in water bodies (e.g. [127, Austrian EPA 2015]) or in waste water (e.g. [128, Danish EPA 2017]). One of these studies ([129, Danish EPA 2015]) points to synthetic textiles as a source of secondary microplastics, i.e. microplastics resulting from the fragmentation, weathering or maintenance of larger items. For instance, the study considers the following pathways for releases of synthetic fibres: laundering, synthetic cloth used for wet cleaning, synthetic fibres removed by vacuum cleaning or washing of floors and furniture surfaces, fibres released outdoors from clothing and outdoor textiles. This corresponds however to the use phase of the textiles and not to the production phase which is the scope of this BREF.

No information was collected on the emissions of microplastics to water from the production of textiles via the data collection (see Section 3.1) but a study carried out by Swerea IVF [125, SVEREA IVF 2018] shows that microplastics were found in the effluents of five textiles plants in Sweden. Emissions of microplastics therefore seem relevant for the textiles sector, as they may be for other industrial or non-industrial activities, but the significance of these emissions has not been established. According to the study ‘Swedish sources and pathways for microplastics to the marine environment’ [126, IVL 2016], the main sources of microplastics are road wear and abrasion of tyres, artificial turfs, laundry, industrial production and handling of plastic pellets, and protective and decorative coatings on buildings, although the study underlines that more reliable data are needed.

In conclusion, at the time of drafting this document, there was little information available as to the emissions of microplastics to water from textile production facilities, in terms of emissions actually monitored and therefore in terms of the significance of these emissions.

It is to be noted nevertheless that even though microplastics emissions are not monitored directly, some microplastics would be covered by the parameter TSS, as the glass fibre filters used for monitoring TSS typically show pore sizes around 1 μm. [130, STERLITECH 2019]
The parameter TSS is addressed in Section 3.4.6.
3.4.20 Figures and tables with water emission levels

In the following figures, the average concentration is represented by a blue diamond and the minimum and maximum concentration by error bars.

The meanings of the acronyms used in the graphs of this section are as follows.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIR</td>
<td>Direct discharge</td>
</tr>
<tr>
<td>ELV</td>
<td>Emission limit value</td>
</tr>
<tr>
<td>FREQ</td>
<td>Frequent monitoring</td>
</tr>
<tr>
<td>IND</td>
<td>Indirect discharge</td>
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<tr>
<td>NI</td>
<td>No information</td>
</tr>
<tr>
<td>PER</td>
<td>Periodic discharge</td>
</tr>
<tr>
<td>WW</td>
<td>Waste water</td>
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</table>
Figure 3.11: Specific amount of waste water discharged (Part 1 of 2)

Figure 3.12: Specific amount of waste water discharged (Part 2 of 2)
Figure 3.13: COD emissions to water for direct discharges
Figure 3.14: TOC emissions to water for direct discharges

Source: [196, TWG 2019]
Figure 3.15: COD/TOC ratio in emissions to water for direct discharges
Figure 3.16: COD emissions to water for indirect discharges (Part 1 of 2)
Figure 3.17: COD emissions to water for indirect discharges (Part 2 of 2)

Source: [196, TWG 2019]
Figure 3.18: TOC emissions to water for indirect discharges
Figure 3.19: COD/TOC ratio in emissions to water for indirect discharges.
Figure 3.20: BODs emissions to water for direct discharges

Source: [196, TWG 2019]
Figure 3.21: BOD₅/COD ratio in emissions to water for direct discharges
Figure 3.22: BOD₅ emissions to water for indirect discharges (Part 1 of 2)

Source: [196, TWG 2019]
Figure 3.23: BODs emissions to water for indirect discharges (Part 2 of 2)

Source: [196, TWG 2019]
Figure 3.24: BOD$_5$/COD ratio in emissions to water for indirect discharges

NB: For a better visualisation, the maximum ratios BOD$_5$/COD obtained for the points of discharge IT070_w[1] (1.32) and PT108_w[1] (2.24) are not shown in the figure.

Source: [196, TWG 2019]
Figure 3.25: TSS emissions to water for direct discharges

Source: [196, TWG 2019]
Figure 3.26: TSS emissions to water for indirect discharges

Source: [196, TWG 2019]
Figure 3.27: TSS emissions to water for indirect discharges (not showing values higher than 2 000 mg/l)
Figure 3.28: Total N emissions to water for direct discharges
Figure 3.29: Ammonium emissions to water for direct discharges

Source: [196, TWG 2019]
For a better visualisation, the average (998.41 mg/l) and maximum value (2790 mg/l) of the point of discharge CZ016_w[1] are not shown in the figure.

Source: [196, TWG 2019]

Figure 3.30: Total N emissions to water for indirect discharges
Figure 3.31: Ammonium emissions to water for indirect discharges

Source: [196, TWG 2019]

NB: For a better visualisation, the maximum value (925 mg/l) of the point of discharge SE120_w1 is not shown in the figure.
Figure 3.32: Total P emissions to water for direct discharges

Source: [196, TWG 2019]
For a better visualisation, the ELV (160 mg/l) of the point of discharge FR136_w[1] is not shown in the figure.

Source: [196, TWG 2019]

Figure 3.33: Total P emissions to water for indirect discharges
Figure 3.34: Antimony emissions to water for direct and indirect discharges
For a better visualisation, the ELV (15 mg/l) of the point of discharge FR136_w1 is not shown in the figure.

Source: [196, TWG 2019]

Figure 3.35: Copper emissions to water for direct and indirect discharges (Part 1 of 2)
For a better visualisation, the ELV (10 mg/l) of the point of discharge UK127_w (1) is not shown in the figure.

Source: [196, TWG 2019]

Figure 3.36: Copper emissions to water for direct and indirect discharges (Part 2 of 2)
For a better visualisation, the ELVs over 0.1 mg/l are not shown. The rage of the ELVs not shown are from 0.5 mg/l to 10 mg/l.

Source: [196, TWG 2019]

Figure 3.37: Chromium emissions to water for direct and indirect discharges (Part 1 of 2)
For a better visualisation, the ELV (5 mg/l) of the point of discharge UK121_w[1] and the maximum value (15.8 mg/l) of the point of discharge IT137_w[1] are not shown in the figure.

Source: [196, TWG 2019]

Figure 3.38: Chromium emissions to water for direct and indirect discharges (Part 2 of 2)
For a better visualisation, the ELVs over 2 mg/l are not shown. The ELVs not shown are around 4 mg/l, and one ELV of 10 mg/l reported for the point of discharge UK127_w{1}. Source: [196, TWG 2019]

Figure 3.39: Nickel emissions to water for direct and indirect discharges
Figure 3.40: Nickel emissions to water for direct and indirect discharges (not showing values higher than 0.4 mg/l)
Figure 3.41: Nickel emissions to water for direct and indirect discharges (not showing values higher than 0.1 mg/l)
For a better visualisation, the ELVs over 0.5 mg/l are not shown. The range of ELVs not shown are from 0.6 mg/l to 5 mg/l. FR136_w[1] reported an ELV of 15 mg/l.

Source: [196, TWG 2019]

Figure 3.42: Zinc emissions to water for direct and indirect discharges (Part 1 of 2)
For a better visualisation, the maximum value (29.9 mg/l) of the point of discharge FR135_w\{1\} is not shown in the figure.

Source: [196, TWG 2019]

Figure 3.43: Zinc emissions to water for direct and indirect discharges (Part 2 of 2)
NB: Values not shown in the figure for the point of discharge
AT005: max. = 7.4 mg/l
BE0013: min. = 20 mg/l, avg. = 20 mg/l, max. = 20 mg/l
BE007: min. = 81 mg/l, avg. = 119.3 mg/l, max. = 200 mg/l.
Source: [196, TWG 2019]

Figure 3.44: AOX emissions to water for direct and indirect discharges
Figure 3.45: AOX emissions to water for direct and indirect discharges (not showing values higher than 0.5 mg/l)

Source: [196, TWG 2019]
Figure 3.46: HOI emissions to water for direct and indirect discharges

For a better visualisation, the ELVs over 150 mg/l are not shown. The ELVs not shown are 200 mg/l.

Source: [196, TWG 2019]
Figure 3.47: HOI emissions to water for direct and indirect discharges (not showing values higher than 50 mg/l)
For a better visualisation, the ELVs over 20 mg/l are not shown. The ELVs not shown are 200 mg/l. IT070_w{1} reported an ELV of 70 mg/l.

Source: [196, TWG 2019]

Figure 3.48: Sulphide emissions to water for direct and indirect discharges
Figure 3.49: Sulphide emissions to water for direct and indirect discharges (not showing values higher than 0.2 mg/l)

Source: [196, TWG 2019]
Table 3.1: Alkylphenols and alkylphenol ethoxylates emissions to water

<table>
<thead>
<tr>
<th>Point of discharge</th>
<th>Substance</th>
<th>Type of discharge</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Maximum load over 3 years (g/day)</th>
<th>ELV (mg/l)</th>
<th>Combination of techniques</th>
<th>Monitoring standard</th>
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<tr>
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<td>4-n-Nonylphenol</td>
<td>DIR</td>
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<td>0</td>
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<td>Equalisation, Neutralisation, Grit separators, Activated sludge process, Anaerobic treatment</td>
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<td>In-house method, UPLC/MS/MS</td>
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<td>In-house method, UPLC/1/vfS /MS</td>
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<td>NI</td>
<td>NI</td>
<td>Neutralisation</td>
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</tr>
<tr>
<td>AT004_w</td>
<td>OP</td>
<td>IND</td>
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<td>NI</td>
<td>Neutralisation, Activated sludge process</td>
<td>DIN EN ISO 18857-2</td>
</tr>
<tr>
<td>DE031_w</td>
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<td>IND</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>NI</td>
<td>NI</td>
<td>No information</td>
<td>ASTM D7065</td>
</tr>
</tbody>
</table>

NB:
AP = Alkylphenols
APEO = Alkylphenol ethoxylates
DIR = Direct discharge
ELV = Emission limit value
IND = Indirect discharge
NI = No information
NP = Nonylphenol
NPEO = Nonylphenol ethoxylates
OP = Octylphenol
OP1EO = Octylphenol monooethoxylate
Source: [196, TWG 2019]
### Table 3.2: Perfluorocarbons emissions to water

<table>
<thead>
<tr>
<th>Point of discharge</th>
<th>Substance</th>
<th>Type of discharge</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Maximum load over 3 years (g/day)</th>
<th>ELV (mg/l)</th>
<th>Combination of techniques</th>
<th>Monitoring standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT097_w {1}</td>
<td>6 substances</td>
<td>DIR</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>NI</td>
<td>NI</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
<td>With reference to DIN38407-42 or CEN/TS15968 and followed by LCMS or LC/MS/MS analysis</td>
</tr>
<tr>
<td>SE119_w {1}</td>
<td>PFAS</td>
<td>IND</td>
<td>0.00048</td>
<td>0.00079</td>
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<td>NI</td>
<td>NI</td>
<td>Equalisation, Oil separation, Neutralisation</td>
<td>NI</td>
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<td>IND</td>
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<td>0.00001</td>
<td>0.00001</td>
<td>NI</td>
<td>NI</td>
<td>Sedimentation, Equalisation, Neutralisation</td>
<td>NI</td>
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<tr>
<td>SE120_w {1}</td>
<td>PFDA</td>
<td>IND</td>
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<td>0.0000087</td>
<td>0.0000087</td>
<td>NI</td>
<td>NI</td>
<td>Neutralisation, Oil separation, Sedimentation, Equalisation</td>
<td>NI</td>
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<tr>
<td>IT065_w {1}</td>
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<td>IND</td>
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<td>NI</td>
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<td>MI1207 rev2:2018</td>
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<tr>
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<td>0.00073</td>
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<td>0.000496</td>
<td>0.000496</td>
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<td>DIR</td>
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<td>0.000031</td>
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<td>MI1207 rev2:2018</td>
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<td>BE010_w</td>
<td>PFHxS</td>
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<td>0.00006</td>
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<td>PFOA</td>
<td>IND</td>
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<td>0.0000373</td>
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<td>PFOA</td>
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<td>0.000078</td>
<td>0.000078</td>
<td>0.041184</td>
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<td>NI</td>
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<td>BE014_w</td>
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<td>0.02627</td>
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<td>WAC/IV/A/025</td>
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<td>DIR</td>
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<td>Compound</td>
<td>Type</td>
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<td>Daughter 2</td>
<td>Daughter 3</td>
<td>Daughter 4</td>
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<td>DA2</td>
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<tr>
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<td>NI</td>
<td>NI</td>
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<td>NI</td>
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<tr>
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<td>DIR</td>
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<td>0.0005</td>
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<td>0.000009</td>
<td>NI</td>
<td>NI</td>
<td>Equalisation, Neutralisation</td>
<td>NI</td>
</tr>
<tr>
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<td>0.0002155</td>
<td>0.0000246</td>
<td>0.0038868</td>
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<td>NI</td>
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<td>SE118_w{1}</td>
<td>PFOS</td>
<td>IND</td>
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<td>0.00003</td>
<td>0.00003</td>
<td>NI</td>
<td>NI</td>
<td>Sedimentation, Equalisation, Neutralisation</td>
<td>NI</td>
</tr>
<tr>
<td>DE031_w{1}</td>
<td>PFOS; PFOA</td>
<td>IND</td>
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<td>0</td>
<td>0</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>Liquid Chromatograph Mass Spectrometer</td>
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<tr>
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<td>0.000052</td>
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<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Reverse osmosis</td>
<td>MI1207 rev2:2018</td>
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<tr>
<td>DE034_w{1}</td>
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<td>DIR</td>
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<td>0.000984</td>
<td>0.000984</td>
<td>0.519552</td>
<td>NI</td>
<td>Activated sludge process, Nitrification/denitrification</td>
<td>NI</td>
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<tr>
<td>DE032_w ( ^{[1]} )</td>
<td>Sum10PFT</td>
<td>DIR</td>
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<td>0.000777833</td>
<td>0.0011</td>
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<td>NI</td>
<td>Equalisation, Neutralisation, Grit separators, Coagulation and flocculation, Sedimentation, Sand filtration, Nitrification/denitrification, Activated sludge process</td>
<td>NI</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
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<td>---</td>
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<td>---</td>
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<td>NI</td>
<td>Equalisation, Neutralisation, Grit separators, Coagulation and flocculation, Sedimentation, Sand filtration, Nitrification/denitrification, Activated sludge process</td>
<td>NI</td>
</tr>
</tbody>
</table>

**NB:**
- DIR = Direct discharge
- ELV = Emission limit value
- IND = Indirect discharge
- NI = No information
- PFAS = Per- and polyfluoroalkyl substances
- PFBA = Perfluorobutanoic acid
- PFDA = Perfluoro-decanoic acid
- PFHpA = Perfluorohexanoic acid
- PFHxA = Perfluorohexanoic acid
- PFOA = Perfluorooctanoic acid
- PFOS = Perfluorooctanesulfonic acid
- PFPeA = Perfluoropentanoic acid

*Source:* [196, TWG 2019]
<table>
<thead>
<tr>
<th>Point of discharge</th>
<th>Substance</th>
<th>Type of discharge</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Maximum load over 3 years (g/day)</th>
<th>ELV (mg/l)</th>
<th>Combination of techniques</th>
<th>Monitoring standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT097_w {1}</td>
<td>277 substances</td>
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<td>NI</td>
<td>NI</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
<td>APAT CNR IRSA 5060 Man 29 2003</td>
</tr>
<tr>
<td>IT092_w {1}</td>
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<td>0.00001</td>
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<td>NI</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Reverse osmosis</td>
<td>APAT CNR IRSA 5060 Man 29 2003</td>
</tr>
<tr>
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<td>Atrazine</td>
<td>IND</td>
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<td>0.0005</td>
<td>NI</td>
<td>NI</td>
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<td>APAT CNR IRSA 5060 Man 29 2003</td>
</tr>
<tr>
<td>IT076_w {1}</td>
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<td>IND</td>
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<td>0.00007</td>
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<td>APAT CNR IRSA 5060 Man 29 2003</td>
</tr>
<tr>
<td>IT092_w {1}</td>
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<td>DIR</td>
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<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Reverse osmosis</td>
<td>APAT CNR IRSA 5060 Man 29 2003</td>
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<td>DIR</td>
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<td>0.000053</td>
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<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Reverse osmosis</td>
<td>APAT CNR IRSA 5060 Man 29 2003</td>
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<tr>
<td>UK128_w {1}</td>
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<td>IND</td>
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<td>0.00020075</td>
<td>0.001685</td>
<td>NI</td>
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<td>Organophosphorus pesticides</td>
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<td>0.070090833</td>
<td>0.21586</td>
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<td>1.7</td>
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<tr>
<td>Source: [196, TWG 2019]</td>
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<table>
<thead>
<tr>
<th>Product Type</th>
<th>Discharge Type</th>
<th>Emission Limit Value</th>
<th>Method</th>
<th>Notes</th>
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<tr>
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<tr>
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<td>0.0013</td>
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</table>

NBs:
- DIR = Direct discharge
- ELV = Emission limit value
- IND = Indirect discharge
- NI = No information

Source: [196, TWG 2019]
<table>
<thead>
<tr>
<th>Point of discharge</th>
<th>Substance</th>
<th>Type of discharge</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Maximum load over 3 years (g/day)</th>
<th>ELV (mg/l)</th>
<th>Combination of techniques</th>
<th>Monitoring standard</th>
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<tr>
<td>IT097_w [1]</td>
<td>13 substances</td>
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<td>0.00018</td>
<td>0.00018</td>
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<td>NI</td>
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<td>Neutralisation, Oil separation, Sedimentation, Equalisation</td>
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NB:
- DecaBDE = Decabromodiphenyl ether
- DIR = Direct discharge
- ELV = Emission limit value
- HpBDE = Heptabromodiphenyl ether
- IND = Indirect discharge
- NI = No information
- NonaBDE = Nonabromodiphenyl ether

Source: [196, TWG 2019]
### Table 3.5: Surfactants emissions to water

<table>
<thead>
<tr>
<th>Point of discharge</th>
<th>Substance</th>
<th>Type of discharge</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Maximum load over 3 years (g/day)</th>
<th>ELV (mg/l)</th>
<th>Combination of techniques</th>
<th>Monitoring standard</th>
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Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Adsorption (e.g. powdered/granular activated carbon, lignite coke, etc.), Other
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NB:
BIAS = Bismuth active substance method
CTAB = Cetyltrimethylammonium bromide method
DBAS = Disulfine blue active substance method
DIR = Direct discharge
ELV = Emission limit value
IND = Indirect discharge
MBAS = Methylene blue active substances assay
NI = No information
TAS = Test aimed at determining the content of non-ionic surfactants
Source: [196, TWG 2019]
Table 3.6: Toxicity emissions to water

<table>
<thead>
<tr>
<th>Point of discharge</th>
<th>Toxicity test</th>
<th>Monitoring frequency</th>
<th>Type of sampling</th>
<th>Unit</th>
<th>Individual measurements (unless mentioned otherwise)</th>
<th>ELV</th>
<th>Standard monitoring method</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE009 w{2}</td>
<td>Daphnia magna</td>
<td>No information</td>
<td>Grab/spot sample</td>
<td>%</td>
<td>10</td>
<td></td>
<td>OECD202</td>
<td>One time measurement (2012) Daphnia Magna;</td>
</tr>
<tr>
<td>FR131 w{1}</td>
<td>Daphnia magna</td>
<td>4 times per year</td>
<td>24-hour flow proportional composite sample</td>
<td>No information</td>
<td>Report 12 measurements, all equal to 0</td>
<td>none</td>
<td>NF EN ISO 6341</td>
<td>measurements carried out for water agencies to calculate a fee</td>
</tr>
<tr>
<td>FR134 w{1}</td>
<td>Daphnia magna</td>
<td>Twice per year</td>
<td>Grab/spot sample</td>
<td>No information</td>
<td>Report 6 measurements, all equal to 0</td>
<td>none</td>
<td>NF EN ISO 6341</td>
<td></td>
</tr>
<tr>
<td>IT096 w{1}</td>
<td>Daphnia magna</td>
<td>Yearly</td>
<td>Grab/spot sample</td>
<td>%</td>
<td>Report 3 measurements, all equal to 0</td>
<td>50</td>
<td>APAT CNR IRSA 8020B Man 29 2003</td>
<td>Value refered to sampling period</td>
</tr>
<tr>
<td>IT067 w{1}</td>
<td>Daphnia magna</td>
<td>No information</td>
<td>Grab/spot sample</td>
<td>%-24h</td>
<td>3</td>
<td>50</td>
<td>APAT CNR IRSA 8020B Man 29 2003</td>
<td>Value refered to sampling period - test on Daphnia Magna</td>
</tr>
<tr>
<td>IT092 w{1}</td>
<td>Daphnia magna</td>
<td>Other (see in &quot;additional information&quot;)</td>
<td>Grab/spot sample</td>
<td>%</td>
<td>0</td>
<td>50</td>
<td>APAT CNR IRSA 8020B Man 29 2003</td>
<td>Monitoring frequency: spot Value refered to sampling period - Test on Daphnia Magna</td>
</tr>
<tr>
<td>IT097 w{1}</td>
<td>Daphnia magna</td>
<td>Yearly</td>
<td>Grab/spot sample</td>
<td>%</td>
<td>0-0-3</td>
<td>50</td>
<td>APAT CNR IRSA 8020B Man 29 2003</td>
<td>value refered to sampling period - Test on Daphnia Magna</td>
</tr>
<tr>
<td>IT067 w{1}</td>
<td>Vibrio fisceri</td>
<td>No information</td>
<td>Grab/spot sample</td>
<td>%I 30'</td>
<td>11</td>
<td>50</td>
<td>UNI EN ISO 11348-3:2009</td>
<td>Value refered to sampling period - test on Vibrio fisceri</td>
</tr>
<tr>
<td>IT092 w{1}</td>
<td>Vibrio fisceri</td>
<td>Other (see in &quot;additional information&quot;)</td>
<td>Grab/spot sample</td>
<td>%</td>
<td>3</td>
<td>50</td>
<td>UNI EN ISO 11348-1:2009</td>
<td>Monitoring frequency: spot Value refered to sampling period - Test on Vibrio Fiscieri</td>
</tr>
<tr>
<td>SE119 w{1}</td>
<td>Vibrio fisceri</td>
<td>Other (see in &quot;additional information&quot;)</td>
<td>24-hour flow proportional composite sample</td>
<td>%</td>
<td>4.2 ; 5.5</td>
<td>1.3 % (15 min exp)</td>
<td>SS-EN ISO 11348-3:2008 (mod); SS-EN ISO 11348-3:2008 (mod)</td>
<td>Microtox Ec50 (15 min exp). Once every second year (Flow proportional over one week).</td>
</tr>
<tr>
<td>Code</td>
<td>Org/Type</td>
<td>Monitoring Frequency</td>
<td>Sampling Method</td>
<td>Test Duration</td>
<td>Median Value</td>
<td>Standard Value</td>
<td>Measurement</td>
<td>Notes</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------</td>
<td>----------------------</td>
<td>--------------------------</td>
<td>---------------</td>
<td>--------------</td>
<td>----------------</td>
<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td>IT097</td>
<td>Vibrio fisceri</td>
<td>Yearly</td>
<td>Grab/Spot Sample</td>
<td>%</td>
<td>11-7-14</td>
<td>50</td>
<td>UNI EN ISO 11348-3:2009</td>
<td>value referred to sampling period - Test on vibrio fisceri</td>
</tr>
<tr>
<td>BE009</td>
<td>Vibrio fisceri</td>
<td>No information</td>
<td>Grab/Spot Sample</td>
<td>%</td>
<td>8.9</td>
<td>ISO 11348-3:1996E</td>
<td>One time measurement 2012 (Vibrio Fischeri)</td>
<td></td>
</tr>
<tr>
<td>BE007</td>
<td>Vibrio fisceri</td>
<td>Yearly</td>
<td>Grab/Spot Sample; Not applicable</td>
<td>LC50 (96h)</td>
<td>0.431</td>
<td>WAC/V/B/004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ES058</td>
<td>Vibrio fisceri</td>
<td>4 times per year</td>
<td>Grab/Spot Sample</td>
<td>Equitox</td>
<td>2.45-0-0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE011</td>
<td>Fish</td>
<td>No information</td>
<td>Grab/Spot Sample</td>
<td>OECD203</td>
<td>11.1-11-42-41.7</td>
<td>50</td>
<td>OECD203</td>
<td>2 measurements &lt; 10%, expressed in %effect</td>
</tr>
<tr>
<td>BE009</td>
<td>Fish</td>
<td>No information</td>
<td>Grab/Spot Sample</td>
<td>%</td>
<td>45-12.5-78.4-0</td>
<td>OECD203</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE025</td>
<td>Fish eggs</td>
<td>4 times per year</td>
<td>Grab/Spot Sample</td>
<td>GEI</td>
<td>11-7-14</td>
<td>2</td>
<td>DIN EN ISO 15088</td>
<td></td>
</tr>
<tr>
<td>IT097</td>
<td>Algae</td>
<td>Yearly</td>
<td>Grab/Spot Sample</td>
<td>%</td>
<td>0-16-31</td>
<td>50</td>
<td>UNI EN ISO 8692:2005 rev.2012</td>
<td>value referred to sampling period - Test on Pseudokirchneriella Subcapitata</td>
</tr>
<tr>
<td>IT067</td>
<td>Algae</td>
<td>No information</td>
<td>Grab/Spot Sample</td>
<td>%</td>
<td>0-16-31</td>
<td>50</td>
<td>UNI EN ISO 8692:2012</td>
<td>Value referred to sampling period - Test on Pseudokirchneriella Subcapitata</td>
</tr>
<tr>
<td>IT092</td>
<td>Algae</td>
<td>Other (see in &quot;additional information&quot;)</td>
<td>Grab/Spot Sample</td>
<td>%</td>
<td>26</td>
<td>50</td>
<td>UNI EN ISO 8692:2012</td>
<td>Monitoring frequency: spot Value referred to sampling period - Test on Pseudokirchneriella subcapitata</td>
</tr>
<tr>
<td>BE009</td>
<td>Algae</td>
<td>No information</td>
<td>Grab/Spot Sample</td>
<td>%</td>
<td>7.9</td>
<td>OECD201</td>
<td>One time measurement (2012) P. Subcapitata;</td>
<td></td>
</tr>
<tr>
<td>SE120</td>
<td>Activated sludge (nitr. inhib.)</td>
<td>Other (see in &quot;additional information&quot;)</td>
<td>Flow proportional composite sample</td>
<td>%</td>
<td>5; 14</td>
<td>EN ISO 9509:2006;EN ISO 9509:2006</td>
<td>One week every two years, See Appendix 2, &lt;10; See Appendix 1</td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>Type of Inhibition</td>
<td>Sampling Frequency</td>
<td>Sample Type</td>
<td>%</td>
<td>Methodology</td>
<td>Certification</td>
<td>Frequency of Analysis</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------</td>
<td>--------------------</td>
<td>-------------</td>
<td>---</td>
<td>-------------</td>
<td>---------------</td>
<td>-----------------------</td>
<td></td>
</tr>
<tr>
<td>SE119 w{1}</td>
<td>Activated sludge (nitr. inhib.)</td>
<td>Other (see in &quot;additional information&quot;)</td>
<td>24-hour flow proportional composite sample</td>
<td>%</td>
<td>100; 5</td>
<td>No inhibition; No inhibition</td>
<td>EN ISO 9509:2006; EN ISO 9509:2006</td>
<td>Once every second year (flow proportional over one week). 40 vol% sample (%)</td>
</tr>
<tr>
<td>SE119 w{1}</td>
<td>Activated sludge inhibition</td>
<td>Other (see in &quot;additional information&quot;)</td>
<td>24-hour flow proportional composite sample</td>
<td>%</td>
<td>35; 8</td>
<td>No inhibition; No inhibition</td>
<td>EN 8192-1995B; EN 8192-1995B</td>
<td>Once every second year (flow proportional over one week). 40 vol% sample, 180 minutes)</td>
</tr>
<tr>
<td>IT063 w{1}</td>
<td>No information</td>
<td>Yearly</td>
<td>Other or more than one type</td>
<td>No information</td>
<td>17-3</td>
<td>No information</td>
<td></td>
<td>Average sample of 3 hours</td>
</tr>
</tbody>
</table>

*Source:* [196, TWG 2019]
3.5 Emissions to air

3.5.1 Overview

The 108 questionnaires submitted represent a total of 494 monitored points of emissions to air. Most of the plants reported between 1 and 10 monitored emission points to air. A total of 13 plants reported more than 10 monitored emission points, up to a maximum of 39 for Plant ES058.

On the other hand, it is to be noted that 21 plants did not report any monitored point of emissions to air. The overview is given in Figure 3.52.

Information about pollutant concentrations in emissions to air was not reported for all emission points but only for 462 emission points. As more than one pollutant may be monitored at a given emission point, this represents a total of 1003 data sets. A data set corresponds to a combination of individual measurements for one given parameter at one given emission point.

For 62% of the 1003 data sets, the reported monitoring frequency is once every 3 years (which means in practice than the monitoring data sets concerned consist of only one value). The other main monitoring frequencies are once per year (about 18%) and twice per year (about 14%). More frequent monitoring represents a very small minority (see Figure 3.50 below).

For 8 data sets, corresponding to 5 emission points, no information was reported on the monitoring frequency.

Source: [196, TWG 2019]

Figure 3.50: Distribution of the monitoring frequency (number of data sets concerned)
Concerning the monitoring frequency reported as ‘other’, more details are given in Table 3.7 below.

Table 3.7: Other monitoring frequencies reported for emissions to air

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Parameter</th>
<th>Monitoring frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT003_{1}</td>
<td>Dust</td>
<td>Once every 5 years</td>
</tr>
<tr>
<td>AT003_{1}</td>
<td>TVOC</td>
<td>Once every 5 years</td>
</tr>
<tr>
<td>AT003_{2}</td>
<td>TVOC</td>
<td>Once every 5 years</td>
</tr>
<tr>
<td>BE007_{1}</td>
<td>Dust</td>
<td>Measurements done in 2013</td>
</tr>
<tr>
<td>BE007_{1}</td>
<td>NO_X</td>
<td>Measurements done in 2013</td>
</tr>
<tr>
<td>BE007_{1}</td>
<td>CO</td>
<td>Measurements done in 2013</td>
</tr>
<tr>
<td>BE007_{1}</td>
<td>TVOC</td>
<td>Measurements done in 2013</td>
</tr>
<tr>
<td>BE009_{1}</td>
<td>NO_X</td>
<td>Measurements done in 2014</td>
</tr>
<tr>
<td>BE009_{1}</td>
<td>CO</td>
<td>Measurements done in 2014</td>
</tr>
<tr>
<td>BE009_{1}</td>
<td>TVOC</td>
<td>Measurements done in 2014</td>
</tr>
<tr>
<td>BE009_{2}</td>
<td>SO_X</td>
<td>Measurements done in 2012</td>
</tr>
<tr>
<td>BE009_{2}</td>
<td>NO_X</td>
<td>Measurements done in 2012</td>
</tr>
<tr>
<td>BE009_{2}</td>
<td>CO</td>
<td>Measurements done in 2012</td>
</tr>
<tr>
<td>BE009_{2}</td>
<td>TVOC</td>
<td>Measurements done in 2012</td>
</tr>
<tr>
<td>BE009_{3}</td>
<td>NO_X</td>
<td>Measurements done in 2012</td>
</tr>
<tr>
<td>BE009_{3}</td>
<td>CO</td>
<td>Measurements done in 2012</td>
</tr>
<tr>
<td>BE009_{3}</td>
<td>TVOC</td>
<td>Measurements done in 2012</td>
</tr>
<tr>
<td>BE009_{4}</td>
<td>SO_X</td>
<td>Measurements done in 2012</td>
</tr>
<tr>
<td>BE009_{4}</td>
<td>NO_X</td>
<td>Measurements done in 2012</td>
</tr>
<tr>
<td>BE009_{4}</td>
<td>CO</td>
<td>Measurements done in 2012</td>
</tr>
<tr>
<td>BE009_{4}</td>
<td>TVOC</td>
<td>Measurements done in 2012</td>
</tr>
<tr>
<td>BE010_{1}</td>
<td>NO_X</td>
<td>One measurement in 2016 for all parameters</td>
</tr>
<tr>
<td>BE010_{1}</td>
<td>CO</td>
<td>One measurement in 2016 for all parameters</td>
</tr>
<tr>
<td>BE010_{1}</td>
<td>TVOC</td>
<td>One measurement in 2016 for all parameters</td>
</tr>
<tr>
<td>BE010_{1}</td>
<td>NH_3</td>
<td>One measurement in 2016 for all parameters</td>
</tr>
<tr>
<td>BE010_{2}</td>
<td>NO_X</td>
<td>One measurement in 2016 for all parameters</td>
</tr>
<tr>
<td>BE010_{2}</td>
<td>CO</td>
<td>One measurement in 2016 for all parameters</td>
</tr>
<tr>
<td>BE010_{2}</td>
<td>TVOC</td>
<td>One measurement in 2016 for all parameters</td>
</tr>
<tr>
<td>BE010_{2}</td>
<td>NH_3</td>
<td>One measurement in 2016 for all parameters</td>
</tr>
<tr>
<td>BE010_{3}</td>
<td>NO_X</td>
<td>One measurement in 2016 for all parameters</td>
</tr>
<tr>
<td>BE010_{3}</td>
<td>CO</td>
<td>One measurement in 2016 for all parameters</td>
</tr>
<tr>
<td>BE010_{3}</td>
<td>TVOC</td>
<td>One measurement in 2016 for all parameters</td>
</tr>
<tr>
<td>DE023_{4}</td>
<td>NO_X</td>
<td>No information</td>
</tr>
<tr>
<td>DE023_{4}</td>
<td>CO</td>
<td>No information</td>
</tr>
<tr>
<td>DE047_{5}</td>
<td>NO_X</td>
<td>Every 2 years</td>
</tr>
<tr>
<td>DE047_{5}</td>
<td>CO</td>
<td>Every 2 years</td>
</tr>
<tr>
<td>SE120_{1}</td>
<td>SO_X</td>
<td>No information</td>
</tr>
</tbody>
</table>

Finally, in addition to the 1003 data sets with periodic monitoring, continuous monitoring was reported for 1 data set (BE013_{01}), concerning emissions of ammonia to air.
Concerning abatement techniques, no information was reported for 387 emission points (66% of the emission points) and for 82 emission points (14% of the emission points) it was reported that no techniques were used.

The use of abatement techniques was reported for 120 emission points (18% of the total number of emission points). The distribution of abatement techniques is shown in Figure 3.51 below.

![Figure 3.51: Number of emission points equipped with a given abatement technique](image)

Source: [196, TWG 2019]

The removal efficiency of the abatement techniques was given in only 36 data sets out of the 1003 reported.

### 3.5.2 Presentation of the data

In the following sections, each graph presents the minimum, average and maximum emission concentration over the 3-year reference period as well as the emission limit value (ELV), the maximum emission load over the 3-year reference period and the abatement techniques applied at the emission points.

For a total of 133 emission points, the concentration values were reported as corrected to a reference O₂ level. In order to have all the data referenced under the same conditions, the concentration values have been recalculated to represent them without the correction to a reference O₂ level. Out of 133 emission points, 38 did not report the measured O₂ level, so those emission points have not been included in the presentation of the data. Table 3.8 shows those emission points that have not been included in the graphs.
Table 3.8: Emission points that reported the concentration corrected to a reference O\(_2\) level, but that did not report the measured O\(_2\) level

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR131([2])</td>
<td>Dust</td>
</tr>
<tr>
<td>FR131([3])</td>
<td>Dust</td>
</tr>
<tr>
<td>FR131([2])</td>
<td>SO(_X)</td>
</tr>
<tr>
<td>FR131([3])</td>
<td>SO(_X)</td>
</tr>
<tr>
<td>CZ016([1])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>CZ016([2])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>CZ016([3])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>CZ016([4])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>CZ016([5])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>CZ016([6])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>CZ017([1])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>CZ017([2])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>CZ017([3])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>CZ017([4])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>IT083([2])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>IT083([3])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>IT083([4])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>IT083([5])</td>
<td>NO(_X)</td>
</tr>
<tr>
<td>CZ016([1])</td>
<td>CO</td>
</tr>
<tr>
<td>CZ016([3])</td>
<td>CO</td>
</tr>
<tr>
<td>CZ016([4])</td>
<td>CO</td>
</tr>
<tr>
<td>CZ016([5])</td>
<td>CO</td>
</tr>
<tr>
<td>CZ016([6])</td>
<td>CO</td>
</tr>
<tr>
<td>CZ017([1])</td>
<td>CO</td>
</tr>
<tr>
<td>CZ017([2])</td>
<td>CO</td>
</tr>
<tr>
<td>CZ017([3])</td>
<td>CO</td>
</tr>
<tr>
<td>CZ017([4])</td>
<td>CO</td>
</tr>
<tr>
<td>IT083([8])</td>
<td>CO</td>
</tr>
<tr>
<td>IT083([9])</td>
<td>CO</td>
</tr>
<tr>
<td>IT083([10])</td>
<td>CO</td>
</tr>
<tr>
<td>IT083([13])</td>
<td>CO</td>
</tr>
<tr>
<td>CZ017([1])</td>
<td>TVOC</td>
</tr>
<tr>
<td>DE023([2])</td>
<td>TVOC</td>
</tr>
<tr>
<td>FR131([2])</td>
<td>TVOC</td>
</tr>
<tr>
<td>FR131([3])</td>
<td>TVOC</td>
</tr>
<tr>
<td>DE023([2])</td>
<td>Formaldehyde</td>
</tr>
</tbody>
</table>

Finally, the data are shown in ascending order of maximum emission concentration.
3.5.3 Organic compounds

The emissions of total volatile organic compounds (TVOC) are shown in Figure 3.53, Figure 3.54 and Figure 3.55. The concentrations range from 0.2 mg/Nm$^3$ to 340 mg/Nm$^3$ and the loads from 1 g/h to 3 385 g/h. According to the data collection, the main processes linked to emissions to air of organic compounds are thermal treatment associated with wet processing, coating and laminating, printing and singeing.

Abatement techniques are use in a minority of cases (for 45 emission points out of 294 for which TVOC emissions were reported). In those cases, the techniques used are mainly wet scrubbing (see description in Section 4.1.8.2) and condensation (see Section 4.1.8.4). Thermal oxidation (see Section 4.1.8.5) is also used in three cases, ionisation (see Section 4.1.8.12) in one case and adsorption (see Section 4.1.8.11) in one case.

When the emission points are equipped with those techniques, the maximal concentration ranges from 0.8 mg/Nm$^3$ to 119 mg/Nm$^3$.

In addition to TVOC, very few data were reported for emissions to air of specific organic compounds, namely tetrachloroethylene (PER) (two data sets, associated with dry cleaning and with thermofixation after solvent scouring), dimethylacetamide (one data set, associated with finishing and coating) and styrene (one data set associated with coating).

No information at all was reported on the other compounds considered as KEIs for the review of the BREF (see Section 1.4), namely N-methyl-2-pyrrolidone, N-ethyl-2-pyrrolidone, dimethylformamide, toluene, acrylonitrile, acrylamide and 1,3-butadiene.

3.5.4 Formaldehyde

The emissions of formaldehyde are shown in Figure 3.56. The concentrations range from 0.02 mg/Nm$^3$ to 20 mg/Nm$^3$ and the loads vary from 1 g/h to 328 g/h. According to the information reported, the processes associated with emissions of formaldehyde to air are coating and laminating, thermal treatment associated with finishing and printing, thermal treatment associated with finishing and printing, singeing and printing.

Out of the 59 emission points for which emissions of formaldehyde were reported, 19 are equipped with abatement techniques, which are the same as for TVOC (see Section 3.5.4). In those cases, the maximal concentration ranges from 0.02 mg/Nm$^3$ to 15 mg/Nm$^3$.

3.5.5 Oil mist

The emissions of oil mist are shown in Figure 3.57. The concentrations range from 0.2 mg/Nm$^3$ to 62.1 mg/Nm$^3$ and the loads range from 1 g/h to 932 g/h. According to the data collection, this parameter is monitored in Italy and the UK only. The emission sources are reported to be thermal treatment associated with finishing and wool carbonising.

3.5.6 Dust

The emissions of dust were reported for 175 emission points and are shown in Figure 3.58 and Figure 3.59. The concentrations range from 0 mg/Nm$^3$ to 112 mg/Nm$^3$ and the emission loads range from 0 g/h to 1 400 g/h.

Dust emissions were reported for singeing, fabric production and thermal treatment (e.g. drying, curing and heat fixation) mainly.
Concerning singeing, as mentioned in Section 2.6.1.1.1, the fabric is combed under aspiration before singeing to eliminate the remaining dust and fibre but dust is nevertheless emitted to air.

The techniques applied to reduce emissions of dust to air have been reported for 31 emission points. They generally consist of wet scrubber (see description in Section 4.1.8.2), electrostatic precipitator (see Section 4.1.8.3) and cyclone (see Section 4.1.8.7). In those cases, the maximum concentration ranges from 0.1 mg/Nm$^3$ to 18 mg/Nm$^3$.

Absolute filters (see Section 4.1.8.8) and fabric filters (see Section 4.1.8.9) were also reported in four cases and the emission points equipped with techniques are connected to the weighing, handling or packaging of material.

Finally, other techniques such as self-cleaning filters or lint extraction systems were also reported to be used.

### 3.5.7 Ammonia (NH$_3$)

The emissions of NH$_3$ are shown in Figure 3.60. The concentrations range from 0.1 mg/Nm$^3$ to 43 mg/Nm$^3$ and the load varies between 1 g/h and 264 g/h.

Figure 3.60 shows only the emissions which are periodically monitored. It should be noted that ammonia is also continuously monitored in one case (BE013_{01}), with an average concentration of 8.0 mg/Nm$^3$ and a maximal concentration of 56.2 mg/Nm$^3$.

Plant BE013 carries out flame-retardance finishing of fabric with THPC (Tetrakis(hydroxymethyl)phosphonium chloride) which is subsequently cured using NH$_3$. The air extracted from NH$_3$ curing is treated with water scrubbing and the emissions are reported to be 0 mg/Nm$^3$. The air from the working area is extracted by hoods and sent directly to the atmosphere without treatment (which corresponds to the emission point BE013_{01}).

According to the reported information, the processes associated with ammonia emissions are printing, coating and thermal treatment associated with finishing and with printing.

It is to be noted also that Plant BE010 uses ammonium sulphamate for flame-retardance finishing, which could explain the level of NH$_3$ emissions (up to 16 mg/Nm$^3$ and mass flow of 264 g/h).

Wet scrubbing (see description in Section 4.1.8.2) is the technique used to reduce emissions of ammonia to air and was reported in four cases. In those cases, the maximal concentrations range from 2.7 mg/Nm$^3$ to 38.6 mg/Nm$^3$.

### 3.5.8 Waste gases from combustion processes

It is important to note that the information given in this section does not address emissions from combustion used to generate energy or steam as these emission sources are not within the scope of this document.

The emissions addressed in this section are emissions from thermal treatment equipment (e.g. stenters, dryers, heating chambers) in which the heat from the combustion of fuel is used to treat textile material or liquor/baths by direct contact of flue-gases or indirect conduction/radiation through a solid wall.
3.5.8.1 Nitrogen oxides (NO\textsubscript{X})

The emissions of NO\textsubscript{X} are shown in Figure 3.61 and Figure 3.62 and were reported for thermal treatment and thermosol dyeing. The concentrations range from 1 mg/Nm\textsuperscript{3} to 238 mg/Nm\textsuperscript{3}. The corresponding loads are generally low, up to 874 g/h, except for one emission point corresponding to the use of thermal oxidation. No techniques were reported for the abatement of NO\textsubscript{X} emissions to air.

3.5.8.2 Carbon monoxide (CO)

The emissions of CO are shown in Figure 3.63 and Figure 3.64 and generally are also low. The concentrations range from 2 mg/Nm\textsuperscript{3} to 285 mg/Nm\textsuperscript{3} and the loads from 5 g/h to 18 101 g/h. The main emission source which has been reported is thermal treatment. No techniques have been reported for the abatement of CO emissions to air.

3.5.8.3 Sulphur oxides (SO\textsubscript{X})

The emissions of SO\textsubscript{X} are shown in Figure 3.65. Data were reported for only 13 emission points, 9 of them connected to thermal treatment and the last one to thermosol dyeing. The emissions are generally low: the concentrations range from 0.1 mg/Nm\textsuperscript{3} to 28 mg/Nm\textsuperscript{3} and the loads between 3 g/h and 433 g/h, the highest load corresponding to the use of oil as fuel for thermal fixation. No techniques have been reported for the abatement of SO\textsubscript{X} emissions to air.

3.5.9 [General issues concerning] Odour [nuisances in the textile industry]

| From ex-Section 3.5 |

Some processes in the textile industry are often accompanied by odour emissions.

Odour-intensive substances and typical ranges for odour concentrations are summarised in Table 3.9 and Table 3.10.
Table 3.9: Odour-intensive substances in the textile industry

<table>
<thead>
<tr>
<th>Substance</th>
<th>Possible source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epsilon-caprolactame</td>
<td>Heat-setting of polyamide 6 and polyamide 6 blends; Paste and powder coating with PA 6 and PA 6-copolymers</td>
</tr>
<tr>
<td>Paraffins, fatty alcohols, fatty acids, fatty acid esters (less odour-intensive substances, but high concentrations)</td>
<td>Heat-setting of grey textiles and inefficiently pre-washed textiles</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>Printing, wetting agents, machine cleaning, coating</td>
</tr>
<tr>
<td>Aromatic compounds</td>
<td>Carriers</td>
</tr>
<tr>
<td>Acetic acid, formic acid</td>
<td>Various processes</td>
</tr>
<tr>
<td>Hydrogen sulphide, mercaptans</td>
<td>Sulphur dyeing</td>
</tr>
<tr>
<td>Sulphur derivatives</td>
<td>Reducing agents, hot acid cracking in wool scouring mills</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Printing (e.g. from the use of urea), coating, non-woven processing</td>
</tr>
<tr>
<td>Acrylates</td>
<td>Printing (e.g. from the use of thickening agents), coating, non-woven processing</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>Easy-care finishing, finishing of non-woven fabrics, permanent flame retardants</td>
</tr>
<tr>
<td>Terpene (d limonene)</td>
<td>Solvents, machine cleaners</td>
</tr>
<tr>
<td>Styrene</td>
<td>SBR polymerisation, styrene addition to SBR compounds</td>
</tr>
<tr>
<td>4-Vinylcyclohexene (4-VCH)</td>
<td>SBR polymerisation (4-VCH is a dimer of butadiene that is formed during SBR-polymerisation)</td>
</tr>
<tr>
<td>Butadiene</td>
<td>Monomere in SBR polymerisation</td>
</tr>
<tr>
<td>4-phenylcyclohexene (4-PCH)</td>
<td>SBR polymerisation (4-PCH is formed by reaction between styrene and butadiene)</td>
</tr>
<tr>
<td>Aldehydes</td>
<td>Singeing</td>
</tr>
<tr>
<td>Acroleine</td>
<td>Decomposition of glycerol</td>
</tr>
<tr>
<td>Phosphoric acid esters (esp. tributylphosphate)</td>
<td>Wetting agents, de-aeration agents</td>
</tr>
<tr>
<td>Phthalates</td>
<td>Levelling and dispersing agents</td>
</tr>
<tr>
<td>Amines (low molecular)</td>
<td>Various processes</td>
</tr>
<tr>
<td>Alcohols (octanol, butanol)</td>
<td>Wetting agents, antifoaming agents</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]
### Table 3.10: Typical examples of odour concentrations in some textile processes

<table>
<thead>
<tr>
<th>Substrate/Process</th>
<th>Range of odour concentration (OU\textsubscript{E}/Nm\textsuperscript{3})</th>
<th>Average odour concentration (OU\textsubscript{E}/Nm\textsuperscript{3})</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA 6 Heat-setting grey fabric</td>
<td>2 000-4 500</td>
<td>2 500</td>
</tr>
<tr>
<td>PA 6 Finishing of thermofixed and pre-washed fabrics</td>
<td>500-2 000</td>
<td>1 100</td>
</tr>
<tr>
<td>PES Heat-setting grey fabric</td>
<td>1 500-2 500</td>
<td>2 000</td>
</tr>
<tr>
<td>PES Finishing of thermofixed and pre-washed fabrics</td>
<td>500-1 500</td>
<td>800</td>
</tr>
<tr>
<td>CO Finishing</td>
<td>300-1 000</td>
<td>500</td>
</tr>
<tr>
<td>Fibre blends Heat setting</td>
<td>1 000-2 500</td>
<td>1 500</td>
</tr>
<tr>
<td>Fibre blends Finishing of thermofixed and pre-washed fabrics</td>
<td>500-2 000</td>
<td>1 200</td>
</tr>
<tr>
<td>Sulphur dyeing</td>
<td>NI</td>
<td>Up to 10 000</td>
</tr>
<tr>
<td>Singeing</td>
<td>NI</td>
<td>Up to 2 500</td>
</tr>
<tr>
<td>Non-wovens (monomer-containing binders)</td>
<td>NI</td>
<td>Up to 10 000</td>
</tr>
<tr>
<td>Printing (mansards)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- pigment</td>
<td>282</td>
<td></td>
</tr>
<tr>
<td>- vat dyes (2 steps)</td>
<td>NI</td>
<td>586</td>
</tr>
<tr>
<td>- disperse dyes</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>- vat dyes (discharge)</td>
<td></td>
<td>286</td>
</tr>
<tr>
<td>Printing (steamer)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- pigment</td>
<td>670</td>
<td></td>
</tr>
<tr>
<td>- disperse dyes</td>
<td>NI</td>
<td>608</td>
</tr>
<tr>
<td>- vat dyes (2 steps)</td>
<td></td>
<td>633</td>
</tr>
<tr>
<td>Drying carrier-dyed textiles (\textsuperscript{1})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- carrier: benzyl benzoate, phthalic acid ester</td>
<td>800-2 800</td>
<td></td>
</tr>
<tr>
<td>- carrier: biphenyl, dimethyl phthalate</td>
<td>NI</td>
<td>4 800</td>
</tr>
<tr>
<td>- carrier: alkylphthalimide</td>
<td></td>
<td>478</td>
</tr>
<tr>
<td>Drying of textiles without carriers</td>
<td>NI</td>
<td>4 790</td>
</tr>
</tbody>
</table>

**NB:**

OU\textsubscript{E}: odour unit.

NI: No information.

(\textsuperscript{1}) Data are based on fabric that has been dyed but not dried; drying and air emission measurements were carried out on a laboratory scale.

Source: [179, UBA, 2001]

### 3.5.10 Figures with air emissions levels

In the following figures, the average concentration is represented by a blue square and the minimum and maximum concentration by error bars. Emission limit values (ELVs) are shown with a red line.
Figure 3.52: Number of monitored points of emission to air by plant

Source: [196, TWG 2019]
NB: For a better visualisation, the ELVs are not shown. The range of the ELVs reported is from 20 mg/Nm$^3$ to 300 mg/Nm$^3$, except IT073$_4$ which reported an ELV of 3 000 mg/Nm$^3$.

Source: [196, TWG 2019]

Figure 3.53: TVOC emissions to air (Part 1 of 3)
NB: For a better visualisation, the ELVs over 20 mg/Nm$^3$ are not shown. The range of the ELVs reported is from 20 mg/Nm$^3$ to 200 mg/Nm$^3$, except IT073\_[5], \_[6],\_[7] and\_[8] which reported an ELV of 1500 mg/Nm$^3$.

*Source:* [196, TWG 2019]

Figure 3.54: TVOC emissions to air (Part 2 of 3)
Figure 3.55: TVOC emissions to air (Part 3 of 3)

Source: [196, TWG 2019]
Figure 3.56: Formaldehyde emissions to air

Source: [196, TWG 2019]
NB: For a better visualisation, the maximum value (62.1 mg/Nm$^3$) of the emission point IT077_w[8] is not shown in the figure.

Source: [196, TWG 2019]

Figure 3.57: Oil mist emissions to air
NB: For a better visualisation, the ELVs over 20 mg/Nm$^3$ are not shown. The majority of the ELVs reported are around 150 mg/Nm$^3$.

Source: [196, TWG 2019]

Figure 3.58: Dust emissions to air (Part 1 of 2)
Figure 3.59: Dust emissions to air (Part 2 of 2)

Source: [196, TWG 2019]
For a better visualisation, the maximum value (38.6 mg/Nm$^3$) of the emissions point UK127 and average value (43 mg/Nm$^3$) of the point of discharge DE044 are not shown in the figure.

Source: [ 196, TWG 2019 ]

Figure 3.60: Ammonia emissions to air
NB: For a better visualisation, the ELVs are not shown. The ELVs are in a range from 100 mg/ Nm³ to 500 mg/ Nm³. 

Source: [196, TWG 2019]

Figure 3.61: NOx emissions to air (Part 1 of 2)
NB: For a better visualisation, the ELVs over 300 mg/Nm$^3$ are not shown. The ELVs not shown are in a range from 350 mg/ Nm$^3$ to 500 mg/ Nm$^3$.

Source: [ 196, TWG 2019 ]

Figure 3.62: NOx emissions to air (Part 2 of 2)
NB: For a better visualisation, the ELVs over 30 mg/Nm$^3$ are not shown. The ELVs not shown are in a range from 80 mg/ Nm$^3$ to 400 mg/ Nm$^3$.

Source: [196, TWG 2019]

Figure 3.63: CO emissions to air (Part 1 of 2)
NB: For a better visualisation, the ELVs of 400 mg/ Nm$^3$ for the emission point CZ019_w[2] and CZ019_w[6] and 3 000 mg/ Nm$^3$ for the emission IT137_w[2] are not shown in the figure.

Source: [196, TWG 2019]

Figure 3.64: CO emissions to air (Part 2 of 2)
NB: For each emission point, the value next to the blue square corresponds to their average over 3 years. For a better visualisation, the ELV of 500 mg/Nm$^3$ for the emission point PT109_w[13] is not shown in the figure.

Source: [196, TWG 2019]

Figure 3.65: SO$_x$ emissions to air
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3.6 Specific water and energy consumption

During the data collection, information was reported about the specific water consumption (i.e. cubic metre of water consumed per tonne of textile treated) or the specific energy consumption (i.e. kWh of energy consumed per tonne of textile treated). This information was reported at two levels of aggregation: at plant level (see Section 3.6.1) and, when relevant, at process level (see Section 3.6.2).

3.6.1 Consumption at plant level

3.6.1.1 Specific water consumption

The specific water consumption at plant level is shown in Figure 3.68 and Figure 3.69. The upper part of each figure shows the average specific water consumption reported per plant and for the 3-year period (2016-2018). The second part shows the percentage of recycled/reused water for each year. The third part shows the combination of BAT candidates reported in the data collection.

All the graphs are sorted by ascending order of average specific water consumption over the 3-year period.

3.6.1.2 Specific energy consumption

The specific energy consumption at plant level is shown in Figure 3.70 and Figure 3.71.

The upper part of the figures shows the average specific energy consumption for the 3-year period (2016-2018). The second part shows the combination of BAT candidates reported in the questionnaires. The graph is sorted by ascending order of the average specific energy consumption.

Figure 3.72 and Figure 3.73 show the breakdown of the energy consumption at plant level and consist of four parts. The first part shows the average specific energy consumption for the 3-year period (2016-2018). The second and third parts show the average specific electricity consumption and average specific heat consumption respectively. The last part shows the proportion of recovered heat in the heat consumed. The graph is sorted by ascending order of the average specific energy consumption.

3.6.2 Consumption at process level

The specific water and energy consumption at the process level was considered confidential business information (CBI) by the TWG. In order to maintain the confidentiality of this information throughout the data assessment, the plant name is not mentioned in graphs and tables where the CBI is used but is replaced by randomly attributed CBI codes for each individual process.

The principles for presenting the data in graphs and tables which are in this section are the same as for specific water and energy consumption at plant level (see Sections 3.6.1.1 and 3.6.1.2, respectively). However, as the data at process level are considered CBI, the following approach has been used to present the CBI data in the present document:

- not to show in the graphs and tables any contextual information (e.g. process parameters or techniques applied) as this could give clues as to the plants’ identity;
to present CBI data for a given process only when at least 10 plants of the data collection carry out this process, as a smaller sample may also facilitate the identification of the plants concerned.

3.6.2.1 Overview

Figure 3.66 and Figure 3.67 show the distribution of specific water and energy consumption levels of the different processes carried out at the plants of the data collection, respectively. Some of the highest reported values are clearly outliers (e.g. surpassing the next highest value by several orders of magnitude), possibly due to mistakes in reporting the correct units.

Source: [196, TWG 2019]

Figure 3.66: Specific water consumption of the different processes carried out at the plants
This section focuses in particular on the following processes:

- washing of synthetic fibres;
- singeing;
- desizing;
- mercerising;
- scouring;
- bleaching;
- batch and continuous dyeing;
- printing;
- batch and continuous finishing;
- coating;
- thermal treatment.

### 3.6.2.2 Washing of synthetic fibres

Figure 3.74 and Figure 3.75 show the specific water and energy consumption of washing of synthetic fibres, respectively.

The specific water consumption ranges from 1 m$^3$/t to 80 m$^3$/t and the specific energy consumption from 129 kWh/t to 5 069 kWh/t.
3.6.2.3 Singeing

Figure 3.76 shows the specific energy consumption of singeing which ranges from 25 kWh/t to 1 030 kWh/t.

3.6.2.4 Desizing

Figure 3.77 and Figure 3.78 show the specific water and energy consumption of desizing, respectively.

The specific water consumption ranges from 1 m$^3$/t to 80 m$^3$/t and the specific energy consumption from 109 kWh/t to 3 500 kWh/t.

3.6.2.5 Mercerising

Figure 3.79 and Figure 3.80 show the specific water and energy consumption of mercerising, respectively.

The specific water consumption ranges from 1 m$^3$/t to 61 m$^3$/t and the specific energy consumption from 243 kWh/t to 7 406 kWh/t.

3.6.2.6 Scouring

Figure 3.81 and Figure 3.82 show the specific water and energy consumption of scouring, respectively.

The specific water consumption ranges from 1 m$^3$/t to 43 m$^3$/t and the specific energy consumption from 5 kWh/t to 13 117 kWh/t.

The range 1 m$^3$/t to 43 m$^3$/t corresponds to the specific water consumption of batch scouring, while the specific water consumption for continuous scouring ranges from 2 m$^3$/t to 20 m$^3$/t.

3.6.2.7 Bleaching

Figure 3.83 and Figure 3.84 show the specific water and energy consumption of bleaching, respectively.

The specific water consumption ranges from 1 m$^3$/t to 130 m$^3$/t and the specific energy consumption from 29 kWh/t to 3 545 kWh/t.

The range 1 m$^3$/t to 130 m$^3$/t corresponds to the specific water consumption of batch bleaching, while the specific water consumption for continuous bleaching ranges from 1 m$^3$/t to 8 m$^3$/t.

In total, 13 plants reported using the technique consisting of combined pretreatment of cotton (see Section 4.4.3). Figure 3.85 shows the specific water consumption reported by these plants for desizing, scouring and bleaching. The values range from 0 m$^3$/t to 33 m$^3$/t.
3.6.2.8 Dyeing

3.6.2.8.1 Batch dyeing

Figure 3.86 and Figure 3.87 show the specific water and energy consumption of batch dyeing, respectively.

The specific water consumption ranges from 1 m³/t to 356 m³/t and the specific energy consumption from 1 kWh/t to 12 218 kWh/t.

The range from 1 m³/t to 356 m³/t corresponds to the specific water consumption of batch dyeing of fabrics (woven and knitted), while the specific water consumption for batch dyeing of loose fibre ranges from 14 m³/t to 191 m³/t and the specific water consumption for batch dyeing of yarns ranges from 3 m³/t to 330 m³/t.

3.6.2.8.2 Continuous dyeing

Figure 3.88 and Figure 3.89 show the specific water and energy consumption of continuous dyeing, respectively.

The specific water consumption ranges from 0 m³/t to 110 m³/t and the specific energy consumption from 2 051 kWh/t to 42 459 kWh/t.

3.6.2.9 Printing

Table 3.11 shows the specific water and energy consumption of printing. The specific water consumption ranges from 13 m³/t to 934 m³/t and the specific energy consumption from 41 kWh/t to 9 120 kWh/t.

3.6.2.10 Finishing

3.6.2.10.1 Batch finishing

Little information has been collected about batch finishing in terms of water and energy consumption. The specific water consumption ranges from 0 to 148 m³/t and the specific energy consumption from 42 to 12 818 kWh/t.

3.6.2.10.2 Continuous finishing

Figure 3.90 and Figure 3.91 show the specific water and energy consumption of continuous dyeing, respectively.

The specific water consumption ranges from 0 m³/t to 148 m³/t and the specific energy consumption from 29 kWh/t to 12 818 kWh/t.

3.6.2.11 Coating

Figure 3.92 shows the specific energy consumption of coating, which ranges from 228 kWh/t to 5 970 kWh/t.
3.6.2.12 Thermal treatment

Figure 3.93 shows the specific energy consumption of thermal treatment, which ranges from 120 kWh/t to 8800 kWh/t.

3.6.3 Figures and tables with water and energy consumption levels

The meanings of the acronyms used in Figure 3.68 and Figure 3.69 are as follows:

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAT1</td>
<td>Management and good housekeeping</td>
</tr>
<tr>
<td>BAT2</td>
<td>Optimising water consumption in textile operations</td>
</tr>
<tr>
<td>BAT3</td>
<td>Water reuse/recycling in batch dyeing processes</td>
</tr>
<tr>
<td>BAT4</td>
<td>Reduction of water consumption in cleaning operations</td>
</tr>
<tr>
<td>BAT5</td>
<td>Water and energy conservation in batch washing and rinsing</td>
</tr>
<tr>
<td>BAT6</td>
<td>Water and energy conservation in continuous washing and rinsing</td>
</tr>
<tr>
<td>BAT7</td>
<td>Procedures to avoid spillages and overfilling</td>
</tr>
<tr>
<td>BAT8</td>
<td>Adjustment of scheduling in production</td>
</tr>
<tr>
<td>BAT9</td>
<td>Automatic controllers of fill volume and liquor temperature</td>
</tr>
<tr>
<td>BAT10</td>
<td>Drain and fill method for rinsing</td>
</tr>
<tr>
<td>BAT11</td>
<td>Smart rinsing systems</td>
</tr>
<tr>
<td>BAT12</td>
<td>Overflow or ‘flood’ rinsing</td>
</tr>
<tr>
<td>BAT13</td>
<td>Automatic stop valves</td>
</tr>
<tr>
<td>BAT14</td>
<td>Counter-current washing</td>
</tr>
<tr>
<td>BAT15</td>
<td>Reduction of carry-over</td>
</tr>
<tr>
<td>BAT16</td>
<td>Dry cleaning of process baths before rinsing</td>
</tr>
<tr>
<td>BAT17</td>
<td>Reuse rinsing water</td>
</tr>
<tr>
<td>BAT18</td>
<td>Reuse cooling water</td>
</tr>
<tr>
<td>BAT19</td>
<td>Reuse cleaning water</td>
</tr>
<tr>
<td>BAT20</td>
<td>On-line monitoring</td>
</tr>
<tr>
<td>BAT21</td>
<td>Other</td>
</tr>
</tbody>
</table>
Chapter 3

The meanings of the acronyms used in Figure 3.70 and Figure 3.71 are as follows.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAT1</td>
<td>Management and good housekeeping</td>
</tr>
<tr>
<td>BAT2</td>
<td>Minimising energy consumption in wool scouring installations</td>
</tr>
<tr>
<td>BAT3</td>
<td>Minimisation of energy consumption of stenter frames</td>
</tr>
<tr>
<td>BAT4</td>
<td>Water and energy conservation in batch washing and rinsing</td>
</tr>
<tr>
<td>BAT5</td>
<td>Water and energy conservation in continuous washing and rinsing</td>
</tr>
<tr>
<td>BAT6</td>
<td>Heat recovery from waste water</td>
</tr>
<tr>
<td>BAT7</td>
<td>Heat recovery from waste gases</td>
</tr>
<tr>
<td>BAT8</td>
<td>Heat recovery from warm process water</td>
</tr>
<tr>
<td>BAT9</td>
<td>Optimisation of energy consumed by the compressed air system</td>
</tr>
<tr>
<td>BAT10</td>
<td>Combined Heat and Power</td>
</tr>
<tr>
<td>BAT11</td>
<td>On-line monitoring</td>
</tr>
<tr>
<td>BAT12</td>
<td>Other</td>
</tr>
</tbody>
</table>
Figure 3.68: Water consumption at plant level (Part 1 of 2)

Source: [196, TWG 2019]
NB: For a better visualisation, the values for water consumption for Plants IT059 (732-530-565 m$^3$/t) and SE120 (101,680-91,360-82,720 m$^3$/t) are not shown.

Source: [196, TWG 2019]

Figure 3.69: Water consumption at plant level (Part 2 of 2)
Figure 3.70: Energy consumption at plant level (Part 1 of 2)
Figure 3.71: Energy consumption at plant level (Part 2 of 2)

Source: [196, TWG 2019]
Figure 3.72: Breakdown of the energy consumption at plant level (Part 1 of 2)

Source: [196, TWG 2019]
Figure 3.73: Breakdown of the energy consumption at plant level (Part 2 of 2)
Figure 3.74: Specific water consumption of washing of synthetic fibres

Source: [196, TWG 2019]
Figure 3.75: Specific energy consumption of washing of synthetic fibres

Source: [196, TWG 2019]
Figure 3.76: Specific energy consumption of singeing

Source: [ 196, TWG 2019 ]
Figure 3.77: Specific water consumption of desizing

Source: [196, TWG 2019]
Figure 3.78: Specific energy consumption of desizing

Source: [196, TWG 2019]
Figure 3.79: Specific water consumption of mercerising

Source: [196, TWG 2019]
Figure 3.80: Specific energy consumption of mercerising

Source: [196, TWG 2019]
Figure 3.81: Specific water consumption of scouring

Source: [196, TWG 2019]
Figure 3.82: Specific energy consumption of scouring

Source: [196, TWG 2019]
Figure 3.83: Specific water consumption of bleaching

Source: [196, TWG 2019]
Figure 3.84: Specific energy consumption of bleaching

Source: [196, TWG 2019]
Figure 3.85: Specific energy consumption of combined pretreatment of cotton (see Section 4.4.3)
Figure 3.86: Specific water consumption of batch dyeing
Figure 3.87: Specific energy consumption of batch dyeing

Source: [196, TWG 2019]
Figure 3.88: Specific water consumption of continuous dyeing

Source: [196, TWG 2019]
Figure 3.89: Specific energy consumption of continuous dyeing

Source: [196, TWG 2019]
### Table 3.11: Specific water and energy consumption of printing

<table>
<thead>
<tr>
<th>CBI code</th>
<th>Specific net (fresh) water consumption</th>
<th>Specific net energy consumption</th>
<th>Electricity consumption</th>
<th>Net heat consumption</th>
<th>Proportion of recycled/reused water in the total water consumed</th>
<th>Proportion of recovered heat in the heat consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m³/tonne of textiles processed</td>
<td>kWh/tonne of textiles processed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRI4</td>
<td>18.1</td>
<td>17.3</td>
<td>17.3</td>
<td>2 040</td>
<td>2 051</td>
<td>2 000</td>
</tr>
<tr>
<td>PRI6</td>
<td>47</td>
<td>54.6</td>
<td>56.4</td>
<td>5 561</td>
<td>1 366</td>
<td>1 754</td>
</tr>
<tr>
<td>PRI9</td>
<td>0</td>
<td>9.5</td>
<td>12.9</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>PRI10</td>
<td>23.4</td>
<td>26.1</td>
<td>34.3</td>
<td>2 164</td>
<td>2 053</td>
<td>2 101</td>
</tr>
<tr>
<td>PRI114</td>
<td>934</td>
<td>877</td>
<td>724</td>
<td>42 459</td>
<td>41 707</td>
<td>36 597</td>
</tr>
<tr>
<td>PRI115</td>
<td>30.3</td>
<td>26.6</td>
<td>21.4</td>
<td>4 030</td>
<td>3 706</td>
<td>3 763</td>
</tr>
</tbody>
</table>

**NB:** NI = No information.

*Source:* [196, TWG 2019]
Figure 3.90: Specific water consumption of continuous finishing

Source: [196, TWG 2019]
Figure 3.91: Specific energy consumption of continuous finishing

Source: [196, TWG 2019]
Figure 3.92: Specific energy consumption of coating

Source: [196, TWG 2019]
Figure 3.93: Specific energy consumption of thermal treatment

Source: [196, TWG 2019]
3.7 Waste generation and management

From ex-Section 3.6

In textile finishing industries, many different solid and liquid wastes are generated and have to be disposed of. Some of them can be recycled or reused, whereas others are incinerated or landfilled. There are also some wastes which (in a few cases) are treated in anaerobic digesters.

Generally speaking, little information was reported about the generated and recycled waste.

3.7.1 Raw wool scouring

Table 3.12 below contains the information reported by four plants about the recovery of grease and the amount of waste sent off site for recovery or disposal. All four plants use an integrated dirt removal and grease recovery loop.

Plants UK128 and UK129 are wholly or predominantly scourers of coarse wools, which contain lower percentages of grease in a more oxidised (less hydrophobic) form, which is more difficult to separate centrifugally.

Table 3.12: Grease recovered and waste sent off site in raw wool scouring

<table>
<thead>
<tr>
<th>Plant code</th>
<th>Type of raw wool (fleece)</th>
<th>Specific amount of grease recovered (kg/kg of raw wool)</th>
<th>Specific amount of waste with code 04 02 10 sent off site (kg/kg of raw wool)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2016</td>
<td>2017</td>
</tr>
<tr>
<td>IT075</td>
<td>Extra/super fine</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>IT076</td>
<td>Extra/super fine</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>UK128</td>
<td>Coarse</td>
<td>0.01</td>
<td>0.011</td>
</tr>
<tr>
<td>UK129</td>
<td>Coarse</td>
<td>0.015</td>
<td>0.0135</td>
</tr>
</tbody>
</table>

NB: NI = No information. 
Source: [196, TWG 2019]

3.7.2 Desizing

Only one plant (PT108) reported information about the percentage of sizing agent recovered during desizing. This percentage is reported to be 0%.

3.7.3 Mercerising

In total, 6 plants reported information about the percentage of alkali recovered from mercerising (see Table 3.13 below).
Table 3.13: Alkali recovered from mercerising

<table>
<thead>
<tr>
<th>Plant code</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE030</td>
<td>75</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>ES058</td>
<td>95</td>
<td>76</td>
<td>99</td>
</tr>
<tr>
<td>FR134</td>
<td>35</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>PT108</td>
<td>75</td>
<td>80</td>
<td>85</td>
</tr>
<tr>
<td>UK127</td>
<td>95</td>
<td>95</td>
<td>95</td>
</tr>
</tbody>
</table>

Source: [196, TWG 2019]

It is to be noted that Plant BE013 reported a recovery rate of 99% but this plant carries out a specific process using ammonia (see Section 2.6.1.1.3). Following mercerising, the ammonia is recovered by distillation.

### 3.7.4 Dyeing

In total, 24 plants reported data about the fate of spent dye baths and padding liquors, for a total of 65 data sets. This information is summarised in Figure 3.94, for each year for which information was reported.

In 51 instances (corresponding to 18 plants), no spent dye baths or padding liquor was reported as waste (i.e. sent off site for disposal and recovery). In those cases, the spent dye baths or padding liquor is mostly considered waste water.

In the 14 other instances (corresponding to 6 plants), spent dye baths or padding liquor were reported as waste and no waste water was reported. The case of Plant FR133 in particular is of note; all spent dye baths are said to be recycled with evaporation-concentration. The treatment sludge is the only remaining waste.

Spent dye baths or padding liquor are recycled in only three plants, including FR133 mentioned above. In the case of FR130, the specific amount of recycled spent dye baths or padding liquor is particularly high and would need to be checked.

In addition to the 24 plants that reported data, 6 plants reported that the spent dye bath is sent to waste water treatment.

### 3.7.5 Printing

Four plants reported data about the fate of printing residues (spent printing pigments and paste), for a total of 10 data sets. This information is summarised in Table 3.14.
### Table 3.14: Printing residues

<table>
<thead>
<tr>
<th>Plant code</th>
<th>Year</th>
<th>Description of waste</th>
<th>European List of Waste codes of printing residues sent off site (for disposal and recovery)</th>
<th>Printing residues sent off site (for disposal and recovery)</th>
<th>Printing residues recycled/reused</th>
<th>Printing residues treated as waste waters</th>
<th>m³/t of textile treated</th>
<th>t/t of textile treated</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE025</td>
<td>2016</td>
<td>Paste residues</td>
<td>NI</td>
<td>0.01</td>
<td>0.01</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2017</td>
<td></td>
<td>NI</td>
<td>0.01</td>
<td>0.01</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2018</td>
<td></td>
<td>NI</td>
<td>0.01</td>
<td>0.01</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE032</td>
<td>2016</td>
<td>AVV 16 10 03</td>
<td>NI</td>
<td>0.1024</td>
<td>0.1731</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2017</td>
<td></td>
<td>NI</td>
<td>0.0762</td>
<td>0.1559</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2018</td>
<td></td>
<td>NI</td>
<td>0.0992</td>
<td>0.1887</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE049</td>
<td>2016</td>
<td>Residual paste</td>
<td>04 02 16*</td>
<td>0.02</td>
<td>0.026</td>
<td>0.009</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2017</td>
<td></td>
<td>04 02 16*</td>
<td>0.02</td>
<td>0.03</td>
<td>0.009</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2018</td>
<td></td>
<td>04 02 16*</td>
<td>0.02</td>
<td>0.03</td>
<td>0.009</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE118</td>
<td>2016</td>
<td>Printing paste</td>
<td>04 02 17</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>7 t waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2017</td>
<td></td>
<td>04 02 17</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>10 t waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2018</td>
<td></td>
<td>04 02 17</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>10 t waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK127</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>0.005</td>
<td>NI</td>
<td></td>
<td></td>
<td>Approximately 5kg/t. Reuse acid dyes on repeat print jobs</td>
</tr>
</tbody>
</table>

NB: NI = No information.
Source: [196, TWG 2019]

In two other cases (BE009 and FR131), printing paste residues are said to be treated as waste water, and in one case (PT099), it is reported that no printing residues are produced.

### 3.7.6 Finishing

In total, 16 plants reported data about the fate of spent dye baths and padding liquors, for a total of 51 data sets. This information is summarised in Figure 3.95, for each year for which information was reported.

In 30 instances (corresponding to 10 plants), no spent finishing baths or padding liquor was reported as waste (i.e. sent off site for disposal and recovery). In those cases, the spent finishing baths or padding liquor are mostly considered waste water.

In 21 instances (also corresponding to 10 plants), spent finishing baths or padding liquor were reported as waste and no waste water was reported (except in two cases).
Concerning waste water, Plant DE022 reported that waste water from some processes (like coating and finishing) is evaporated.

### 3.7.7 Leftover chemicals

Information about the specific amount of chemicals disposed of as waste at plant level was reported by 58 plants for a total of 177 data sets. The data are shown in Table 3.15, Table 3.16, Table 3.17 and Table 3.18 for the following European List of Waste Codes (EWCs):

- 04 02 16*: dyestuffs and pigments containing hazardous substances;
- 04 02 17: dyestuffs and pigments other than those mentioned in 04 02 16;
- 16 03 03*: inorganic wastes containing hazardous substances;
- 16 03 05*: organic wastes containing hazardous substances.

#### Table 3.15: Specific amount of waste (kg/t of textiles treated) – EWC 04 02 16*

<table>
<thead>
<tr>
<th>Plant code</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>CZ017</td>
<td>0.03</td>
<td>0.36</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>DE025</td>
<td>0.00</td>
<td>0.00</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>DE042</td>
<td>0.00</td>
<td>0.00</td>
<td>11.00</td>
<td></td>
</tr>
<tr>
<td>DE049</td>
<td>0.00</td>
<td>0.00</td>
<td>20.00</td>
<td></td>
</tr>
<tr>
<td>IT059</td>
<td>0.20</td>
<td>0.33</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>IT063</td>
<td>0.00</td>
<td>0.53</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>IT088</td>
<td>0.00</td>
<td>0.40</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>IT137</td>
<td>2.53</td>
<td>0.00</td>
<td>0.00</td>
<td>Chemicals referred to product lines for discontinued customers</td>
</tr>
<tr>
<td>PT110</td>
<td>0.00</td>
<td>0.24</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>UK124</td>
<td>0.00</td>
<td>0.00</td>
<td>15.63</td>
<td></td>
</tr>
</tbody>
</table>

*Source: [196, TWG 2019]*
### Table 3.16: Specific amount of waste (kg/t of textiles treated) – EWC 04 02 17

<table>
<thead>
<tr>
<th>Plant code</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE025</td>
<td>0.00</td>
<td>0.00</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>DE029</td>
<td>10.00</td>
<td>10.00</td>
<td>10.00</td>
<td></td>
</tr>
<tr>
<td>DE042</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>DE045</td>
<td>0.00</td>
<td>3541.00</td>
<td>12650.00</td>
<td>In 2018 disposal of old chemicals</td>
</tr>
<tr>
<td>DE047</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>SE118</td>
<td>21.00</td>
<td>23.70</td>
<td>37.90</td>
<td></td>
</tr>
<tr>
<td>UK124</td>
<td>0.00</td>
<td>426.22</td>
<td>267.83</td>
<td>High load effluent that cannot be treated by on-site WWTP.</td>
</tr>
<tr>
<td>UK126</td>
<td>5.24</td>
<td>7.89</td>
<td>5.00</td>
<td>These leftover dyes are mainly diluted dyestuff used in the print dyeing process. The actual dyestuff content is less than 3% by weight, it is a water-based formula that makes up the other 97%. The calculation is therefore based as 1 kg = 1 l. Dyestuff powder is not disposed of. The actual quantities are far lower than data inputted allow. The corresponding years are all below 9 kg of waste per tonne of textiles.</td>
</tr>
</tbody>
</table>

Source: [196, TWG 2019]

### Table 3.17: Specific amount of waste (kg/t of textiles treated) – EWC 16 03 03*

<table>
<thead>
<tr>
<th>Plant code</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT088</td>
<td>0.00</td>
<td>0.16</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>PT114</td>
<td>0.04</td>
<td>0.06</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>UK121</td>
<td>0.00</td>
<td>10.00</td>
<td>0.00</td>
<td>2018 column is 2015 data.</td>
</tr>
<tr>
<td>UK124</td>
<td>1.30</td>
<td>0.00</td>
<td>1.26</td>
<td></td>
</tr>
</tbody>
</table>

Source: [196, TWG 2019]
Table 3.18: Specific amount of waste (kg/t of textiles treated) – EWC 16 03 05*

<table>
<thead>
<tr>
<th>Plant code</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR136</td>
<td>4.80</td>
<td>0.09</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>IT063</td>
<td>0.05</td>
<td>0.13</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>IT067</td>
<td>0.00</td>
<td>0.50</td>
<td>0.00</td>
<td>Occasional waste</td>
</tr>
<tr>
<td>IT082</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>PT109</td>
<td>0.00</td>
<td>0.02</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>UK121</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>UK124</td>
<td>0.00</td>
<td>6.55</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

*Source: [196, TWG 2019]*

3.7.8 Figures on waste generation and management
Figure 3.94: Fate of spent dye baths and padding liquors

Source: [196, TWG 2019]
Figure 3.95: Fate of spent finishing baths and padding liquors

Source: [196, TWG 2019]
4 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT

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 as well as process-integrated and end-of-pipe techniques. 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 the prevention or limiting of the environmental consequences of accidents and incidents. They also cover the prevention or reduction of 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 4.1 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 that 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 4.1: Information for each technique

<table>
<thead>
<tr>
<th>Heading within the sections</th>
<th>Type of information included</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>A brief description of the technique with a view to being used in the BAT conclusions.</td>
</tr>
<tr>
<td><strong>Technical description</strong></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><strong>Achieved environmental benefits</strong></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><strong>Environmental performance and operational data</strong></td>
<td>Actual and plant-specific performance data (including emission levels, consumption levels – of raw materials, water, energy – and amounts of residues/wastes generated) from well-performing installations/plants (with respect to the environment taken as a whole) applying the technique accompanied by the relevant contextual information. Any other useful information on the following items: 1. how to design, operate, maintain, control and decommission the technique; 2. emission monitoring issues related to the use of the technique; 3. sensitivity and durability of the technique; 4. 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 is included 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.</td>
</tr>
<tr>
<td><strong>Cross-media effects</strong></td>
<td>Relevant negative effects on the environment due to implementing the technique, allowing a 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 waters 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.</td>
</tr>
<tr>
<td><strong>Technical considerations relevant to applicability</strong></td>
<td>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 plants or processes within the sector to which the...</td>
</tr>
</tbody>
</table>
technique cannot be applied;

- constraints to implementation in certain generic cases, considering, e.g.:

  I. whether it concerns a new or an existing plant, taking into account factors involved in retrofitting (e.g. space availability) and interactions with techniques already installed;
  
  II. plant size, capacity or load factor;
  
  III. quantity, type or quality of product manufactured;
  
  IV. type of fuel or raw material used;
  
  V. animal welfare;
  
  o climatic conditions.

These restrictions are indicated together with the reasons for them.

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 plant.

| Economics | Information on the costs (capital/investment, operating and maintenance costs including details on how they 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 euros (EUR). If a conversion is made from another currency, the data in the original currency and the year when the data were collected are indicated. The price/cost of the equipment or service is accompanied by the year it was purchased.

Information on the market for the sector is given in order to put costs of techniques into context.

Information relevant to both newly built, retrofitted and existing plants is included. 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 its calculation can be reported.

The Reference Document on Economics and Cross-media Effects (ECM) and the Reference Report on Monitoring of Emissions to Air and Water from IED Installations (ROM) are taken into account with regard to economic aspects and monitoring costs, respectively.

| Driving force for implementation | 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 are provided.

This subsection should be very short and use a list of bullet points.

| Example plants | Reference to a 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.

| Reference literature | 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 many pages, reference will be made to the relevant page(s) or section(s).
4.1 General techniques [good management practices]

4.1.1 General management techniques

4.1.1.1 Environmental management system (EMS)

Description
A formal system to demonstrate compliance with environmental objectives.

Technical description
The Industrial Emission 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 4.1).

![Figure 4.1: Continuous improvement in an EMS model](image)

An EMS can take the form of a standardised or non-standardised (‘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. The European Union eco-management and audit scheme (EMAS) according to Regulation (EC) No 1221/2009 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 IED only regulates installations.

An EMS can contain the following features:

i. commitment, leadership, and accountability of the management, including senior management, for the implementation of an effective EMS;

ii. an analysis that includes the determination of the organisation’s context, the identification of the needs and expectations of interested parties, the identification of characteristics of the installation that are associated with possible risks for the environment (or human health) as well as of the applicable legal requirements relating to the environment;

iii. development of an environmental policy that includes the continuous improvement of the environmental performance of the installation;

iv. establishing objectives and performance indicators in relation to significant environmental aspects, including safeguarding compliance with applicable legal requirements;

v. planning and implementing the necessary procedures and actions (including corrective and preventive actions where needed), to achieve the environmental objectives and avoid environmental risks;

vi. determination of structures, roles and responsibilities in relation to environmental aspects and objectives and provision of the financial and human resources needed;

vii. ensuring the necessary competence and awareness of staff whose work may affect the environmental performance of the installation (e.g. by providing information and training);

viii. internal and external communication;

ix. fostering employee involvement in good environmental management practices;

x. establishing and maintaining a management manual and written procedures to control activities with significant environmental impact as well as relevant records;

xi. effective operational planning and process control;

xii. implementation of appropriate maintenance programmes;

xiii. emergency preparedness and response protocols, including the prevention and/or mitigation of the adverse (environmental) impacts of emergency situations;

xiv. when (re)designing a (new) installation or a part thereof, consideration of its environmental impacts throughout its life, which includes construction, maintenance, operation and decommissioning;

xv. implementation of a monitoring and measurement programme; if necessary, information can be found in the Reference Report on Monitoring of Emissions to Air and Water from IED Installations [ 20, COM 2018 ];

xvi. application of sectoral benchmarking on a regular basis;

xvii. periodic independent (as far as practicable) internal auditing and periodic independent external auditing in order to assess the environmental performance and to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;

xviii. evaluation of causes of nonconformities, implementation of corrective actions in response to nonconformities, review of the effectiveness of corrective actions, and determination of whether similar nonconformities exist or could potentially occur;
Chapter 4

xix. periodic review, by senior management, of the EMS and its continuing suitability, adequacy and effectiveness;
xx. following and taking into account the development of cleaner techniques.

Specifically for the textile industry, it is also important to incorporate the following potential features in the EMS:

xxi. an inventory of input and output streams (see Section 4.1.1.2);
xxii. a water efficiency plan (see Section 4.1.3.1);
xxiii. an energy efficiency plan (see Section 4.1.4.1);
xxiv. a raw materials management plan (see Section 4.1.5.1);
xxv. a chemicals management system (see Section 4.1.6.1);
xxvi. a waste management plan (see Section 4.1.9.1).

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

From ex-Section 4.1.1
Concerning the maintenance programmes, machinery, pumps and pipework (including abatement systems) should be well maintained and free from leaks. Regular maintenance schedules should be established, with all procedures documented. In particular attention should be paid to the following areas:

• machinery checking: the most significant components of the machinery like pumps, valves, level switches and pressure and flow regulators are checked; should be included in a maintenance checklist
• leak control: verifications audits are should be carefully conducted to detect potential leaks from broken and leaking pipes, drums, pumps and valves, not only in the water system but also from the oil heat transfer and chemicals dispensing systems in particular;
• filter maintenance: regular cleaning and checking of filters;
• calibration of measuring equipment, such as chemicals measuring and dispensing devices, thermometers;
• thermal treatment units (e.g. stenters): all units should be cleaned and maintained regularly (at least once a year) cleaned and maintained. This should includes cleaning deposits from the exhaust gas ducts conducting system and from the intake system of the burner air inlet.

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 level of detail and the degree of formalisation of the EMS will generally 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 accurately determine 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 [21, IAF 2010].

Driving force 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 fulfil 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 number of installations throughout the EU. In total, 58 plants from the data collection apply an EMS.

Reference literature

[Management and good housekeeping]

Description
The notes on management and housekeeping given here, although far from being exhaustive, attempt to point out some general principles and pollution prevention approaches that are almost universally applicable in textile mills.

Education/training of employees
Staff training is an important element of environmental management. All staff should understand clearly the precautions needed to avoid resource wastage and pollution. Training should be resources (chemicals, fibres, energy, water), process and machinery specific.

Senior management should have a clearly expressed commitment to environmental improvement, preferably in the form of an environmental policy and an implementation strategy, made available to all staff.

Equipment maintenance and operations audit
Moved to Section 4.1.1.1

Chemicals storage, handling, dosing and dispensing
Moved to Section 4.1.6.4.1

Improved knowledge of chemicals and raw materials used
Moved to Section 4.1.1.2
Main achieved environmental benefits
The main environmental advantages achievable by systematic performance of optimised housekeeping and management measures are savings in the consumption of chemicals, auxiliaries, fresh water and energy and the minimisation of solid waste and pollution loads in waste water and off-gas.

Workplace conditions can also be improved.

Operational data
Vary with the type of measure considered. Cross references to fuller information about some techniques are given above.

Cross-media effects
None believed likely.

Applicability
Most of the described methods are cheap and do not require investment in new equipment, although the immediate applicability of some of the techniques in existing mills may be limited by considerations of space, logistics etc. and the need for major structural modifications. Particularly, space availability may be an issue in some existing plants if implementing measures such as the optimisation of boiler houses and the installation of heat recovery systems for off-gases [311, Portugal, 2002].

Some measures, such as the installation of automated dosing systems and process control devices, may be expensive, depending on how sophisticated they are.

The success of management and good housekeeping measures is largely dependent on the commitment and organisational skills of management. Tools such as EN ISO 9000 ff, EN ISO 14001 and EMAS will support this approach. Information and communication are required at company level and within the whole supply chain.

Economics
The described measures enable improved operational reliability and reproducibility, which is economically beneficial. The main economic benefits are savings in the consumption of energy, fresh water, chemicals, and in the cost of waste water, off-gas cleaning and discharge of solid waste.

Driving force for implementation
Cost savings, improvement of operational reliability, improved environmental performance and compliance with legislation are the main reasons for implementing good general management / good housekeeping.

Reference plants
Various textile finishing mills in Europe have implemented good general management practices to improve their environmental performance and are working in accordance with good housekeeping principles.

Reference literature

4.1.1.2 Input/output streams [evaluation/inventory]

From ex-Section 4.1.2

Description
The compilation of relevant basic data on input and output streams of resources (e.g. inputs like materials, energy, water, and outputs like waste gases, waste waters, wastes, energy losses, etc.). Basic data for streams include the information on environmentally important characteristics, like presence of hazardous substances, their toxicity, composition and quantities. These data are used in mass balances, efficiency plans and for monitoring of emissions.

Technical description
All environmental problems are directly linked with input/output streams. In the interests of identifying options and priorities for improving environmental and economic performance, it is therefore vital to know as much as possible about their quality and quantity.

Input/output stream inventories can be drawn up on different levels. The most general level is an annual site-specific overview.

Figure 4.2 indicates the relevant input/output streams. Starting from the annual values, specific input and output factors for the textile substrate can be calculated (e.g. litres of water consumption/kg of processed textiles or g of COD in waste water/kg of processed textiles). Although these factors have their limitations, they allow preliminary comparisons with other sites/plants or similar processes and they provide a baseline against which to start tracking ongoing consumption and emission levels. Available data for different categories of waste water are presented in Chapter 3.
The inventory contains the following information:

(i) Information about the textiles 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
       techniques to prevent or reduce emissions, including their performance (e.g. abatement efficiency).

(ii) Information about water consumption and usage (e.g. flow diagrams and water mass
     balances), and identification of actions to reduce water consumption and waste water
     volume (see Section 4.1.3.1).

(iii) Information about the quantity and 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 substances/parameters and their
         variability (e.g. COD/TOC, nitrogen species, phosphorus, metals, priority substances,
         microplastics);
(c) data on bioeliminability (e.g. BOD, BOD to COD ratio, Zahn-Wellens test, biological inhibition potential (e.g. inhibition of activated sludge)).

(iv) Information 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 substances/parameters and their variability (e.g. dust, organic compounds);
(c) flammability, lower and higher explosive limits, reactivity;
(d) presence of other substances that may affect the waste gas treatment system or plant safety (e.g. water vapour, dust).

(v) Information about energy consumption and usage (see Section 4.1.4.1).

(vi) Information about the quantity of raw materials used (see Sections 4.1.5 and 4.1.5.3.1), as well as the quantity and characteristics of residues generated (see Section 4.1.9.1), and identification of actions for continuous improvement of resource efficiency (e.g. use of solvents by means of a solvent management plan).

(vii) Identification and implementation of an appropriate monitoring strategy with the aim of increasing resource efficiency, taking into account energy, water and raw materials consumption. Monitoring can include direct measurements, calculations or recording with an appropriate frequency. The monitoring is broken down at the most appropriate level (e.g. at process or plant/installation level).

The systematic listing and evaluation of applied chemicals (dyestuffs and pigments, textile auxiliaries and basic chemicals) is very important for identifying critical compounds. It is therefore recommended that eight forms be used, one for each of the following classes (see example in Figure 4.3):

- auxiliaries and finishing agents for fibres and yarns
- pretreatment agents
- textile auxiliaries for dyeing and printing
- finishing assistants
- technical auxiliaries for multipurpose use in the textile industry
- textile auxiliaries not mentioned in the Textile Auxiliaries Buyer’s Guide “Melland/TEGEWA, 2000”
- basic chemicals (all inorganic compounds, all aliphatic organic acids, all organic reducing and oxidising agents, urea)
- dyestuffs and pigments.

The first six categories are identical with Textile Auxiliaries Buyer’s Guide.

The following table shows an example form for dyeing and printing.

<table>
<thead>
<tr>
<th>From ex-Section 4.1.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>The process inputs and outputs should be known and regularly monitored. This includes inputs of textile raw material, chemicals, heat, power and water, and outputs of product, waste water, air emissions, sludges, solid wastes and by-products (see Section 4.1.1.2).</td>
</tr>
</tbody>
</table>

Pre-screening of incoming raw materials (fibres, chemicals, dyestuffs, auxiliaries, etc.) is of the utmost importance for pollution prevention (see Section 4.1.5.1.1). The supplier provides should take the responsibility for providing adequate information that enables the mill to make a responsible environmental evaluation, even on of proprietary products.

The detailed information provided to the finisher about textile raw material is not limited to the technical characteristics of the textile substrate but Information from the supplier should also include also the kind type and amount of preparation agents and sizing agents, and the amount of residual monomers, metals and biocides (e.g. ectoparasiticides for wool) present on the fibre. These substances/impurities are carried over into the process and account for a significant percentage of the pollutant load from textile mills. Improved knowledge of the raw material will allow the manufacturer to prevent or at least control the resulting emissions.
### Form 3: Form for the listing of textile auxiliaries for dyeing and printing

<table>
<thead>
<tr>
<th>Nº</th>
<th>Commercial name</th>
<th>Chemical characterization</th>
<th>Process, application</th>
<th>Danger symbol</th>
<th>Annual consumption (kg/yr)</th>
<th>Biological degradation elimination (%) and testing method</th>
<th>Spec. COD value (mg O₂/g)</th>
<th>Spec. BOD₅ value (mg O₂/g)</th>
<th>Heavy metal content (mg/g)</th>
<th>Org. halogen content (mg/g)</th>
<th>COD-load (kg O₂/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.16</td>
<td>Revatol S Gran.</td>
<td>Nitrobenzenesulphonic acid, Na-salt</td>
<td>Dyeing</td>
<td>Xi</td>
<td>5400</td>
<td>590; OECD 302 B</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td>5446</td>
</tr>
<tr>
<td>3.04</td>
<td>Alviron OL-EM II.</td>
<td>Formulation of surfactants and high-boiling alcohols</td>
<td>Dyeing</td>
<td>——</td>
<td>3800</td>
<td>590; after adaptation</td>
<td>0.760</td>
<td></td>
<td></td>
<td></td>
<td>2888</td>
</tr>
<tr>
<td>3.12</td>
<td>Cyclanon ARC Plv.</td>
<td>Sulphinic acid derivative and dispersing agent</td>
<td>Dyeing</td>
<td>Xi</td>
<td>3650</td>
<td>20—70; OECD confirmatory test</td>
<td>0.335</td>
<td></td>
<td></td>
<td></td>
<td>3223</td>
</tr>
<tr>
<td>3.02</td>
<td>Lamapon UV-11</td>
<td>Polysaccharide</td>
<td>Dyeing</td>
<td>——</td>
<td>2500</td>
<td>570; OECD 302 B</td>
<td>0.350</td>
<td></td>
<td></td>
<td></td>
<td>875</td>
</tr>
<tr>
<td>3.04</td>
<td>Dreiagen E2R II.</td>
<td>Aromatic polyether sulphonic derivative</td>
<td>Dyeing</td>
<td>Xi</td>
<td>1400</td>
<td>46; OECD 302 B</td>
<td>0.616</td>
<td></td>
<td></td>
<td></td>
<td>804</td>
</tr>
<tr>
<td>3.23</td>
<td>Sandacid PBD II.</td>
<td>Aliphatic carboxylic acid derivative</td>
<td>Dyeing</td>
<td>——</td>
<td>1250</td>
<td>50; OECD 302 B</td>
<td>0.109</td>
<td></td>
<td></td>
<td></td>
<td>386</td>
</tr>
<tr>
<td>3.04</td>
<td>Paraped P-4L</td>
<td>Polysodium phosphate</td>
<td>Dyeing</td>
<td>——</td>
<td>850</td>
<td>570; OECD confirmatory test</td>
<td>0.430</td>
<td></td>
<td></td>
<td></td>
<td>366</td>
</tr>
<tr>
<td>3.23</td>
<td>Eqasol 010 Plv.</td>
<td>Mixture of organic and inorganic salt</td>
<td>Dyeing</td>
<td>Xi</td>
<td>620</td>
<td>—</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>3.10</td>
<td>Indosol E-50-4L</td>
<td>Aliphatic polystyrene</td>
<td>Dyeing</td>
<td>——</td>
<td>480</td>
<td>50; OECD 302 B</td>
<td>0.420</td>
<td></td>
<td></td>
<td></td>
<td>202</td>
</tr>
</tbody>
</table>

Figure 4.3: Form for the listing of textile auxiliaries for dyeing and printing
[179, UBA, 2001]
The listing allows a first rough assessment of the applied chemicals and a calculation of COD input to the process. The information on biological degradation/elimination is the basis for the selection of products with higher biodegradability/bioeliminability. The full picture, however, can only be had by assessing each of the ingredients of the commercial formulations used. In addition, the information on biological degradation/elimination often has to be critically questioned with respect to the properties of chemicals and the testing methods.

The next level is the process or machine level. Chapter 3 contains examples of analysis of consumption and emission levels for some specific processes. In many cases this level of information directly leads to identification of options for improvement and optimisation. Shows an example of input/output assessment at process specific level (the example deals with energy and water consumption, but the same approach can be applied for other parameters).

Main-Achieved environmental benefits
The described evaluation and inventory of input/output mass streams is an essential management tool for the identification of optimisation potential, both environmental and economic. It is the prerequisite for a continuous improvement process.

Environmental performance and operational data
The application of such a management tool requires highly qualified staff and the commitment of the management committee at the highest level. The work of such experts generally pays for itself, but this is not yet widely understood.

The input/output streams inventory allows cross-media effects to be taken into consideration during the assessment of potential optimisation options. This means the achievement of a high level of protection of the environment as a whole.

Cross-media effects
None identified. There are no cross-media effects to be mentioned. On the contrary, the input/output streams assessment/inventory allows cross-media effects to be taken into consideration during the assessment of potential optimisation options. This means the achievement of a high level of protection of the environment as a whole.

Technical considerations relevant to applicability
The technique is applicable to both new and existing and new and existing installations. Provided that the management of a company is convinced of the benefits of such a tool, there are no limitations in its applicability, regardless of the size of the mill.

The scope (e.g. level of detail) and nature of the inventory will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

Economics
There is no specific information available on economic aspects but, generally speaking, because of the big significant potential for improvements in the textile sector, the application of the described management tool described pays for itself within a short time [26, UBA, 2001].

Driving force for implementation
Savings on raw materials and production costs is good business. The application of this type of approach makes it easier to implement environmental management systems such as under EMAS or ISO 14001:2015.

Reference Example plants
There are various textile finishing industries in Western Europe which have implemented input/output streams evaluation and documentation as inventories on site level. Only A few are also systematically applying this instrument on process level.
A total of 104 plants reported applying this technique.

References literature
[26, UBA, 2001]

4.1.1.3 Monitoring and control of operational parameters

Description
Key operational and process parameters are monitored and controlled by use of advanced automatic process controls and systems (e.g. for on-line monitoring) in process steps and machinery used for processing and treatment of textile fibres.

Technical description
Key operational and process parameters are monitored and/or controlled at both: process/machine level (e.g. by means of sensors controlled by PIC/PLC (process integrated/logic controllers) or microprocessors) and plant level (e.g. by on-line integrated computer control systems like SCADA). These parameters are related to the characteristics of the textile, raw materials, working liquors and treatment conditions. They include:

- level, dosage, temperature, pH, conductivity, concentration and liquor ratio and control of uptake of working liquors and treatment conditions in wet treatments;
- temperature, humidity and heat supply control in thermal treatments;
- machine rate control;

Basic control can be upgraded with sophisticated systems that provide feedback on these operational parameters and that are also able to track water, energy and chemicals consumption, to store procedures and recipes, to track changes and to enhance the reproducibility of processes.

Expert software systems based on self-learning by algorithms (using fuzzy logic and artificial neural networks) are developed and used in textile processing. [199, Siemens 2005]

Achieved environmental benefits
Reduced effluents, chemicals, water and energy consumption.

Environmental performance and operational data
The energy consumption of textile plants is reduced significantly (e.g. by over 25%) by the use of retrofitted frequency controllers on motors. [33, CITEVE 2014]

Automatic dye machine controllers offer an effective means for enhanced control of dyeing processes, based on microprocessors, allowing for feedback on process parameters such as the pH, colour, and temperature of the working liquor. They analyse process parameters continuously and respond more quickly and accurately than manually controlled systems. Automatic dye machine controllers have the potential to reduce the volume of effluents by up to 4.3 %. [33, CITEVE 2014]

Individually, process control improvements may result in relatively low water and energy consumption and cost reduction, but together they make a significant contribution.

Most of these advanced control technologies are usually preinstalled in new equipment and machinery.

On-line monitoring and advanced process control in washing steps after pretreatment, dyeing or finishing, including the measurement of COD concentration, conductivity and redox potential, are used to determine the point at which the dyes, various agents and chemicals are completely rinsed off to control the rinsing process steps, their duration and amount of fresh water used. In
the bleaching process, the concentration of reducing or oxidising agents on fabrics and the completeness of \( \text{H}_2\text{O}_2 \) removal after bleaching can be monitored to prevent the excessive use of chemicals. Similarly in vat dyeing, the concentration of reducing agents can be monitored to regulate the use of chemicals.

**Cross-media effects**
None identified.

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of this technique.

**Economics**
Plant investments in these systems/controls typically have a high financial return and quick payback time. This includes both the initial installation and the ongoing maintenance of the equipment and systems (e.g. sensors, controllers).

Table 4.2 shows the costs and benefits of the implementation of dye machine controllers in plants of different sizes.

**Table 4.2: Dye machine controllers’ costs and benefits**

<table>
<thead>
<tr>
<th>Cost item</th>
<th>Small plant (8 000 kg/week)</th>
<th>Medium plant (60 000 kg/week)</th>
<th>Large plant (117 000 kg/week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost (average per plant)</td>
<td>USD 280 000</td>
<td>USD 450 000</td>
<td>USD 800 000</td>
</tr>
<tr>
<td>Net annual operating savings (average per plant)</td>
<td>USD 79 770</td>
<td>USD 128 200</td>
<td>USD 227 900</td>
</tr>
<tr>
<td>Simple payback period (year)</td>
<td></td>
<td>3.5</td>
<td></td>
</tr>
</tbody>
</table>

Note: Costs and savings are associated with the volume of production for each plant size and not just for one machine.

*Source: Marbek Resource Consultants, 2001 as cited in [152, Hasanbeigi 2010]*

**Driving force for implementation**
- Reduced water, energy and chemicals consumption.
- Reduced operating costs.

**Example plants**
Many plants reported using advanced process monitoring and control.

**Reference literature**
[33, CITEVE 2014], [199, Siemens 2005], [152, Hasanbeigi 2010].

**4.1.2 Monitoring**

**4.1.2.1 Monitoring of influent and effluent**

**Description**
For waste water streams identified by the inventory of inputs and outputs (see Section 4.1.1.2), the key parameters (e.g. continuous monitoring of waste water flow, pH and temperature) are monitored at key locations (e.g. at the inlet and/or outlet of the pretreatment, at the inlet to the final treatment, at the point where the emission leaves the installation).

**Technical description**
Proper operation of a waste water treatment facility requires the monitoring and targeted adjustment of various process parameters in the influent and effluent of the facility. Monitoring of the relevant parameters can be accomplished by online measurements (that facilitate rapid
intervention and control) or analytical results derived from waste water samples. Parameters to be monitored and the frequency of monitoring depend on the characteristics of the waste water to be treated, the final effluent discharge medium and the waste water treatment techniques used within the facility, based on an inventory of waste water streams. They may include, for instance, the waste water flow, pH, temperature, conductivity or BOD.

The monitoring is carried out at key locations, e.g. at the point where the emission leaves the installation and/or at the inlet and/or outlet to pretreatment and at the inlet to final treatment. Important parameters are monitored at the level of each waste water treatment technique to ensure the proper operation of the techniques and the subsequent treatment steps.

**Achieved environmental benefits**

Monitoring the influent and effluent of a waste water treatment facility helps to maintain the proper operation of the facility and to detect accidental releases and thus helps to prevent any possible adverse environmental effects upon discharge of waste waters.

**Environmental performance and operational data**

No information provided.

**Cross-media effects**

Some equipment, chemicals and energy are required for carrying out monitoring. The COD measurement relies on the use of very toxic compounds (i.e. mercury and chromate).

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

**Economics**

The costs associated with monitoring the influent and effluent waste water of a WWTP relate to personnel and equipment used for sampling and measurement.

**Driving force for implementation**

To ensure the proper operation of the WWTP and to ensure that the required quality of the effluent waste water from the WWTP is met and in line with the effluent discharge criteria.

**Example plants**

Monitoring of influent and effluent in a waste water treatment facility is applied in a number of installations throughout the EU.

**Reference literature**

[24, COM 2016]

**4.1.2.2 Monitoring of emissions to water**

**Description**

Regular monitoring of emissions to water.

**Technical description**

Monitoring of the relevant parameters can be accomplished by online measurements (that facilitate rapid intervention and control of the WWTP) or analytical results derived from waste water samples. Parameters to be monitored and the frequency of monitoring depend on the activities which generate the waste water, the type of waste water treatment and the destination of the effluent (direct discharge or indirect discharge after treatment in an industrial or municipal WWTP).

The monitoring of emissions is carried out in accordance with EN standards or, if EN standards are not available, in accordance with ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.
Achieved environmental benefits
Monitoring the waste water of a waste treatment plant helps to maintain the proper operation of the waste treatment plant and to detect accidental releases and thus helps to prevent any possible adverse environmental effects when the waste waters are discharged.

Environmental performance and operational data
Figure 4.4 summarises the information from the data collection on parameters monitored in textile plants.

Cross-media effects
Some equipment, ancillary materials and energy are required for carrying out monitoring. The COD measurement relies on the use of very toxic compounds (i.e. mercury and chromate).

Technical considerations relevant to applicability
Generally applicable to all plants where there are emissions to water.

Economics
The costs associated with monitoring the effluent waste water of a waste water treatment plant relate to personnel and equipment used for sampling and measurement.

See [ 20, COM 2018 ] for more details.

Driving force for implementation
Environmental legislation.

Example plants
See examples in Chapter 3.
4.1.2.3 Monitoring of emissions to air

Description
Regular monitoring of emissions to air.

Technical description
Monitoring of the relevant parameters can be accomplished by online measurements (which facilitate rapid intervention and control) or analytical results derived from air samples. Parameters to be monitored and the frequency of monitoring depend inter alia on the activities connected to the emissions to air.

The monitoring of emissions is carried out in accordance with EN standards or, if EN standards are not available, ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

Achieved environmental benefits
Monitoring the waste gas of a textile plant helps to maintain the proper operation of the plant and to detect accidental releases and thus helps to prevent any possible adverse environmental effects when the waste gas is emitted.

Environmental performance and operational data
Figure 4.5 summarises the information from the data collection on parameters monitored in textile plants.

![Graph showing the number of emission points to air when a given parameter is monitored](source: [196, TWG 2019])

Figure 4.5: Number of emission points to air when a given parameter is monitored
Cross-media effects
Some equipment, ancillary materials and energy are required for carrying out monitoring.

Technical considerations relevant to applicability
Generally applicable to all plants where there are channelled emissions to air.

Economics
The costs associated with monitoring the waste gas relate to personnel and equipment used for sampling and measurement.

See [20, COM 2018] for more details.

Driving force for implementation
Environmental legislation.

Example plants
See examples in Chapter 3.

Reference literature
[20, COM 2018]

4.1.2.4 Emission factor [concept (emissions to air)]

<table>
<thead>
<tr>
<th>From ex-Section 4.3.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
</tr>
<tr>
<td>Use of an emission factor calculation to monitor emissions to air.</td>
</tr>
</tbody>
</table>

Technical description
The emission factor concept concerns the emissions of volatile organic compounds carbon and dangerous substances (expressed as organic carbon) that are potentially found in the exhaust air from heat-setting, the thermosol process, impregnation and fixation of finishing agents. The concept was developed in Germany by public authorities (national and federal states level) in co-operation with the German Association of textile finishing industry association (TVI-Verband) and TEGEWA “LAI, 1997”.

The fundamental principle of this concept is that in most cases the emissions produced by the single components in the auxiliary formulations are additive. As a result, the emission potential of each recipe can be calculated on the basis of emission factors given for the single substances present in the formulation (for certain substances, however, the correlation between emission and process parameters is more complex).

It is necessary to distinguish between:

- a substance-based emission factor; and
- a textile substrate-based emission factor.

The substance-based emission factor (fc or fs) is defined as the amount of substances (organic or inorganic) in grams that can be released at defined process conditions (curing time, curing temperature and type of substrate) from one kilogram of auxiliary. There are two types of substance-based emission factors: 1) fc, which gives the total emission produced by the organic substances present in the formulation, expressed as total organic carbon; 2) fs, which gives the emission attributable to specific toxic or carcinogenic organic substances or to inorganic compounds, such as ammonia and hydrogen chloride, etc. present in the formulation.

In Germany, where the technique is widely applied, the substance-based emission factors are provided to the finisher by the auxiliary supplier, in addition to the information reported in the
Material Safety Data Sheets. The factors are based on measurements, calculations or conclusions made by analogy (according to TEGEWA guidance for calculation of substance-based emission factors) [211, Germany 2002].

The textile substrate-based emission factor (WFc or WFs) is defined as the amount of organic and inorganic substances in grams that can be released as defined process parameters (curing time, curing temperature and type of substrate) from one kilogram of textile treated with a given auxiliary formulation. The textile substrate-based emission factor can be calculated on the basis of the emission factors of the individual components of the formulation/recipe (fc or fs), their concentration in the liquor (FK) and the liquor pick-up. One example of the calculation of the textile-based emission factor is reported in Table 4.3.

Table 4.3: Two examples for the calculation of air emission factors

<table>
<thead>
<tr>
<th>RECIPE 1</th>
<th>FK (g/kg)</th>
<th>FA (g/kg)</th>
<th>fs (g/g)</th>
<th>fc (g/g)</th>
<th>FK<em>FA</em>fs (g/kg)</th>
<th>WFs (g/kg)</th>
<th>FK<em>FA</em>fc (g/kg)</th>
<th>WFc (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton; 170°C</td>
<td>20</td>
<td>0.65</td>
<td>-</td>
<td>0.015</td>
<td></td>
<td>0.2</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>Fatty acid ester</td>
<td>20</td>
<td>0.65</td>
<td>-</td>
<td>0.005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polysiloxane</td>
<td>100</td>
<td>0.65</td>
<td>0.0041FO</td>
<td>0.0009</td>
<td>0.27FO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross-linking agent</td>
<td>Stearyl urea derivative (catalyst)</td>
<td>20</td>
<td>0.65</td>
<td>0.0165FO</td>
<td>0.0162</td>
<td>0.21FO</td>
<td></td>
<td>0.21</td>
</tr>
<tr>
<td><strong>Total 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.48FO</td>
<td></td>
<td>0.54</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RECIPE 2</th>
<th>FK (g/kg)</th>
<th>FA (g/kg)</th>
<th>fs (g/g)</th>
<th>fc (g/g)</th>
<th>FK<em>FA</em>fs (g/kg)</th>
<th>WFs (g/kg)</th>
<th>FK<em>FA</em>fc (g/kg)</th>
<th>WFc (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton; 150°C</td>
<td>50</td>
<td>1</td>
<td>-</td>
<td>0.005</td>
<td>-</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Softening agent</td>
<td>Formaldehyde-free cross-linking agent</td>
<td>12</td>
<td>1</td>
<td>-</td>
<td>0.01</td>
<td>-</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Catalyst</td>
<td></td>
<td>12</td>
<td>1</td>
<td>-</td>
<td>0.008</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Total 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.47</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Notes:
- FK: concentration in the recipe (g auxiliary/kg liquor)
- FA: liquor pick-up (kg liquor/kg textile substrate)
- fs: substance-based emission factor (g emission/g auxiliary) (in the case of toxic or carcinogenic organic substances or in the case of inorganic substances such as ammonia, hydrogen chloride, etc.)
- fc: substance-based emission factor, expressed as total organic carbon (g Org-C/g auxiliary)
- WFs: Σ(FK*FA*Fs) - textile-based emission factor, within the same class of substances
- WFc: Σ(FK*FA*Fc) - textile-based emission factor, expressed as total organic carbon
- FO: formaldehyde

The calculated textile substrate-based emission factors WFc/s can then be compared with the limit values for textile substrate-based emission factors set by environmental authorities (referred to for a standard air to textile substrate ratio of 20 m³ air/kg of textile substrate).

Main-Achieved environmental benefits

The concept can be regarded as a system to control and also to prevent air emissions to air from textile finishing. The auxiliary-based substance emission factor makes it possible to predict the emissions of a given recipe based on the emission factors of the single components. In this way the operator knows the emissions of his process before carrying it out. He can therefore concentrate, at the product and process design stage, on minimising the emissions at the source, for example by reducing the amount of auxiliaries or selecting auxiliaries with lower emission potential (see Section 4.1.6.3).
Environmental performance and operational data

Typical auxiliary-based emission factors are summarised in Annex IV. The control of the air emissions to air of the recipes/formulations for finishing by pre-calculation of the textile substrate-based emission factors should be is done regularly (at least once a year) and especially before using a new recipe or changing the components of an existing recipe.

The following reflects the air emission values, related to an air to textile substrate ratio of 20 m$^3$/kg, applied achieved in Germany and achievable thanks to the application with the use of the emission factor concept:

- **Harmful organic substances** such as toxic substances, suspected carcinogens: \( \leq 0.4 \text{ g/kg of textile substrate as the total emission, with an emission mass flow from the entire plant of 0.10 \text{ kg/h or higher.}} \)
- **Carcinogenic substances** a maximum of 0.02 g/kg textile substrate as total emission, with an emission mass flow from the entire plant of 2.5 g/h or higher.
- **Carcinogenic, mutagenic or reprotoxic substances:**
  - Class I: max. 0.001 g/kg of textile as the total emission (if the mass flow of the whole installation is 0.15 g/h or higher);
  - Class II: max. 0.010 g/kg of textile as the total emission (if the mass flow of the whole installation is 1.5 g/h or higher);
  - Class III: max. 0.020 g/kg of textile as the total emission (if the mass flow of the whole installation is 2.5 g/h or higher).
- **Other organic substances:** \( \leq 0.8 \text{ g C/kg of textile substrate, as the total emission, with an emission mass flow from the entire plant of 0.8 kg C/h or higher.} \)

All substances belonging to class I (2.1.7TA-Luft) exceeding 500 ppm in the auxiliary formulation have to be declared. In addition, information on substances classified under item 2.3TA-Luft (carcinogenic substances) exceeding 10 ppm is obligatory (“TA-Luft, 1986”).

Substances or preparations which are classified as carcinogens, mutagens or toxic to reproduction under Directive 67/548 EEC as last amended by Directive 1999/33/EG and last adapted by Directive 2000/33/EG, are assigned or need to carry the risk phrases R45, R46, R49, R60, R61 shall be replaced as far as possible by less harmful substances or preparations within the shortest possible time.

**Cross-media effects**
None identified believed likely.
However, it has to be kept in mind as a general consideration, that the use of a factor makes access to the accumulated information difficult, unless it is fully disclosed [281, Belgium, 2002].

**Technical considerations relevant to applicability**
The emission factor concept is generally applicable if the producers of chemicals determines the emission factor of the auxiliaries (preparations) in textile mills and is especially suitable for facilities performing chemical finishing treatments and thermosol processes.

This technique is widely applied in Germany, where it is accepted by the environmental authorities. For other countries, the application of the emission factor concept depends entirely on the national competent bodies.

**Economics**
There are no costs for the textile finisher apart from the cost of calculating the emission factors for the finishing recipes used in the process, which is negligible. A correct selection of low-emission auxiliaries can significantly reduce costs for air emission abatement.

**Driving force for implementation**
Reduced emissions to air.
• Reduction of abatement costs (Economics).

Pre-calculation of emissions enables the finisher to take actions in order to meet the emission limit values set by environmental authorities.

In Germany, where the emission factor concept is accepted by the environmental authority, an important driving force for implementing this technique has been the possibility that it gives of avoiding or reducing expensive emission measurements (pre-calculation).

Example Reference plants
Many in Germany.
A total of 47 plants from DE and 1 plant from IT reported using this approach.

Reference literature
[26, UBA, 2001], [62, Germany 2001] [36, ÖKOPOL 2011]

4.1.3 Water efficiency
4.1.3.1 [Optimising water consumption in textile operations] Water management plan and water audits

Description
A water management plan and water audits are part of the environmental management system (EMS) and include:

- flow diagrams and a water mass balance;
- establishment of water efficiency objectives;
- implementation of water optimisation techniques (e.g. control of water usage, reuse/recycling, detection and repair of leaks);

Water audits are carried out at least annually to ensure that the objectives of the water management plan are met.

Technical description
Some water optimisation techniques to consider are as follows:

From ex-Section 4.1.4
Textile processing is known to be a water-intensive sector. Many techniques in this chapter, including some of the housekeeping measures already mentioned in other parts of this document, deal with reducing water consumption. Some aspects are common to many treatments. This section is intended to be a summary of the factors that may be of more importance for optimal water usage.

a) Controlling water consumption
A prerequisite of any programme to prevent unnecessary use–waste of water is to firstly collect information on the installation and the volumes consumed in the various processes. This kind of audit/assessment should actually be as part of a wider programme involving the collection of information on types, quantities, composition and sources of all waste streams (see Section 4.1.1.2).

As with water consumption, data at site level is already a good benchmark in determining whether water consumption is excessive and is a good baseline against which to measure improvements. In order to allow a process-specific analysis, however, it is fundamental for setting priorities and identifying potential pollution prevention options. Water use is should be monitored and recorded at machine/process level and water meters are should be regularly maintained and calibrated.
b) Reducing water consumption

- By improved working practices:
  Production procedures are established and the personnel trained, in order to avoid inappropriate working practices and the absence of automated control systems that can lead to significant wastage of water, e.g.:
  - overfilling which may occur during filling and rinsing, for example, where machines are equipped only with manual water control valves; there is potential for overfilling
  - displacement spillage during immersion of the fibre in the machine which may account for up to 20% of the total operating volume over the course of a dyeing cycle (this may also lead to losses of dyes and hazardous chemicals if these are introduced before the displacement takes place).

Well-documented production procedures and training are important. Dyeing machines should at least be fitted with modern process control equipment, capable of accurately controlling both the fill volume and the liquor temperature.

- By production optimisation:
  - Optimisation of scheduling in production (e.g. in dyeing, dyeing dark shades after pale shades reduces water and chemicals consumption for machine cleaning. In finishing, proper scheduling minimises machine stops and heating up/cooling down steps.)
  - Adjustment of processes in pretreatment to quality requirements in downstream processes (e.g. bleaching is often not necessary if dark shades are produced).

- By technical modifications:
  - Installation of automatic controllers to facilitate accurate control of fill volume and liquor temperature (e.g. batch dyeing machines).

- By reducing liquor ratio:
  In continuous dyeing, the dye is applied in the form of a concentrated liquor. The volume of water consumed per kg of processed fabric in the dyeing process is therefore fairly low even when using conventional application systems (e.g. padders). This volume can be even lower in more recently developed application systems (e.g. fluidyer, foam, flexnip application systems – see Section 10.4.2).

Flexnip application systems are – contrary to U-shaft – unsuitable for dyeing because in the short contact time (0.1-0.2 s) the dyes would not penetrate the fibre effectively (see description of both systems in Section 4.5.1.3). However, this kind of application is applicable for pretreatment and finishing. [36, ÖKOPOL 2011]

As already explained in Section 2.7.8.2, in batch operations the amount of water used per kg of processed substrate is higher, although there has been considerable improvement in this field too. All major machine manufacturers now have units for dyeing at a low liquor ratio. An investment in such units pays because it cuts operating costs (energy, water, chemicals, dyes, etc.) and raises productivity by reducing processing times (see also Section 2.7.8.2 and Section 4.5.1.6).

- By improving washing efficiency:
  See Section 4.1.3.3.

**Moved to Section 4.1.3.3**

- By combining processes:
  Combining and scheduling processes reduces the number of chemical dumps. This is often feasible for pretreatment operations (e.g. scouring/desizing, scouring/desizing/bleaching – see for example Section 4.4.3). Combining pretreatment into the colouration stage is also possible in some cases.
By reusing/recycling water:
See Section 4.1.3.2.

Re-using water
Water reuse has been moved into a separate technique

From ex-section 4.1.1. Part of this text is used above.

In order to develop waste minimisation options in a process, a detailed understanding of the plant wastes and operations is required. In particular, optimal use of water and energy should start from monitoring of water, heat and power consumption of sub-units of the process and characterisation of the facility waste streams. This general, but fundamental, approach is explained in Section 4.1.3.

Using this improved knowledge of the process, a number of low-technology measures can be identified. A first group of measures applicable to wet processes (in which water and energy consumption are often related because energy is used to a great extent to heat up the process baths):

- installation of flow control devices and automatic stop valves which link the main drive mechanism of the range to the water flow (e.g. on continuous washers – Section 4.9.2)
- installation of automatic controllers to facilitate accurate control of fill volume and liquor temperature (e.g. batch dyeing machines)
- substitution of overflow-flood rinsing method (in batch processes) in favour of drain and fill or other methods (e.g. smart rinsing) based on optimised process control (see Section 4.9.1)
- optimisation of scheduling in production (e.g. in dyeing: dyeing dark shades after pale shades reduces water and chemicals consumption for machine cleaning; in finishing: proper scheduling minimises machine stops and heating-up/cooling down steps)
- adjustment of processes in pretreatment to quality requirements in downstream processes (e.g. bleaching is often not necessary if dark shades are produced)
- combination of different wet treatments in one single step (e.g. combined scouring and desizing, combined scouring/desizing and bleaching – an example is given in Section 4.5.3)
- water reuse (e.g. reuse of final rinsing baths, dye bath reuse, use water for pre-washing carpets in after-washing, countercurrent flows in continuous washing – see Section 4.6.22)
- reuse of cooling water as process water (and also for heat recovery).

Note that whenever water is reused/ recycled it is important to discriminate between water usage and water consumption of the process. When water is reused in the process the overall water consumption naturally reduces.

Main Achieved Environmental benefits
Significant savings in water and energy consumption are possible (energy is used to a great extent to heat up the process baths). Reduced leaks, spillages and emissions to soil and groundwater.

Environmental performance and operational data
The following specific water consumption levels are considered achievable based on the data reported in Chapter 3 and expert judgement (assessment of the process, available machinery and applied techniques) [179, UBA, 2001]:
finishing of woven fabric consisting mainly of wool
(for processes that require high liquor ratio):
<250 l/kg

The data about specific water consumption of different processes is shown in Section 3.6.2. Consumption levels achieved when applying the water-saving measures mentioned in this Section are shown in Table 4.4.

Table 4.4: Specific water consumption when applying water-saving measures

<table>
<thead>
<tr>
<th>Specific process(es)</th>
<th>Specific water consumption (Yearly average) (m³/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bleaching (¹)</strong></td>
<td></td>
</tr>
<tr>
<td>Batch</td>
<td>3–48 (²)</td>
</tr>
<tr>
<td>Continuous</td>
<td>3–8</td>
</tr>
<tr>
<td><strong>Scouring of cellulosic materials (¹)</strong></td>
<td></td>
</tr>
<tr>
<td>Batch</td>
<td>2–43 (⁴)</td>
</tr>
<tr>
<td>Continuous</td>
<td>2–20</td>
</tr>
<tr>
<td><strong>Desizing of cellulosic materials (¹)</strong></td>
<td></td>
</tr>
<tr>
<td>Batch</td>
<td></td>
</tr>
<tr>
<td>Continuous</td>
<td></td>
</tr>
<tr>
<td><strong>Mercerisation</strong></td>
<td></td>
</tr>
<tr>
<td>Batch</td>
<td>2–20</td>
</tr>
<tr>
<td><strong>Washing of synthetic material</strong></td>
<td></td>
</tr>
<tr>
<td>Batch</td>
<td>2–20</td>
</tr>
<tr>
<td><strong>Batch dyeing</strong></td>
<td></td>
</tr>
<tr>
<td>Fabric</td>
<td>10–175 (⁴)</td>
</tr>
<tr>
<td>Yarn</td>
<td>3–140 (⁴)</td>
</tr>
<tr>
<td>Loose fibre</td>
<td>13–62</td>
</tr>
<tr>
<td><strong>Continuous dyeing</strong></td>
<td></td>
</tr>
</tbody>
</table>

(¹) The specific water consumption for the combined pre-treatment of cotton textiles by bleaching, scouring and desizing (see Section 4.4.3) is 9–20 m³/t. The lower end of the range is typically achieved with a continuous treatment.
(²) The lower end of the range is typically achieved with a high level of water recycling (e.g. above XX).
(³) The lower end of the range is typically achieved with a high level of water recycling (e.g. above XX).
(⁴) The lower end of the range is typically achieved with a high level of water recycling (e.g. above 85 %).
(⁵) The lower end of the range is typically achieved with a high level of water recycling (e.g. above 85 %).
(⁶) The lower end of the range is typically achieved with a high level of water recycling (e.g. above 95 %).

Source: [196, TWG 2019]

Request to TWG: please provide information to complete footnotes (2) and (3).

Cross-media effects
None believed likely.
Reduced water consumption results in a high concentration of pollutants and requires corresponding waste water treatment. [36, ÖKOPOL 2011]

Technical considerations relevant to applicability
The principles described here are generally applicable at a general level.
The level of detail of the water management plan will generally be related to the nature, scale and complexity of the plant.

Economics
In existing mills, investment in new equipment and/or structural modifications (e.g. for the segregation of streams) is likely to be necessary.

Driving force for implementation
Savings in water consumption.

Reference-Example plants
See cross-referenced techniques in other sections of this document.
A total of 28 plants from the data collection apply a water-saving plan: BE007, BE008, BE009, BE011, BE014, CZ016, DE021, DE024, DE025, DE029, DE039, DE041, DE044, DE049,
Chapter 4

DE051, FR130, FR133, FR136, IT065, IT067, IT082, IT092, PT108, PT115, PT117, SE119, SE120 and UK126.

Reference literature

4.1.3.2 Reuse and/or recycling of water and process baths

Description
This includes:

- Reuse and/or recycling of washing and rinsing water;
- reuse and/or recycling of cleaning water;
- reuse of process baths;
- reuse and/or recycling of cooling water as process water (and also for heat recovery);
- recycling of treated waste water (permeate) from treatment (membrane, reverse osmosis) of segregated dyeing or desizing effluents.

Technical description

From ex-Section 4.1.4

Batch processes do not easily allow for water recycling. When trying to reuse waste water in batch operations, storage facilities for reusable waste water are needed. Other problems associated with reuse of waste water from batch bleaching and scouring are the non-continuous character of the waste stream and the higher liquor ratios.

However, a continuous countercurrent flow of textiles and water is also possible in batch processing. Machines are now available with built-in facilities for waste stream segregation and capture. For example, the washing water from a previous load can be recovered and fully used in the bleach bath for the current load, which can then be used to scour the next load. In this way, each bath is used three times.

Some examples of water recycling and reuse are reported in this chapter (see Sections 4.6.22 and 4.7.7):

The internal separation of process liquor from the washing liquor applied to some modern batch dyeing machines (see above) is essential to allow easier bath segregation and reuse, in cases where the characteristics of the liquor make it feasible.

Storage tanks may be needed to store spent baths, washing or rinsing water for reuse.

a) Reuse and/or recycling of washing and rinsing water
[ 152, Hasanbeigi 2010 ]

This water can be reused in another washing or rinsing operation which accepts low-grade water, or it can be reused as process water in wet processing operations with or without the addition of chemicals. Examples include:

- the reuse of washing water from bleaching in caustic washing and scouring make-up and rinsing water;
- the reuse of rinsing water from scouring for desizing or washing printing equipment;
- the reuse of washing water from mercerising to prepare scouring, bleaching, and wetting-out baths;
- the use of water for pre-washing carpets in after-washing.

Generally, the rinsing water resulting after bleaching or batch dyeing can be reused several times. For instance, the rinsing water of bleaching processes can be reused for rinsing after a
caustic treatment and, in some cases, the water can be reused for a third time to rinse degraded sizing agents.

After batch dyeing, the final-step rinsing water is hardly contaminated and can be reused for the first rinsing step of the next dyeing process. If the fabric at the start of the process is put into the bath and is taken out after washing, then the rinsing water can remain in the bath and there is no need to store it separately.

The washing water can also be used in pretreatment before the dyeing process. In practice, the reuse of rinsing water from dyeing processes is complicated due to pigments remaining in the water (especially in the case of dark colours). Consequently, a prerequisite for recycling is the application of light colours (low pigment concentrations) of pigments with a high fixation rate. Before implementing this measure, an assessment is made as to whether the wash and/or rinsing water is sufficiently clean to be reused.

b) Reuse and/or recycling of cleaning water
See examples in Section 4.1.3.4 and Section 4.6.1.1.

c) Reuse of process baths
Spent bleach, dye or finishing baths are reused, after analysis and make-up if needed.

See example in Section 4.5.1.7 for the reuse of spent dye bath in batch dyeing.

d) Reuse and/or recycling of cooling water
[152, Hasanbeigi 2010]
Many cooling water systems are operated on a once-through basis. In general, cooling water and condensate water can be pumped to hot water storage tanks for reuse in functions where heated water is required, such as for dye make-up water, bleaching, rinsing and cleaning.

e) Recycling of treated segregated waste waters from dyeing and desizing

Membrane techniques (e.g. ultrafiltration, nanofiltration, reverse osmosis), ion exchange and evaporation are applied in various ways for the treatment of segregated streams from dyeing and desizing to allow water reclamation, recovery and reuse, closely integrated with these processes (see Figure 4.6). For more details on these techniques, see Sections 4.1.7.3 and 4.4.8.1. A specific combination of sedimentation/ultrafiltration/evaporation used for reuse of waste water and recovery of salt from dyeing processes in large proportions (e.g. full scale) is known as zero liquid discharge. [135, RICARDO 2019] Energy consumption for such reuse and recovery is substantial.
Figure 4.6: Treatment of selected segregated waste water streams using a series of membrane techniques (ultrafiltration, nanofiltration and reverse osmosis)

Achieved environmental benefits
Significant savings in water and energy consumption are possible for techniques a, b, c, and d (energy is used to a great extent to heat up the process baths). Section 4.1.4.3 addresses the techniques to recover energy by reuse of warm water.

Technique e reduces consumption of fresh water and auxiliary chemicals (e.g. salt).

Environmental performance and operational data
A bleach bath recovery system can be utilised in both the knit and woven segments, and can result in a reuse of 50% of the total water used in a typical 100% cotton full bleach process, including pre-scour, bleach and neutralisation. Savings also arise from reduced energy consumption and waste water disposal charges. The average temperature of the recovered water is estimated to be 40 °C. [152, Hasanbeigi 2010]

Holding tanks are needed to store the spent process baths before reuse or treatment for reuse/recovery.

Cross-media effects
Reduced water consumption results in a high concentration of pollutants and requires corresponding waste water treatment. [36, ÖKOPOL 2011]

Technique e generates concentrated permeate, which has to be treated appropriately (e.g. either handled as waste or treated with evaporation for the recovery of salt – which increases the energy consumption significantly).

Technical considerations relevant to applicability
The reuse of process baths is applicable to new plants and major plant upgrades.

The other techniques described here are generally applicable.
Chapter 4

Economics
Table 4.5 describes the capital cost and annual operating savings for water reuse techniques, which vary depending on the size of the plant.

Table 4.5: Capital costs and annual savings related to water reuse techniques

<table>
<thead>
<tr>
<th>Measure</th>
<th>Bleach bath recovery</th>
<th>Reuse of cooling water and condensate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost</td>
<td>USD 80 000 to USD 246 000 (1)</td>
<td>USD 143 000 to USD 212 000 (1)</td>
</tr>
<tr>
<td>Net annual operating</td>
<td>USD 38 500 to USD 118 400 (1)</td>
<td>USD 82 900 to USD 161 500 (1)</td>
</tr>
<tr>
<td>savings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Payback period</td>
<td>2.1 years</td>
<td>1.3 to 1.7 years</td>
</tr>
</tbody>
</table>

(1) 2001 value.

NB: Costs and savings are associated with the amount of production and not just for one machine.
Source: based on [152, Hasanbeigi 2010]

The principal cost items related to reuse of cooling water are pumps, piping modifications, and hot water storage tanks. [152, Hasanbeigi 2010]

Driving force for implementation
- Savings in water consumption.
- Reduced amount of waste water.

Example plants
See cross-referenced techniques in other sections of this document.

Plants IT065 and PT108 reuse cooling water. Plant IT065 also reuses rinsing water.

Plant SE118 collects and reuses spent baths and pastes such as softening baths as well as acrylate paste when coating or padding. When the spent baths or pastes are too contaminated, they are treated as hazardous waste.

Reference literature
[152, Hasanbeigi 2010], [36, OKOPOL 2011], [33, CITEVE 2014], [135, RICARDO 2019].

4.1.3.3 [Water & energy conservation in batch] Optimisation of water efficiency in washing and rinsing

From ex-Section 4.1.4

In both batch and continuous processing, water consumption for washing is significantly higher than for the treatment itself (e.g. dyeing) (see also Section 2.7.8.2). Modern continuous washing machines have greatly improved their washing efficiency. In batch processes, it is not straightforward easy to achieve a high washing efficiency with little water and in a short time and therefore a low liquor ratio does not always correlate with reduced water use as one might expect. Indeed it is not uncommon to find machines able to dye with a liquor ratio of 1:5 and then rinse with a liquor ratio of 1:10. Moreover, conventional machines can only handle unloading by increasing the liquor ratio.

These problems were recently tackled by machine manufacturers and dyestuff suppliers. Recent Technological developments have decreased specific water consumption in batch processing to levels more typical of continuous operations. A constant liquor ratio across variable load sizes is now a standard feature of modern equipment for batch processes. Efficient washing techniques have also been especially developed for batch operations (see Section 4.1.3.3.1). Furthermore,
various functions typical of continuous processing have been transferred to batch machines, such as (see Section 4.5.1.6):

- in-process separation of the bath from the substrate;
- internal separation of process liquor from the washing liquor;
- mechanical liquor extraction (e.g. by squeeze rollers, vacuum extractors, suction or blowing/ejection of liquid by compressed air) between the washing and/or rinsing steps to reduce carry-over and improve washing efficiency;
- internal countercurrent flow in the batch washing process.

### 4.1.3.3.1 Water & energy conservation in Batch washing and rinsing

#### Ex-Section 4.9.1

**Description**

Washing and rinsing are two of the most common operations in the textile industry. Optimisation of washing efficiency can conserve significant amounts of water and energy. In batch processes, typical efficient washing and rinsing techniques include:

- ‘drain and fill’ rinsing;
- overflow or “flood” rinsing.
- ‘smart rinsing’.

**Technical description**

In overflow or ‘flood’ rinsing, clean water is fed into the machine and drained through an overflow weir, usually set near the normal running level. This technique is useful for removing the surface scum resulting from poor quality water, chemicals or from inefficient pretreatment, but it is inefficient in terms of water consumption, especially in machines with a high liquor ratio.

Better options are as follows:

a) The ‘drain and fill’ method [205, M. Bradbury, 2000]

The ‘drain and fill’ method is a more efficient technique in terms of water consumption. Here, rinsing is achieved by successive filling, running and draining steps. Among the various factors playing a role in this process, it is worth noting the influence of the liquor ratio and draining time on the rinsing efficiency, as calculated using the equation below.

\[ C_f = C_s \times \frac{R}{L.R.} \]

where:

- \( C_f \) = concentration of solute in the subsequent rinse bath;
- \( C_s \) = concentration of solute in the previous bath;
- \( R \) = retention capacity (or carry-over) of the substrate (l/kg);
- \( L.R. \) = liquor ratio (l/kg).

From the equation it can be demonstrated that at lower liquor ratios more rinsing steps are required in order to achieve the same dilution effect, but actually using less water. The following example for cotton dyeing with reactive dyes clearly shows this. Considering an exhausted dye liquor containing 60 g/l electrolyte, with a retention capacity of the substrate of 3 l/kg (R) and a liquor ratio of 1:15 (L.R.), the concentration of electrolyte \( C_f \) in the subsequent rinse bath after one drain/fill operation will be 12 g/l and after two drain/fill operations will be 2.4 g/l. Conversely, if the liquor ratio is reduced to 1:7, \( C_f \) becomes 26 g/l and 11 g/l, respectively, for one and two subsequent rinses.

Moreover, the substrate in the machine retains much of the previous bath, which is expressed by the \( R \) parameter (retention capacity). This can be reduced by proper draining (increasing draining times) or, in some batch machines (e.g. yarn package dyeing, stock dyeing), by using...
compressed blowing air through the fabric or by vacuum extraction between washing steps.

The main disadvantages of the traditional ‘drain and fill’ rinsing method are:

- the longer production cycle time, which means lower productivity;
- the thermal shock to which the substrate is subjected during the first rinsing;
- the deposition of scum on the substrate between rinses as the liquor drains; this means that the removed chemicals or impurities can re-deposit on the surface of the textile material, especially if the machine is refilled with cold water.

All these limitations have been solved in modern machinery:

- as for the Cycle time: the machines are equipped with special time-saving devices (power draining and filling, combined cooling and rinsing, full volume heated tanks, etc.), which allows shorter time cycles compared to traditional ‘overflow’ rinsing.
- Thermal shock: the thermal shock during the first rinsing step can be avoided using the ‘combined cooling and rinsing’ system. This is again a common feature of modern machinery, which allows simultaneous cooling and rinsing of the processed textile. Clean water is introduced through the jet/overflow nozzle after it has been preheated by passing it through either the machine’s main heat exchanger or an external high-efficiency plate heat exchanger. The contaminated waste liquor is then drained.
- Deposition of scum on the substrate: this remains a limitation of the ‘drain and fill’ method. This is why batch dyeing machines are designed to allow rinsing in either the ‘drain and fill’ or the ‘smart rinsing’ mode. The latter, which is described below, is a ‘controlled overflow’ method that can be used for the first rinsing step before switching to the ‘drain and fill’ mode.

b) ‘Smart rinsing’ systems [205. M. Bradbury, 2000]

The use of low liquor ratio machines is a specific requirement for effective use of ‘smart rinsing’ systems. Rinsing is achieved by feeding clean water into the machine and draining it through an overflow weir set low down in the dyeing machine. In addition, the clean water flow in the machine is regulated at an equivalent rate to that of the liquor draining through the low-level overflow. Compared to traditional overflow rinsing, the dilution effect is increased thanks to the reduced volume of contaminated liquor circulating in the machine. The technique is particularly efficient when hot water is used for rinsing. This can be done in an efficient way by ‘combined cooling and rinsing’, which allows simultaneous cooling and rinsing of the processed textile as described above.

In this case, the final concentration of the solute at the end of the rinsing sequence is given by the following equation:

$$C_f = C_s \times e^{-\frac{Rt}{V_k}}$$

where:

- $C_f$ = final concentration of the solute;
- $C_s$ = starting concentration of the solute;
- $R$ = flow rate of incoming fresh liquor (l/min);
- $t$ = rinsing time (min);
- $V_k$ = volume of liquor bath (l).

The liquor ratio is one determining factor: the higher the liquor volume, the longer is the rinsing time required (and therefore the higher the water consumption) to reach the same dilution effect at the same flow rate. The flow rate $R$ also significantly influences rinsing efficiency. If the rate is reduced, longer rinsing times are needed to achieve the same end point, but this time the water consumption would be unaltered.
Further process optimisation may be achieved by applying systems such as on-line conductivity meters to signal the attainment of a pre-set concentration of salt (when using reactive dyes) or by colorimeters to facilitate rinsing to the optimum end point.

**Main Achieved environmental benefits**
Reduced water consumption.

**Environmental performance and operational data**
‘Drain and fill’ and ‘smart rinsing’ are both more efficient in terms of water consumption than conventional overflow rinsing.

As far as the ‘drain and fill’ method is concerned, by replacing each overflow rinse by two to four ‘drain and fill’ cycles a reduction of 50-75% water consumption can be achieved.

Reduced water consumption also means reduced energy consumption, since hot and warm rinsing steps are often required. In addition, energy savings are obtained with combined cooling and rinsing techniques.

One fundamental feature of both ‘smart rinsing’ and ‘drain and fill’ compared to the conventional overflow method is that it is possible to keep the exhausted concentrated dye liquor and the rinsing waters as separate streams. This means that they can be reused or at least treated separately and thermal energy can thus be recovered.

As in any productivity improvement, the first step should be a complete audit (and possible upgrading) of utilities to ensure that the benefits of the new equipment can be exploited to the full [205, M. Bradbury, 2000].

**Cross-media effects**
None believed likely.
None identified.

**Technical considerations relevant to applicability**
The adoption of the ‘drain and fill’ rinsing technique is generally applicable at a general level to both new and existing equipment, but is more efficient on low liquor ratio machines equipped with the latest time-saving devices (power draining and filling, combined cooling and rinsing, full volume heated tanks, etc.).

The concept of ‘smart rinsing’ has been developed specifically to solve the problems with fabric rinsing.

Both ‘smart rinsing’ and ‘rapid drain and fill’ systems are now available on virtually all new jet and overflow machines [288, MCS, 2002]. The same is valid. This is also the case for the ‘combined cooling and rinsing’ system. Most of the new dyeing machines have systems (e.g. stock tanks with internal heat exchangers large enough to accommodate the nominal running capacity of the machine) in order to allow simultaneous cooling and rinsing of the fabric.

**Economics**
‘Smart rinsing’ and ‘rapid drain and fill’ offer great potential advantages, not only in terms of efficient use of water and energy, but also in allowing shorter production cycles, and thereby a reduction in total production costs.

The application of the conventional ‘drain and fill’ technique, although easy to implement (i.e. no need for investment in new machinery), will not allow shorter production cycle times or an increase in productivity.

**Driving force for implementation**
Reduction of production cycle time (increase in productivity) without compromising right-first-time performance is the main driving force for the application of this technique.
Reference plants
Many plants worldwide.
Plants from the data collection: IT064, IT068, IT071, IT072, IT077, IT089, IT090, IT091, IT094, PT108, PT114.

Reference literature
[205, M. Bradbury, 2000], [176, VITO, 2001], [288, MCS, 2002].

4.1.3.3.2 Continuous washing and rinsing

Ex-Section 4.9.2

Description
In continuous processes, typical washing and rinsing techniques include:

- automatic stop valves;
- countercurrent washing;
- reduction of carry-over;
- heat recovery.

As mentioned in the previous section, most of the finishing processes involve washing and rinsing stages. In continuous operating mode in particular, washing after dyeing, printing, etc. consumes greater quantities of water than the dyeing and printing steps themselves.

Water (and energy) conservation can be achieved by increasing the washing efficiency, but a considerable improvement can often be obtained with the application of simple low-technology (good housekeeping) measures.

Technical description

A) Water flow control
In practice, mills rarely measure and keep control of water use. Every mill should have water meters that can be installed on individual machines to document water use and evaluate improvements. Significant water reduction has been observed in industry experience after the installation of cheap flow control devices on washers [167, Comm., 2000]. A systematic procedure can be applied aimed at defining the optimum flow needed to achieve the desired level of product quality.

a) Automatic stop valves
Automatic stop valves that link the main drive mechanism of the range washing machine to the water flow can save considerable quantities of energy and water by shutting off water flow as soon as a stoppage occurs. With manual control, the water flow may not be switched off until the machine has stopped for more than 30 minutes [146, Energy Efficiency Office UK, 1997].

B) Increasing washing efficiency

Many factors influence washing efficiency (e.g. temperature, residence time, liquor/substrate exchange, etc.). The techniques applied in modern washing machines depend largely on the type of fabric to be washed, e.g. light or very heavy fabrics, etc. Two basic principles/strategies are applied in modern washing machines: countercurrent washing and reduction of carry-over.

b) Countercurrent washing
The countercurrent principle means that the least contaminated water from the final wash is reused for the next second-to-last wash and so on until the water reaches the first wash stage, after which it is discharged. This means also that the cleanest fabric comes into contact with the cleanest water. This technique is relatively straightforward and inexpensive and can be applied...
for washing after continuous desizing, scouring, bleaching, dyeing or printing [11, US EPA, 1995] [33, CITEVE 2014].

A washer configuration with internal countercurrent (and recycling) capabilities is the vertical counter-flow washer, which sprays recirculated water onto the fabric and uses rollers to squeeze waste through the fabric into a sump, where it is filtered and recirculated. This construction allows for high-efficiency washing with low water use. Energy use decreases greatly because less water must be heated [11, US EPA, 1995].

c) Reduction of carry-over
Reduction of carry-over is another fundamental factor. Water (containing contaminants) that is not removed from the textile substrate is ‘carried over’ into the next step, contributing to washing inefficiency. Proper extraction between steps is essential. In continuous washing operations, squeeze rollers or vacuum extractors (more efficient) are used to reduce drag-out and carry-over [11, US EPA, 1995].

Wash boxes with built-in vacuum extractors are available for purchase as well as after-printing washers that combine successive spray and vacuum slots without any bath for the fabric to pass through [11, US EPA, 1995].

d) Introduce Heat recovery equipment
Installing heat recovery equipment on a continuous washer is usually a simple but effective measure, since water inflow and effluent outflow are matched, eliminating the need for holding tanks. The effluent from these machines can become contaminated with fibrous material, so it is important to install heat exchangers capable of handling such loads (e.g. self-cleaning elements) [146, Energy Efficiency Office UK, 1997]

Main Achieved environmental benefits
All measures described contribute to an overall reduction of the water and energy consumed. In order to allow full exploitation of the benefits achievable with the new advanced washing machinery, the implementation of the low-technology measures is fundamental.

Environmental performance and operational data
The Table 4.6 below shows the achievable water consumption levels for washing cotton and viscose woven fabric and their blends with synthetic fibres. The values for the different processes are additive and were submitted by machine manufacturers and confirmed by some finishing mills.

It is worth pointing out that the achievable performances are influenced by the degree of implementation of complementary techniques. Low water consumption levels can only be achieved by synergistic combinations of different possible measures, from the preparation of the fabric through the process chain (e.g. low add-on application techniques for sizing agents, selection of dyes with good washing off properties).
Table 4.6: Achievable specific water consumption levels for continuous washing processes during finishing of open width woven fabric consisting of cotton or viscose and their blends with synthetic fibres

<table>
<thead>
<tr>
<th>Pretreatment Processes</th>
<th>Water consumption (l/kg)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TOTAL</td>
<td>of which HOT WATER</td>
<td></td>
</tr>
<tr>
<td>Washing for desizing</td>
<td>3-4</td>
<td>3-4</td>
<td></td>
</tr>
<tr>
<td>Washing after scouring</td>
<td>4-5</td>
<td>4-5</td>
<td></td>
</tr>
<tr>
<td>Washing after bleaching</td>
<td>4-5</td>
<td>4-5</td>
<td></td>
</tr>
<tr>
<td>Washing after cold bleaching</td>
<td>4-6</td>
<td>4-6</td>
<td></td>
</tr>
<tr>
<td>Washing after mercerisation</td>
<td>4-5 (hot)</td>
<td>4-5</td>
<td></td>
</tr>
<tr>
<td>- Washing to remove NaOH</td>
<td>1-2 (cold)</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>- Neutralisation without drying</td>
<td>1-2 (warm)</td>
<td>&lt; 1</td>
<td></td>
</tr>
<tr>
<td>Washing after dying</td>
<td>10-15</td>
<td>4-8</td>
<td></td>
</tr>
<tr>
<td>Reactive dyestuffs</td>
<td>8-12</td>
<td>3-7</td>
<td></td>
</tr>
<tr>
<td>Vat dyestuffs</td>
<td>18-20</td>
<td>8-10</td>
<td></td>
</tr>
<tr>
<td>Sulphur dyestuffs</td>
<td>12-16</td>
<td>4-8</td>
<td></td>
</tr>
<tr>
<td>Naphthol dyestuffs</td>
<td>15-20</td>
<td>12-16</td>
<td></td>
</tr>
<tr>
<td>Washing after printing</td>
<td>12-16</td>
<td>4-8</td>
<td></td>
</tr>
<tr>
<td>Reactive dyestuffs</td>
<td>14-18</td>
<td>6-10</td>
<td></td>
</tr>
<tr>
<td>Vat dyestuffs</td>
<td>12-16</td>
<td>4-8</td>
<td></td>
</tr>
<tr>
<td>Naphthol dyestuffs</td>
<td>12-16</td>
<td>4-8</td>
<td></td>
</tr>
<tr>
<td>Disperse dyestuffs</td>
<td>12-16</td>
<td>4-8</td>
<td></td>
</tr>
</tbody>
</table>

NA: Not applicable. 
Source: [179, UBA, 2001]

Concerning energy consumption, the use of countercurrent washing may also lead to a water consumption reduction of between 41% and 62%. [33, CITEVE 2014]

Cross-media effects
Highly intensive and efficient washing techniques with low water consumption require intensive mechanical washing conditions such as spraying and sucking, which may require somewhat higher electricity consumption. However, this is largely offset by energy savings achievable by implementing thermal energy recovery measures that are also part of the measures described [179, UBA, 2001].

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
The achievement of performances typical of highly efficient washing machines requires investment in new equipment. However, the application of low-technology measures such as flow control devices, automatic valves, etc. can also produce some reduction in water and energy consumption.

Detailed information was not made available. In order to indicate the order of magnitude, a continuous IPPC capacity preparation washing line for cotton fabric, allowing for minimal water consumption (9 l/kg in total, including odour removal and lint filtration) by combined application of various technical optimisation measures, costs EUR 2.5 million [247, Comm., 2001].

Driving force for implementation
The main driving forces for the implementation of the techniques described are the increasing cost of water supplies and waste water treatment, and the desire to increase productivity (in the case of new highly efficient washing machinery).
Example Reference plants

Many plants.

Plants from the data collection: BE013, DE024, DE044, IT059, IT061, IT064, IT065, IT068, IT069, IT074, IT077, IT078, IT079, IT094, PT108, PT109, UK127.

Reference literature


4.1.3.4 Reduction of water consumption in cleaning the process tanks

Description

The amount of water used for cleaning is reduced by applying the following techniques:

- dry cleaning of process tanks before cleaning them with water;
- cleaning process tanks with a minimum amount of water;
- recycling cleaning waters from process tanks in the production process.

Technique description

a) Dry cleaning of process tanks

A dry cleaning method can be used on process tanks by letting them run empty, using the valve at the bottom of the tanks, and scraping the surface using, for example, rubber blades, brushes, paper, cloths or other absorbent materials.

b) Cleaning process tanks with a minimum amount of water

Once process tanks have been dry-emptied (see above), the next step is to clean the process tanks with water and possibly detergents. The quantity of cleaning water can be limited by, for example, cleaning more than once with a limited amount of water. The last-step cleaning water (least polluted) can possibly be reused as the first cleaning water in the next cleaning activity for process tanks.

c) Recycling cleaning waters from process tanks in the production process

Chemical residues in cleaning water from process tanks can be (partly) recovered by separate collection and then reused, for example for preparing chemicals (e.g. via dilution) for the next finishing activity.

Achieved environmental benefits

Implementation of this measure helps to limit water consumption, as well as the quantity of waste water released and its load. The use of chemicals (clean products and disinfectants) can also be limited.

Environmental performance and operational data

Process tanks used in the textile industry feature a valve at the bottom. Although process tanks cannot be tilted, their height can be reduced (containers can be lowered) to make the dry cleaning process easier.

The dry cleaning method is often performed using mechanical tools (e.g. squeegee, vacuum cleaner).

The presence of displacement devices (e.g. items placed to fill up unused space in the process tanks and to limit their content) could make it more difficult to access the process tanks.

High-pressure cleaning is implemented in the textile sector to limit water consumption and to reduce the amount of waste water. No concrete data are known to be available for the water-saving effect realised by implementing this technique in the textile industry.
Technical considerations relevant to applicability
Dry cleaning of process tanks is generally applicable.

A number of facilities, e.g. a storage tank, are needed to separately collect cleaning waters from process tanks. Furthermore, in order to reuse this rinsing water, measurement equipment is needed.

There are no indicators that cleaning water from process tanks containing deca-BDE, HBCD, Sb$_2$O$_3$, PFOS and/or PFOA cannot be collected. Reuse of cleaning water is more difficult to implement for job-processing companies (compared to integrated textile companies), due to the smaller production batches and the varying production activities. Additionally, the sector has identified a number of potential bottlenecks:

- contamination risk from chemicals (e.g. rinsing waters containing NP/NPE and/or PAHs);
- potential reactions between chemicals.

If these cleaning waters cannot be reused in the production process, the other option is to dispose of them via a qualified processing company.

Cross-media effects
None identified.

Economics
This measure is not accompanied by a noteworthy increase or decrease in costs and is regarded as economically feasible for all textile companies.

Driving force for implementation
Savings in chemical costs and in water consumption.

Example plants
A Flemish textile company (integrated company) indicates that 70% of cleaning waters is reused in the production process.

Reference literature
[27, Derden et. al 2010]

4.1.4 Energy efficiency

4.1.4.1 Energy efficiency plan and energy audits

Description
An energy efficiency plan and energy audits are part of the environmental management system (EMS) and include:

- energy flow diagrams;
- establishment of energy efficiency objectives;
- implementation of actions to achieve these objectives.

Energy audits are carried out at least annually to ensure that the objectives of the energy efficiency plan are met.

Technical description
Extensive information about energy efficiency can be found in [153, BREF ENE 2009]. Some techniques applicable to increase the energy efficiency of textile plants are as follows:

a. Appraising the costs and benefits of different energy options.
b. Monitoring energy flows (consumption and generation by source - see Section 4.1.1.2) and the targeting of areas for reductions.

c. Defining and calculating the specific energy consumption of the activity (or activities), and setting key performance indicators on an annual basis (e.g. MWh/tonne of textile produced).

d. Carrying out an energy survey to identify the opportunities for further energy savings.

e. Using combined heat and power (CHP).

f. Applying operating, maintenance and housekeeping measures to the most relevant energy-consuming systems such as:

- air conditioning, process refrigeration and cooling systems (leaks, seals, temperature control, evaporator/condenser maintenance);
- operation of motors and drives (e.g. high-efficiency motors);
- compressed gas systems (leaks, procedures for use – see Section 4.1.4.4);
- steam distribution systems (leaks, traps, insulation);
- room heating and hot water systems;
- lubrication to avoid high friction losses (e.g. mist lubrication);
- boiler maintenance, e.g. optimising excess air;
- other maintenance relevant to the activities within the plant;
- reviewing equipment requirements on a regular basis.

g. Using techniques that reduce energy consumption and thereby reduce both direct (heat and emissions from on-site generation) and indirect (emissions from a remote power station) emissions. For example:

- building insulation;
- use of energy-efficient site lighting;
- efficient plant layout to reduce pumping distances;
- variable speed drives;
- heat recovery (see Section 4.1.4.3);
- ensuring equipment is switched off, if safe to do so, when not in use;

h. Applying basic, low-cost, physical techniques to avoid gross inefficiencies; including insulation, containment methods (for example, seals and self-closing doors) and avoiding unnecessary discharges of heated water or air (for example, by fitting simple control systems).

i. Setting the time of operation of the high-energy equipment to off-peak periods.

k. Optimising boilerhouses (reuse of condensed water, preheating of air supply, heat recovery in combustion gases) and optimising boiler design according to energy demand profile (see also the LCP BREF).

l. Segregation of hot and cold waste water streams prior to heat recovery and recovery of heat from the hot stream by waste water abatement and reuse (see Section 4.10.4) or by heat exchange.

m. Optimised production planning of finishing jobs to avoid downtimes of the stenter frame and related heating periods.

n. Installing heat recovery systems for waste gases from stenter frames and waste gas treatment devices applying air/air or air/water heat exchange systems – an example is given in Section 4.1.4.4.

o. Optimisation of air conditioning systems (e.g. by sections or by direct conditioning of specific weaving machines for individual adaptation of volume and humidity).

p. Optimisation of the compressed air system and evaluation of a separate system with low pressure (see Section 4.1.4.4).

q. Use of the heat content of the cooling air of the compressor (for process water heating by air/water heat exchange or for yarn drying).

r. Optimisation of the cold and hot water system (installation of a pressure compensation tank, priority circuit for several pressure-boosting pumps, shut-off during shutdown of the plant).

s. Monitoring and controlling the moisture content in the circulating air and on the textile in the stenters (see Section 4.1.4.4).

t. Proper adjustment of drying/curing temperature and drying/curing time.

u. Installing covers on nips and tanks; the fitted covers are easily removable to allow quick access.[33, CITEVE 2014]
v. Unnecessary high steam pressure is avoided for both direct and indirect steam heating. [33, CITEVE 2014]

w. Point-of-use gas-fired water heaters can be used to enable processes to be run independently of the plant’s central boiler systems. This means that boiler and distribution losses associated with centralised systems (which can be as much as 50% of the fuel input) can be eliminated. Point-of-use heating also offers greater flexibility since it allows operation outside the main boiler operating hours. [152, Hasanbeigi 2010]

x. Using cold pad-batch for pre-treatment (e.g. desizing or bleaching) or dyeing of cotton (see Section 2.7.3.1). [162, Cotton Incorporated 2009]

y. Avoiding overheating of the baths and optimising the temperature of rinsing water (see Section 4.5.1.8);

The following measures contribute to a lower environmental impact from energy production as a whole:

- management of peak current for reduction and avoidance of consumption peaks;
- use of low-emission energy sources in the boiler (e.g. natural gas, low-sulphur fuel);
- use of renewable energy sources (sun, wind, water, biomass) for electricity and steam production;
- evaluation and eventual use of combined heat and power generation for steam base load and electricity production.

From ex-Section 4.1.1. Part of this text is used above.

A second group of options specifically focused on energy savings is:

- heat insulation of pipes, valves, tanks, machines (see Section 4.1.6)
- optimising boiler houses (reuse of condensed water, preheating of air supply, heat recovery in combustion gases)
- segregation of hot and cold waste water streams prior to heat recovery and recovery of heat from the hot stream.
- installing heat recovery systems on waste off-gases – an example is given in Section 4.8.1
- installing frequency controlled electric motors
- controlling moisture content in the circulating air and on the textile in stenters (see Section 4.8.1)
- proper adjustment of drying/curing temperature and drying/curing time.

Achieved environmental benefits

Utilising an energy efficiency plan can reduce the energy consumption and the environmental emissions of that energy use.

Environmental performance and operational data

The installation of covers on nips and tanks may reduce the energy consumption needed to heat up the baths by 36%. [33, CITEVE 2014]

Cross-media effects

None identified.

Technical considerations relevant to applicability

The technique is fully applicable.

These techniques are more extensively applied to large consumers of energy. For energy-intensive industries, the application of energy efficiency techniques to building services may only have a minor impact and should not distract effort away from the major energy issues. They can, nonetheless, find a place in the improvement programme, particularly where they may constitute more than 5% of the total energy consumption.
Economics
Energy-efficient systems typically have higher investment costs. However, their operating costs are usually lower (or the revenues higher).

The improvement of the energy efficiency needs to be balanced with the cost of achieving this.

Driving force for implementation
Energy savings.

Example plants
A total of 45 plants from the data collection apply an energy-saving plan.

Reference literature
[32, COM 2009], [29, COM 2018] [33, CITEVE 2014] [36, ÖKOPOL 2011] [152, Hasanbeigi 2010] [162, Cotton Incorporated 2009]

4.1.4.2 Monitoring of energy consumption
[36, ÖKOPOL 2011]

Description
Monitoring of energy consumption, as part of the energy efficiency plan (see Section 4.1.4.1) and the streams inventory (see Section 4.1.1.2).

Technical description
Monitoring comprises the establishment of a register of energy-consuming processes and of all single aggregates including air conditioning and lighting. If no energy consumption meters are installed, the power values of aggregates are registered together with the estimated mean consumption and running times. Consumption data are connected to cost data according to each energy source.

For monitoring consumption, indicators are defined for the entire plant and for single processes, together with determined periods for data collection, e.g. energy consumption (gas, oil, etc.) per tonne of steam produced, electricity consumption for compressed air per tonne of product produced, electricity consumption of big aggregates per tonne of product produced, consumption of steam and electricity per processed good or group of goods, consumption of steam and electricity per processed good during dyeing and drying, gas consumption of the stenter frame per group of goods.

Consumption data are communicated to the workers in charge of the respective process, and training on reduction measures conducted.

Regularly, based on the latest up-to-date energy cost data, the economic viability of potential energy saving measures are recalculated.

Achieved environmental benefits
Reduction of the environmental impact associated with energy production by identification of the main energy consumers and related efficient prioritisation of improvement measures as well as by sensibilisation and training of employees.

Environmental performance and operational data
Plant A: in a fully integrated textile company (producing textiles for private consumers, hotels and hospitals) with approximatively 300 employees, the energy consumption of 12 rotor spinning machines was monitored and compared with electric energy consumption of new machines. [41, EfA 2004]
Plant B: energy consumption was monitored in a textile company with approximately 500 employees, specialised in high-quality textile printing with small runs (8.7 million metres per year; clothes, linen, home textiles).

**Cross-media effects**
None identified.

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of this technique.

Restrictions for the use of consumption meters may occur in existing installations if potential energy savings are expected to be low in relation to the meter installation costs.

**Economics**
Efforts for monitoring energy consumption depend on the size and complexity of the company. Cost savings in Plant A (see below) were reported to be EUR 175,000 per year. No data were available from Plant B.

**Driving force for implementation**
Energy savings.

**Example plants**
Plant A: HCH.Kettelhack Textilfabrik, DE-48432 Emsdetten.
Plant B: Textile company in Switzerland.
Plant of the data collection: DE042.

**Reference literature**
[36, ÖKOPOL 2011] [41, EfA 2004]

4.1.4.3 **Heat recovery by direct reuse of warm water or warm air, or by means of heat exchangers**

[36, ÖKOPOL 2011]

**Description**
Heat is recovered from cooling water or from process water as well as from cooling air, waste gas and steam use. The heat content can be used directly (by reuse) or indirectly (by heat exchangers).

**Technical description**

a) **Heat recovery from water**
Processes which are often appropriate for direct reuse of warm process water are bleaching, dyeing, rinsing and washing, for instance:

- reuse of warm water by counterflow (for peroxide bleaching and alkali boiling-off - see Section 4.4.1, dyeing - see Section 4.5.1.6.2, continuous washing and rinsing - see Section 4.1.3.3.2);
- reuse of appropriate hot dyeing water after analysis and storage in a tank or in a second machine, adding fresh water to make up the amount which was taken out of the process by the fibres; in some cases it is necessary to cool down the water to the appropriate dyeing temperature at the start of the process (see Section 4.5.1.7);
- reuse of appropriate warm rinsing bathes after analysis and storage (see Section 4.1.3.2).

If fresh water is used for process cooling, this can be used directly for warm processes, e.g. for dyeing or rinsing. Warmed-up cooling water occurs for example in the following processes:
• cooling water of soda lye recovery (see Section 4.4.8.2);
• cooling water from batch dyeing (see Section 4.5.1.6);
• cooling water from water-cooled air compressors.

More generally, the water reuse techniques are addressed in Section 4.1.3.2.

The heat content of waste water can often be used indirectly applying a water/water heat exchanger for heating process water as for example from the following processes:
• heat exchanger for waste water from raw wool washing (see Section 4.2.3);
• heat exchanger for waste water from reactive dyeing (see Section 4.5.2.5);
• heat exchanger for waste water from dyeing machines (see Section 4.5.1.6.2);
• heat exchanger for waste water from washing and rinsing (see Section 4.1.3.3).

b) Heat recovery from air

If cooling air is used in a process, warmed-up air can be used directly for warm processes, e.g. for drying of coils and hanks. For instance, heated cooling air from air compressors can be used.

The heat content of waste gas can be used indirectly by means of air/water or air/air heat exchange. This way, waste gas can be used for example from the following processes:
• air/air heat exchanger for waste gas from stenter frames for preheating air introduced into the stenter frame (see Section 4.1.4.4);
• air/air heat exchanger for waste gas from a thermal waste gas abatement system;
• air/air heat exchanger for waste gas from stenter frame for preheating of process water or heating water;
• air/air heat exchanger for waste gas from a thermal waste gas abatement system for preheating of process water or heating water;
• air/water heat exchanger for cooling air of compressors for preheating of process water or heating water;
• air/water heat exchanger for waste gas from steam boilers for preheating of boiler feed water (see [37, COM 2017] and [32, COM 2009]).

c) Heat recovery from steam use

Heat e.g. from hot condensate and boiler blowdown is recovered.

Achieved environmental benefits

Energy resources are saved by using the heat content of air or water. The environmental impact associated with heat production is reduced.

From ex-Section 4.8.1

If hot water is not required, an air to air heat exchanger can be used. Efficiencies are generally 50 % to 60 % ([146, Energy Efficiency Office UK, 1997]). Approximately 30 % savings in energy can be achieved [179, UBA, 2001]. An aqueous scrubber alone or with subsequent electrostatic filtration can optionally be installed for off-gas cleaning.

Exemplary calculations show that the use of the heat content of rinsing water from continuous washing for heating of fresh water leads to energy savings of approximately 75 % [38, M.Kohla et al. 2008].

Plant A reported that the installation of a heat exchanger to recover heat from the waste water of a pad-steam dyeing plant can preheat the water for the washing section from 20 °C to 90 °C. For this installation, 1 600 MWh of natural gas was saved annually. [38, M.Kohla et al. 2008][39, Efa 2003]
Environmental performance and operational data
When directly reusing dye baxes, it is necessary to undertake a thorough analysis of the chemical content to enable exact addition of lost chemicals of the bath and to achieve the desired bath quality.

Direct reuse of rinsing waters also requires an appropriate analysis to avoid a reduction in the quality of the product. The retention time in the intermediate storage tank does not exceed several hours as otherwise biological degradation processes start, hindering reuse.

When using compressor cooling air for drying coils or hanks, it is generally sufficient to use dust filters for cleaning the air. In Plant B, energy savings associated with an air/air heat exchanger were calculated with the following data, also taking into account the increased electricity consumption of the fan:

<table>
<thead>
<tr>
<th>Waste gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste gas volume</td>
</tr>
<tr>
<td>Pressure drop</td>
</tr>
<tr>
<td>Temperature of air inlet</td>
</tr>
<tr>
<td>Temperature of air outlet</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heated air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air inlet volume</td>
</tr>
<tr>
<td>Pressure drop</td>
</tr>
<tr>
<td>Temperature of air inlet</td>
</tr>
<tr>
<td>Temperature of air outlet</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heat exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat exchange</td>
</tr>
<tr>
<td>Efficiency</td>
</tr>
<tr>
<td>Operation hours</td>
</tr>
<tr>
<td>Energy recovery</td>
</tr>
</tbody>
</table>

Additional energy consumption
| Increased fan power: | 2.37 kW |
| Rotary exchanger power: | 0.18 kW |
| Total power increase | ca. 2.6 kW |
| Total energy increase | ca. 11 700 kWh/yr |
| Energy savings | ca. 1 750 950 kWh/yr |

Savings are lower if annual operating times are shorter, e.g. because of set-up times. Furthermore, energy savings are lower if the waste gas has a lower temperature level. For the example above, energy savings were reduced to 18 % when the waste gas temperature was 120 °C instead of 180 °C. [36, ÖKOPOL 2011 ]

From ex-Section 4.8.1
Heat recovery systems are often combined with an aqueous scrubber or electrostatic filtration systems or a combination of these techniques.

Condensed substances (mainly preparation oils) from heat recovery systems are have to be collected separately.
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Cross-media effects
Generally, there are no cross-media effects associated with direct reuse of heated water or heated air. If cleaning before reuse is necessary, small waste amounts occur.

Cleaning of heat exchangers leads to liquid or solid waste, depending on the type of cleaning system.

Technical considerations relevant to applicability
Contaminated process water or cooling air could have negative effects in the event of direct reuse.

Economics
No data on costs are available arising from the analysis of recipes for evaluation of reuse potential.

Implementation of heat exchangers requires regular maintenance which is associated with manpower costs. Cleaning is generally done mechanically by hand, therefore there are no or only low material costs.

Plant A invested approximately EUR 40 000 for the plate heat exchange system at the pad steam dyeing machine. The investment was returned after about 1 year. [38, M.Kohla et al. 2008] [39, EfA 2003].

From ex-Section 4.8.1
Payback data for heat recovery systems (both air/water and air/air systems) are illustrated in Figure 4.8 for drying and heat-setting processes. Information is based on the following reference data [179, UBA, 2001]:

- heat recovery system: counter-flow pipes
- drying temperature: 130 °C
- heat setting: 190 °C
- off-gas volume flow: 15 000 m³/h
- off-gas moisture content (drying): 70 g/m³
- off-gas moisture content (heat-setting): 40 g/m³
- T of the fresh water (before heat recovery): 15 °C
- efficiency: 70 %
- heating value of the gas: 9.3 kWh/m³
- cost of the gas: EUR 0.25 euros/m³
- maintenance cost: EUR 1 000 euros/yr
- interest rate: 6 %
### Table 4.7: Return on investment for different processes (textiles drying and heat-setting), heat recovery systems (air/water and air/air) and number of shifts per day

<table>
<thead>
<tr>
<th>Process</th>
<th>1 shift/day</th>
<th>2 shifts/day</th>
<th>3 shifts/day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Savings</td>
<td>Payback</td>
<td>Savings</td>
</tr>
<tr>
<td></td>
<td>(EUR)</td>
<td>period</td>
<td>(EUR)</td>
</tr>
<tr>
<td>Air/water Fresh water T: 15 °C</td>
<td>Drying</td>
<td>32 050</td>
<td>5.7</td>
</tr>
<tr>
<td>Air/water Fresh water T: 40 °C</td>
<td>Heat-setting</td>
<td>34 450</td>
<td>5.4</td>
</tr>
<tr>
<td>Air/air Fresh air T: 20 °C</td>
<td>Drying</td>
<td>18 050</td>
<td>12.6</td>
</tr>
<tr>
<td>Air/air Fresh air T: 20 °C</td>
<td>Drying</td>
<td>8 000</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>Air/air Heat setting</td>
<td>Drying</td>
<td>11 000</td>
<td>&gt; 20</td>
</tr>
</tbody>
</table>

*Source:* [179, UBA, 2001]

The above information does not consider the installation of other measures such as fabric moisture control and exhaust humidity control. If these systems are installed, according to some sources, heat recovery may not be cost-effective [146, Energy Efficiency Office UK, 1997].

### Driving force for implementation

Energy savings.

### Example plants

**Air/air heat exchangers and water/water heat exchangers**
- Plant A: HCH Kettelhuck GmbH&Co.KG, DE-48432 Rheine (Plant DE030).
- Plant B: Eing Textilveredlung und Handelsgesellschaft mbH & Co. KG, DE-48712 Gescher (Plant DE032).

**Air/water heat exchangers at a waste gas treatment system**
- Schmitz-Werke, DE-48282 Emsdetten (Plant DE042).

**Air/water heat exchangers at compressors**
- Schmitz-Werke, DE-48282 Emsdetten (Plant DE042).

**Direct use of waste heat of compressor cooling**
- Madeira, DE-79100 Freiburg.

### Reference literature

[37, COM 2017] [32, COM 2009] [34, UK 1997] [38, M.Kohla et al. 2008] [39, EfA 2003] [36, ÖKOPOL 2011]

### 4.1.4.4 Optimisation of the compressed air system

#### Description

Organisational and technical measures to reduce the energy consumed by the compressed air system.

#### Technical description

Some techniques to reduce energy consumption include the following:
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- Recover waste heat from the compressors for building heating, water heating, etc.
- Regular check of leakages as the energy consumed is significantly increased even by a small leakage. The most common sources of leaks are couplings, hoses, tubes, fittings, pressure regulators, open condensate traps and shut-off valves, pipe joints, disconnects and thread sealants.
- Compressed air production is stopped during long shutdown times or idle times of equipment, and single areas can be isolated from the rest of the system, in particular if they are associated with infrequent use.
- Instead of one single system of compressed air which supplies the entire plant and which is adapted to the consumer with the highest pressure need, two compressed air systems are installed: one to supply air with lower pressure and one to supply air with higher pressure.
- Rotary compressor systems are equipped with an adjustable speed drive to account for varying compressor loads and/or ambient temperature.

Achieved environmental benefits
Energy needs and the associated environmental impact are reduced by early detection of leakages, the use of waste heat from the compressors, the reduction of the pressure level and the installation of a second pressure system with lower pressure.

Environmental performance and operational data
Only 15% of the electricity consumed by an industrial air compressor is actually converted into compressed air, the rest being lost in waste heat. With large water-cooled compressors, heat recovery efficiencies of 50% to 60% are typical. When used for workspace heating, the recovered heat amounts to 20% of the energy used in compressed air systems annually. [152, Hasanbeigi 2010]

A typical plant that has not been well maintained could have a leak rate of between 20% and 50% of the total compressed air production capacity. Leak repair and maintenance can sometimes reduce this figure to less than 10%. [152, Hasanbeigi 2010]

In the example plant mentioned below, the maximum pressure is only necessary for the weaving section, therefore a separate pipe for compressed air was installed for the weaving section, and the pressure of the remaining system was reduced by 1 bar. A new compressor was installed for the low-pressure system with a new condensation dryer. For the high-pressure system, new condensation dryers were installed, adapting their power to the required compressed air and therefore resulting in additional energy savings. [36, ÖKOPOL 2011]

Cross-media effects
None identified.

Technical considerations relevant to applicability
The technique can be applied in new and existing installations. In existing installations, the economic benefit of an additional compressed air system depends on the distance to the users.

Economics
The total investment for the example plant mentioned below was approximately EUR 80,000. The return on investment was after 18 months. [36, ÖKOPOL 2011]

Driving force for implementation
Energy savings and the related cost reduction are the main drivers for implementing this technique.

Example plants
Schmitz-Werke, DE-48282 Emsdetten (Plant DE042).
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Reference literature
[ 36, ÖKOPOL 2011 ] [ 152, Hasanbeigi 2010 ]

4.1.4.5 Minimisation of energy consumption of stenter frames and dryers

Description
Techniques to reduce energy consumed by stenters and dryers include:

- Mechanical dewatering of the fabric;
- wet-on-wet dyeing or finishing;
- optimising exhaust airflow;
- insulation;
- optimising burner efficiency;
- optimised air circulation;
- avoiding overdrying;
- instrumentation and control of the stenters;
- optimal scheduling of the batches;
- avoiding loss of latent heat in cylinder dryers;
- using high-frequency drying.

Technical description
Stenters are mainly used in textile finishing for heat-setting, drying, thermosol processes and finishing. It can be roughly estimated that, in fabric finishing, each textile substrate is treated on average 2.5 times in a stenter.

The main energy requirements needs for a stenter are for air heating and evaporation. It is therefore fundamental that the fabric moisture content should be minimised before the fabric enters the stenter and that the exhaust airflow within the oven is be reduced.

Energy savings in stenters can be achieved by applying the following techniques.

a) Mechanical dewatering of the fabric
The water content on of the incoming fabric can be minimised using mechanical dewatering equipment such as centrifugation, vacuum extraction systems, optimised squeezing rollers, etc. (the latter is less efficient but less energy-consuming). Up to 15 % energy savings in the stenter (depending on the type of substrate) can be obtained if moisture content of the fabric is reduced from 60 % to 50 % before it enters the stenter.

For synthetic fibres, vacuum extraction achieves approximately 20 % better dewatering efficiency compared to squeezing rollers; the opposite is true for cotton fibres, where squeezing rollers prove more efficient (see Figure 4.7). [ 36, ÖKOPOL 2011 ] [ 146, Kuesters Textile 2019 ]
b) Wet-on-wet dyeing or finishing
Dyestuff or finishing liquor is applied directly to the wet fabric, thus avoiding the need for an intermediate drying step. [152, Hasanbeigi 2010]

c) Optimising exhaust airflow through the oven
Exhaust airflow optimisation is another determining factor. Many stenters are still poorly controlled, relying on manual exhaust adjustment and operator estimation of fabric dryness. For optimum performance, exhaust humidity should be maintained between 0.1 kg and 0.15 kg water/kg of dry air. It is not unusual to find less efficient stenters have an exhaust humidity of only 0.05 kg water/kg of dry air, indicating that the exhaust volume is too high and excessive energy is being used to heat air [146, Energy Efficiency Office UK, 1997]. Energy consumption for air heating can reach up to 60% of the total energy consumption requirement, if the airflow is not monitored [185, Comm., 2001].

Equipment is available (dampers and variable-speed fans) which will automatically adjust the exhaust airflow according to the moisture content of the exhaust air or according to the moisture content or temperature of the fabric after the process. A reduction of fresh air consumption from 10 kg fresh air/kg of textile to 5 kg fresh air/kg of textile results in a 57% energy saving [179, UBA, 2001]. [152, Hasanbeigi 2010]

The exhaust dampers are partially or fully closed during idling time (changing of batches, etc.) [152, Hasanbeigi 2010]

**B) Heat recovery**

Moved to Section 4.1.4.3
Exhaust heat recovery can be achieved by using air-to-water heat exchangers. Up to 70% of energy can be saved. Hot water can be used in dyeing. Electrostatic filtration for off-gas cleaning can optionally be installed. Retrofitting is possible.

If hot water is not required, an air-to-air heat exchanger can be used. Efficiencies are generally 50 to 60% ([146, Energy Efficiency Office UK, 1997]). Approximately 30% savings in energy can be achieved [179, UBA, 2001]. An aqueous scrubber alone or with subsequent electrostatic filtration can optionally be installed for off-gas cleaning.

d) Insulation
Proper insulation of stenter encasement reduces heat losses to a considerable extent. Savings in energy consumption of 20% can be achieved if the insulation thickness is increased from 120 mm to 150 mm (provided that the same insulation material is used).

The insulation of end sections of cylinder dryers can reduce heat waste, thereby saving fuel. This measure, however, is more practical for cylinders with a diameter of one metre or more. For small diameter cylinders, this may not be practicable since the steam pipe, condensate pipe and safety valve get in the way. [152, Hasanbeigi 2010]

D) Heating systems
Direct gas firing is reported to be both clean and cheap. When it was first introduced there was concern that oxides of nitrogen, formed by exposure of air to combustion chamber temperature, would cause fabric yellowing or partial bleaching of dyes. This concern has since been shown to be unjustified [146, Energy Efficiency Office UK, 1997].

However, other sources also show the advantages of new (recently developed) indirect gas firing systems. By means of a flue gas/air heat exchanger the heat generated by the burner flame is directly transferred to the circulating air in the stenter (“Monforts, Textilveredlung 11/12, 2001, p.38”). This system has higher efficiency than conventional indirect heating systems using mainly heating oil. Reactions of off-gas compounds with emissions from the textile materials and auxiliaries (especially generation of formaldehyde) are avoided.

e) Optimising burner efficiency Burner technology
With optimised firing systems and sufficient maintenance of burners in directly heated stenters, the methane emissions can be minimised. A typical range for an optimised burner is 10-15 g methane (calculated as organic carbon)/h, but it has to be taken into account that methane emissions from burners are strongly linked to actual burner capacity.

Stenters are maintained should receive general maintenance by specialised companies at regular intervals. There should also be routine checking of the burner air inlet is regularly checked for blocking by lint or oil, cleaning of pipework is cleaned to remove precipitates and adjusting of burners are adjusted by specialists.

Miscellaneous techniques
With optimised nozzles and air guidance systems, energy consumption can be reduced, especially if nozzle systems are installed that can be adjusted to the width of the fabric.

f) Optimised air circulation
The circulation of hot air within the stenter is optimised: the number of air injection nozzles is adapted to the width of the fabric, the distance between nozzles and fabric is as short as possible, and the pressure drop caused by the stenter internal components is as small as possible. [179, Brückner 2019]

g) Avoiding overdrying
Fibres have a natural moisture level (see Table 4.8) below which it is useless to dry them. It is therefore important to monitor the moisture content of the fabric and to adapt the residence time of the fabric in the stenter/dryer so that the natural moisture level is not exceeded. Hand-held
moisture meters can be used with a roller sensor to monitor the moisture content of fabrics leaving the stenters or drying cylinders. [152, Hasanbeigi 2010]

Table 4.8: Natural moisture level of some fibres

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Natural moisture level (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>7</td>
</tr>
<tr>
<td>Wool</td>
<td>16-18</td>
</tr>
<tr>
<td>Viscose</td>
<td>12.5</td>
</tr>
<tr>
<td>Triacetate</td>
<td>4.5</td>
</tr>
<tr>
<td>Nylon 6.6</td>
<td>4.3</td>
</tr>
<tr>
<td>Nylon 6</td>
<td>4.4</td>
</tr>
<tr>
<td>Polyester</td>
<td>0.4</td>
</tr>
<tr>
<td>Acrylic</td>
<td>1.5</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>0</td>
</tr>
</tbody>
</table>

[Source: [152, Hasanbeigi 2010]

h) Instrumentation and control of the stenters
The stenter operation and the energy consumption are optimised by measuring and controlling the following parameters:

- exhaust air humidity, in order to load exhaust air most efficiently with humidity; this reduces the volume of hot exhaust air, and thus energy losses, dramatically;
- residual moisture of the fabric to avoid overdrying and overheating of fabric;
- fabric and air temperature; several fabric temperature sensors placed inside the stenter along with the fabric provide a good system for the supervision and optimisation of heat treatment processes, mainly for controlling the residence time of the fabric in the stenter. [152, Hasanbeigi 2010]

i) Optimal scheduling of batches
Careful scheduling of fabric batches arriving at the stenters or cylinder dryers can reduce idling time, thereby saving energy. [152, Hasanbeigi 2010]

Proper scheduling in finishing minimises machine stops and heating-up/cooling-down steps and is therefore a prerequisite for energy saving.

j) Avoiding loss of latent heat in cylinder dryers
The cylinder dryers are regularly maintained to avoid steam leaks. The condensate is recovered and returned to the boiler. In addition, flash steam which is produced when condensate is reduced to atmospheric pressure can be recovered as low-pressure steam, and used to heat water or other low-pressure steam processes. [152, Hasanbeigi 2010]

k) Using high-frequency drying
Energy savings could be accomplished by switching from conventional dryers to low-pressure (LP) high-frequency drying (microwave or radio frequency). The LP high-frequency drying method features good drying efficiency and the capability to prevent products from overdrying, which often happens in convection dryers. [152, Hasanbeigi 2010] [180, Carr et al. 2006]

Main Achieved environmental benefits
Savings in energy consumption and therefore minimisation of emissions associated with energy production are the main environmental advantages.
Data about achievable energy savings are already indicated for some of the presented techniques. Obviously, for existing plants, the potential for reductions will vary according to the existing technology and energy management policy in the company.

Environmental performance and operational data

The following data describe an optimised air/cloth ratio in a stenter ([38, M.Kohla et al. 2008]):

<table>
<thead>
<tr>
<th>Material</th>
<th>Air/kg Textile</th>
</tr>
</thead>
<tbody>
<tr>
<td>PES or PA raw material</td>
<td>10 to 12</td>
</tr>
<tr>
<td>pre-washed PES material</td>
<td>5 to 7</td>
</tr>
<tr>
<td>thermo-isolated PES</td>
<td>5 to 7</td>
</tr>
<tr>
<td>condensation of finishing CO</td>
<td>4 to 5</td>
</tr>
</tbody>
</table>

In principle, the waste gas humidity should be as high as possible but 20% humidity can rarely be achieved due to condensation. A level of 12-15% humidity in waste gas is commonly found in practice. [38, M.Kohla et al. 2008]

Minimising energy consumption in the stenters, especially if heat recovery systems are installed, requires adequate maintenance (cleaning of the heat exchanger and stenter machinery, checking of control/monitoring devices, adjusting of burners, etc.).

Data collected on specific energy consumption of thermal treatment is described in Section 3.6.2.12. When applying this technique, the specific energy consumption ranges from 0.5 to 4.4 MWh/t. [196, TWG 2019]

Moved to Section 4.1.4.3

Heat recovery systems are often combined with an aqueous scrubber or electrostatic filtration systems or a combination of these techniques. Condensed substances (mainly preparation oils) from heat recovery systems have to be collected separately.

Cross-media effects

None believed likely.

None identified.

Technical considerations relevant to applicability

All techniques described are applicable to new installations. For existing equipment, the applicability is in some cases limited. For example, improving stenter insulation (see Option C) is not always practicable, although on some older machines it may be cost-effective to insulate the roof panels. Existing stenters cannot be retrofitted with air-to-air heat exchangers.

The installation of high-frequency drying systems may be applicable only to new plants and major plant upgrades.

Economics

Examples of investment costs are given in Table 4.9.
Table 4.9: Investment costs for energy-saving measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Investment cost</th>
<th>Payback period (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery of condensate in wet processing plants</td>
<td>USD 1 000 to USD 16 000 (1)</td>
<td>2.5-6</td>
</tr>
<tr>
<td>Low-pressure microwave drying machine for bobbin drying</td>
<td>USD 500 000 (2)</td>
<td>&lt; 3</td>
</tr>
<tr>
<td>Radio frequency dryer for drying acrylic yarn</td>
<td>USD 220 000 (3)</td>
<td>NI</td>
</tr>
</tbody>
</table>
| Insrumentation and control system for stenter                          | Humidity control: USD 20 000 to USD 220 000 (1)  
Residence time control: USD 80 000 to USD 400 00 (1) | Humidity control: 1.5-5  
Residence time control: 4-6.7                                       |

(1) 2007 value.  
(2) 1997 value.  
(3) 1993 value.  
NB: NI: No information.
Source: [152, Hasanbeigi 2010 ] [ 33, CITEVE 2014 ].

As RF and microwave systems are operating on electric power, the unit of energy cost is usually higher than for conventional dryers. However, the energy efficiency of RF and microwave systems are normally much higher than for conventional system, which tends to offset the higher energy unit cost. [ 180, Carr et al. 2006 ]

Moved to Section 4.1.4.3

Payback data for heat recovery systems (both air/water and air/air systems) are illustrated in Figure 4.8 for drying and heat setting processes. Information is based on the following reference data [179, UBA, 2001]:

- heat recovery system: counter-flow pipes
- drying temperature: 130°C
- heat setting: 190°C
- off-gas volume flow: 15000 m³/h
- off-gas moisture content (drying): 70 g/m³
- off-gas moisture content (heat setting): 40 g/m³
- T of the fresh water (before heat recovery): 15°C
- efficiency: 70 %
- heating value of the gas: 9.3 kWh/m³
- cost of the gas: 0.25 euros/m³
- maintenance cost: 1000 euros/yr
- interest rate: 6 %

<table>
<thead>
<tr>
<th>Process</th>
<th>1-shift/day</th>
<th>2-shift/day</th>
<th>3-shift/day</th>
<th>1-shift/day</th>
<th>2-shift/day</th>
<th>3-shift/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air/water Drying</td>
<td>32050</td>
<td>5.7</td>
<td>64150</td>
<td>2.6</td>
<td>96150</td>
<td>1.7</td>
</tr>
<tr>
<td>Fresh water T=15 °C Heat-setting</td>
<td>34450</td>
<td>5.4</td>
<td>68900</td>
<td>2.4</td>
<td>103350</td>
<td>1.5</td>
</tr>
<tr>
<td>Air/water Drying</td>
<td>48050</td>
<td>12.6</td>
<td>36100</td>
<td>5.9</td>
<td>54150</td>
<td>3.3</td>
</tr>
</tbody>
</table>
Table 4.8: Return on investment for different processes (textiles drying and heat setting), heat recovery systems (air/water and air/air) and number of shifts per day

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Heat-setting</th>
<th>23350</th>
<th>8.6</th>
<th>46700</th>
<th>3.7</th>
<th>70050</th>
<th>2.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh water T: 40 °C</td>
<td>Drying</td>
<td>8000</td>
<td>&gt; 20</td>
<td>16000</td>
<td>15.6</td>
<td>24000</td>
<td>8.5</td>
</tr>
<tr>
<td>Fresh air temp: 20 °C</td>
<td>Heat-setting</td>
<td>11000</td>
<td>&gt; 20</td>
<td>22000</td>
<td>9.6</td>
<td>33000</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Figure 4.8: Return on investment for different processes (textiles drying and heat setting), heat recovery systems (air/water and air/air) and number of shifts per day

The above information does not consider the installation of other measures such as fabric moisture control and exhaust humidity control. If these systems are installed, according to some sources heat recovery may not be cost effective [146, Energy Efficiency Office UK, 1997].

Driving force for implementation
Minimisation of energy consumption (and therefore costs) is the main reason to retrofit optimised stenter technology.

Reference-Example plants
In total, 33 plants from the data collection apply techniques to minimise the energy consumption of stenter frames.

The described technologies are in use in many finishing mills in Europe and worldwide. The indirect heating system based on a flue-gas/air exchanger is currently due to be installed in several finishing—15 plants from the data collection. Meanwhile, 50 plants from the data collection apply direct heating.

Reference literature
[146, Energy Efficiency Office UK, 1997], [179, UBA, 2001], [185, Comm., 2001], [152, Hasanbeigi 2010], [179, Brückner 2019], [180, Carr et al. 2006], [196, TWG 2019]

4.1.4.6 Self-cleaning heat exchanger

Description
Heat exchangers that recover heat from polluted hot waste water streams and avoid obstruction with rotating components (a rotating shaft with heat exchanging surfaces creates the necessary turbulence to keep the pollutants of hot discharged effluent water from sticking to the exchanger surface).

Technical description
Rotating exchangers heat up fresh water and simultaneously cool down water effluent streams, thus cutting down energy usage and meeting legal requirements on effluent temperatures. The operating principle, based on a rotating exchanging shaft, makes the unit self-cleaning and avoids obstruction or reduced heat transfer related to waste water. Moving components minimise plugging issues.

Achieved environmental benefits
Heat is recovered from the effluent and the temperature of water effluent released to the environment is reduced (otherwise the heat is not recovered when the stream contains solids and blocking would limit heat recovery). The consumption of water and chemicals used to clean heat exchangers (to solve plugging) is reduced.

Environmental performance and operational data
Rotating exchangers are used for high-solids polluted waters. An average energy saving of over 70 % for process water heating can be achieved (compared to not without this exchanger). A high pressure is needed to force liquid through the exchanger. If it is gravity-fed, then there is
no need for pumps except in exceptional situations where the flow is intermittent and for which a surge tank is recommended.

**Cross-media effects**
None identified.

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of this technique.

It is applied to both continuous and discontinuous processes when water effluent is discharged at a high temperature from the process.

**Economics**
Operational and maintenance costs are reduced by the self-cleaning feature. Capex costs are higher than conventional heat exchangers. The reduction in opex may justify the increase in capex compared to conventional heat exchangers.

**Driving force for implementation**
- Lower operating and maintenance costs.
- Lower energy usage due to efficiency gains in heat transfer.

**Example plants**
Esquire Knit Composite Ltd. & Echotex Ltd (Bangladesh) [229, Munir 2013].

**Reference literature**
[135, RICARDO 2019], [229, Munir 2013]

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### 4.1.5 Management of textile material quality [management of incoming fibre]

The textile materials that are to be treated in the textile plant can be in the form of fibre, yarn, grey fabric or untreated textile products (woven, knitted, non-woven). Due to the large amounts of textile materials treated during textile manufacturing, even trace amounts of contaminants in them can produce non-negligible amounts of pollutants in the waste gases or waste waters. Incoming quality-control systems for textile materials are important for reducing the pollutant loads in emissions to air and water.

#### 4.1.5.1 Textile materials with low contents of contaminants

**Description**
Criteria for the selection of incoming textile materials are defined to minimise the content of contaminants including toxic substances, poorly biodegradable substances and substances of very high concern. These criteria may be based on certification schemes or standards.

**Technical description**
Procurement of controlled raw materials from carefully selected suppliers that fulfil environmental performance criteria based on certifications, standards, ecolabels, private initiatives/cooperation or results of sustainability assessments is common practice in the textile sector.

Many voluntary certification schemes and initiatives which aim to control the presence of hazardous chemicals along the supply chain have been established (e.g. GOTS, Textile
Standard, OEKO-TEX, Bluesign, ZDHC) in response to regulatory approaches (e.g. REACH, EU Ecolabel, sustainability product standards) and non-governmental campaigns (e.g. Greenpeace Detox campaign). Restricted Substance Lists are used for setting the limiting thresholds of unwanted impurities/residues.

Achieved environmental benefits
Reduced chemical load in the effluent.

Environmental performance and operational data
The requirements for the chemicals used in upstream processing and their quantities remaining on the incoming raw textile materials can be reflected in the agreements and contracts with selected suppliers. The documentation (e.g. certificates) verifying the residue/impurity content of the raw textile material are checked on delivery. This can be facilitated by the involvement of both suppliers and textile plants in the voluntary certification schemes and initiatives (e.g. GOTS, Textile Standard, OEKO-TEX, Bluesign, ZDHC). Different regulatory approaches (e.g. REACH, EU Ecolabel, product standards).

Substantial progress on replacement and reduction of hazardous substances used in the textile supply chain has been achieved in recent years.[200, Greenpeace 2018]

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
The additional (environmental) requirements on the quality of incoming raw textile materials may increase their price. Incoming textile materials with known history and proven impurity/residual content may be more costly.

Driving force for implementation
- Environmental regulations for pollutants.
- Economics (Market reputation of the brands).
- Product standards (internal, national, international).
- Reduced effluent treatment costs.

Example plants
Many plants from the data collection report choosing suppliers within a certain certification scheme.

Reference literature
[27, Derden et al. 2010], [200, Greenpeace 2018].

4.1.5.1.1 Selection of man-made fibres containing preparation agents with improved environmental performance

From ex-Section 4.2.1

Description
The selected man-made fibres have not been prepared with auxiliaries containing mineral oil.

Technical description
Man-made fibres cannot be produced and processed without auxiliaries. As a consequence of pretreatment operations (e.g. washing and heat-setting), these auxiliaries used during the
production of man-made fibres find their way into the waste water and exhaust air of finishing mills. Among the auxiliaries used, coning oils and other preparation agents applied to the fibre after it has been manufactured have been identified as the major causes of the pollution in the downstream processes. This is due to the quality of the formulations employed and to the high loads applied (see also Section 2.6.4.2).

Conventional preparation agents are mainly based on mineral oils, with their well-known disadvantages of high add-on, low temperature stability (they smoke during high-temperature treatments), poor biodegradability, presence of polyaromatic hydrocarbons and generation of difficult-to-sediment sludge in biological waste water treatment plants (see also Section 8.2). Alternatives to the mineral oil-containing preparation systems are preparation agents based on [179, UBA, 2001]:

- polyether/polyester or polyether/polyester carbonates;
- special polyolesters;
- special steric hindered fatty acid esters.

**Main Achieved environmental benefits**

Reduced emissions to air and to water.

**Environmental performance and operational data**

Alternative preparation systems are less volatile and have higher thermal stability. Moreover, they can be applied in lower amounts on the fibre. As a result, reduced odour nuisance in the workplace and reduced emission levels of volatile organic compounds in the exhaust air are achieved.

The table—Table 4.10 below compares the performance of the alternative products with the conventional systems in heat-setting conditions for grey materials.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Emission factor (g C/kg textile)</th>
<th>Concentration (mg C/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral oils</td>
<td>10-16</td>
<td>500-800</td>
</tr>
<tr>
<td>Classic fatty acid esters</td>
<td>2-5</td>
<td>100-250</td>
</tr>
<tr>
<td>Optimised products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sterically hindered fatty acid esters</td>
<td>1-2</td>
<td>50-100</td>
</tr>
<tr>
<td>Polyolesters</td>
<td>0.4-4</td>
<td>20-200</td>
</tr>
<tr>
<td>Polyether/polyester or polyether/polyester carbonates</td>
<td>0.2-1</td>
<td>10-50</td>
</tr>
</tbody>
</table>

NB:
Preparation agent add-on: 2 %; air/textile ratio: 20 m³/kg; heat-setting temperature: 190 °C; curing time: 1.5 min.
*Source*: [179, UBA, 2001], [77, EURATEX, 2000]

The optimised products indicated in the table above are easier to wash out (lower consumption of water, energy and chemicals) and are in general characterised by a higher level of biodegradability compared to mineral oil-based preparation agents. Polyester/polyether carbonate compounds, in particular, show extremely good biodegradability in comparison with mineral oils. Sterically hindered fatty acid esters, on the other hand, only represent an improvement with respect to classic fatty acid esters for emissions to air from thermal treatment (thermofixation). They are in fact less volatile, but they are more difficult to biodegrade due to the increased branching of the chain.
Preparation agents made of polyester/polyether carbonates are water-soluble which results in optimised washing processes, i.e. washing processes can be substituted by a short rinsing process with cold water (20-40 °C) without any detergents or completely dropped, leading to savings in water and detergent consumption. [36, ÖKOPOL 2011]

**Operational data**

**Yarn producers**
Some machine components have to be made up of high-grade steel due to potential corrosion problems. With polyester/polyethercarbonate-based products, compatibility problems with conventional hydrophobic preparation systems mean that thorough equipment cleaning is needed following use.

Low-emission preparation agents are applicable on PES, PA 6.6, PA 6, CV and their blends with PES or CV. As a result, specific trials should be carried out [179, UBA, 2001].

The main fields of application are spooling, lubricating of PA 6-FDY yarns, twisting and texturising. The latter process is done at high temperatures. Using these products prevents deposition of cracking products in machine parts.

Additionally, emissions in the workplace may be reduced notably. [36, ÖKOPOL 2011]

**Fabric producers**
Because of compatibility problems the equipment has to be cleaned carefully (especially in the case of polyester-/polyethercarbonate-based auxiliaries).

**Finishing mills**
Processes in pretreatment have to be adjusted to the new preparation systems. In some cases (e.g. with polyester-/polyethercarbonate-based auxiliaries), washing steps in pretreatment can be simplified or even omitted.

Especially in PA 6-FDY yarns for lingerie the application of these new products shows advantages. Washing before dyeing can be avoided, i.e. washing and dyeing can be performed in one step for fabrics made of PA 6/EL. But also PES fibres/yarns applied with these new products – used especially in the technical field – demonstrate significant advantages. Raw materials finished with these products can be heat-set at once - without further washing. Due to the low waste gas impact, waste gas purification may not be necessary. [36, ÖKOPOL 2011]

**Cross-media effects**
Since new products are less volatile, off-gas emissions are reduced, but a higher amount remains on the fabric after heat-setting and eventually ends up in the waste water.

However, because of the lower quantities applied and the better biodegradability of the new products, the replacement will always bring benefits [179, UBA, 2001].

**Technical considerations relevant to applicability**
However, The applicability depends on the type of fibre and the particular end use of the final product. As a result, specific trials should be carried out [179, UBA, 2001].

Commission finishers often receive no information from the supplier concerning the quality of preparation agents used and have little leverage on this issue. Conventional preparation agents are cheaper and spinning mills look mainly at the economic aspects and at the performance of a given substance in the spinning process. The environmental problems produced in the downstream processes (at the finishing mill) are not seen as a priority by spinning mills. In these cases, it is necessary to work with clients to eliminate these materials from the supply chain.
Economics
The following economic aspects affecting all members of the textile processing chain have to be
taken into consideration [179, UBA, 2001].

Yarn producers
Low-emission auxiliaries are expensive products. This can be compensated by a lower add-on.

Finishing mills
Savings in exhaust-air cleaning equipment, simplified waste water treatment and prevention of
oil-contaminated wastes will reduce investment, maintenance and disposal costs.

Additional cost savings can be achieved with those preparation agents that allow total or partial
omission of the washing step. Increased operational reliability is also to be expected.

Driving force for implementation
Minimising off-gas loads caused by preparation agents (compliance with national regulations)
Environmental legislation and water savings in washing are the main reasons for the use of low-
emission preparation agents.

Example Reference plants
Some fibre/yarn and fabric producers in Europe are using low-emission preparation agents.
Examples of fibre/ yarn producers are listed below [179, UBA, 2001].
Some examples of textile manufacturers applying this technique are listed below: [ 36, ÖKOPOL 2011 ]:

- Elastic Textile Europe GmbH, DE-34626 Neukirchen;
- Gütermann AG, DE-79261 Gutach im Breisgau;
- Röcker & Kohler GmbH & Co KG, DE-72131 Ofterdingen.

Plants from the data collection: BE011, DE034, PT108, UK127.

Inquitex S. A.
Via Augusta 158, 5ª planta
E-08006 Barcelona

Nurel S. A.
P. delle Gracia 53
E-08007 Barcelona

Nylstar GmbH
Postfach 2209
D-24531 Neumünster

Nylstar CD Italy
Via Friuli 55
I-20031 Cesano Maderno (MI)

Textilwerke Deggendorf GmbH
Postfach 1909
D-94459 Deggendorf

Trevira GmbH & Co KG
D-60528 Frankfurt am Main

Unifi Textured Yarns Europe LTD.
Co. Donegal
Letterkenny, Ireland
4.1.5.2 Control of residues, impurities and upstream preparations in textile materials

The textile finisher needs detailed information about the chemicals present on the textile substrate. This includes information on the amount of preparation agents and sizing agents, and the amount of residual monomers, metals, biocides (e.g. ectoparasitcides for wool) present on the fibre. These substances/impurities are carried over into the process and account for a significant percentage of the pollutant load from textile mills. Improved knowledge of the raw material will allow the manufacturer to prevent or at least control the resulting emissions.

Pre-screening of incoming textile materials (fibres, chemicals, dyestuffs, auxiliaries, etc.) is of the utmost importance for pollution prevention. The supplier provides adequate information that enables the mill to make a responsible environmental evaluation, even on proprietary products. This can be achieved by implementing a chain of custody document to accompany the incoming textile material. Testing and analysis of the delivered textile materials at the reception stage as part of the incoming textile material quality control can also be done by the operator. Some information about analytical methods used to control the presence of impurities may be found in [255, ECHA 2016].

4.1.5.2.1 Control of ectoparasitcides (veterinary drugs) and biocides on wool fibres [Minimising residues of organochlorine ectoparasitcides in the raw material by substitution]

From ex-Section 4.2.7

Description
The content of ectoparasitcides (veterinary drugs) and biocides in the incoming raw (or semi-processed) wool is regularly monitored and does not exceed the predefined acceptance threshold.

Technical description
Tests are conducted with test methods such as the IWTO draft test method 59 to verify the ectoparasitcides content of the incoming wool, namely: organochlorines (banned from use but may still be present) (OC), organophosphates (OP), synthetic pyrethroids (SP) and insect-growth regulators (IGR).

The limit values not to be exceeded are, for example, those from the EU Ecolabel for textile products (2014/350/EU), or maximum residue limits set by the Australian Pesticides and Veterinary Medicines Authority (APVMA).

The tests are carried out by the operator or upstream of the supply chain (e.g. by the farmer or seller) on the sales lots. In that case, the certificates with information on the pesticide content accompany the wool lots when delivered to the operator. The geographic origin of the fibre may also be indicative of its ectoparasitcides content.

In mainstream wool-producing countries the competent bodies responsible for wool production and marketing have recognised the importance of minimising OP and SP residues by good flock management, controlled application procedures and the use of recommended withholding periods between sheep treatment and wool harvesting.

Achieved environmental benefits
Reduced pesticide loads in the effluents, waste water treatment sludge and by-products (lanolin) from wool scouring process.
Environmental performance and operational data

Some of the laboratories licensed by the International Wool and Textile Organisation (IWTO) (like Wool Testing Authority Europe, Australian Wool Testing Authority (AWTA), New Zealand Wool Testing Authority, etc) are also conducting testing and certification on compliance with the EU Ecolabel ectoparasiticide concentration thresholds (see Table 4.11) in order to allow European processors to purchase wool with confidence (see Figure 4.9).

Table 4.11:  Sum total restrictions on ectoparasiticide concentrations in wool from the EU Ecolabel for textile products (2014/350/EU)

<table>
<thead>
<tr>
<th>Ectoparasiticide groups</th>
<th>Sum total limit value (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organochlorines (OC)</td>
<td>γ-Hexachlorocyclohexane (lindane), α-hexachlorocyclohexane, β-hexachlorocyclohexane, δ-hexachlorocyclohexane, aldrin, dieldrin, endrin, p,p'-DDT, p,p'-DDD</td>
</tr>
<tr>
<td>Synthetic pyrethroids (SP)</td>
<td>Cypermethrin, deltamethrin, fenvalerate, cyhalothrin, flumethrin</td>
</tr>
<tr>
<td>Organophosphates (OP)</td>
<td>Diazinon, propetamphos, chlorfenvinphos, dichlofenthion, chlorpyriphos, fenchlorphos</td>
</tr>
<tr>
<td>Insect-growth regulators (IGR)</td>
<td>Diflubenzuron, triflumuron, dicyclanil</td>
</tr>
</tbody>
</table>

NB: ppm: mg/kg.
Source: [48, COM 2014]
### Figure 4.9: Sample report on pesticide residues analysis report from AWTA

Emissions of pesticides to water (e.g. Plants UK128 and UK 129) are reported in Section 3.4.15.

**Main achieved environmental benefits**
Emissions of OCs in waste water from wool scouring, dyeing and finishing operations, and from sewage works receiving textile effluents will be reduced. The environmental concentrations of OCs in surface waters receiving treated effluent will also fall. The concentrations in sewage sludge are also likely to fall.

The effectiveness of control measures can be judged by the following UK example. The River Calder in West Yorkshire receives treated textile effluents from the Dewsbury Sewage treatment works. This works receives waste water from ten dyehouses processing wool carpet fibre, two wool scouring companies and a fellmonger. The river is monitored regularly for compliance with EU Environmental Quality Standards.

Table 4.6 indicates river water concentrations (ng/l) downstream of the sewage works as reported by the regulator (Environment Agency) in the two years to June 2000. These data indicate that measures employed by the textile industry (and others) in this catchment area are sufficient to reduce emissions of OCs to below the limit of detection, and within EU Environmental Quality Standards.

<table>
<thead>
<tr>
<th></th>
<th>Gamma HCH (1)</th>
<th>Aldrin</th>
<th>Dieldrin</th>
<th>Endrin</th>
<th>DDT (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU Environmental Quality Standard (nanograms/litre)</td>
<td>100</td>
<td>10</td>
<td>40</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Limit of quantification (nanograms/litre)</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Total number of samples analysed in the 2 years to June 2000</td>
<td>27</td>
<td>24</td>
<td>27</td>
<td>27</td>
<td>23</td>
</tr>
<tr>
<td>Number of samples &gt; limit of quantification</td>
<td>19</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>23</td>
</tr>
<tr>
<td>Maximum recorded value (nanograms/litre)</td>
<td>61</td>
<td>–</td>
<td>6.0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Minimum recorded value (nanograms/litre)</td>
<td>3.0</td>
<td>–</td>
<td>4.0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Mean recorded value (3) (nanograms/litre)</td>
<td>16.4</td>
<td>–</td>
<td>5.0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Number of samples &lt; Limit of quantification</td>
<td>8</td>
<td>24</td>
<td>25</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td>Number of samples Greater than EQS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: [51, ENco 2001]

Notes: (1) Alpha and Beta HCH also recorded for all samples at <1ng/l. (2) Sum of op and pp DDT (2) ???

(*) These values ignore those results less than the limit of quantification (LOQ). If all the results were taken into the calculation using half the LOQ as an estimate for those values <LOQ, the mean values would be 11.7 for Gamma HCH and 1.7 for Dieldrin.

Table 4.6: Organochlorine pesticide concentrations in the River Calder below Dewsbury Sewage Treatment Works (UK). Data for 2 years to June 2000

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

These measures can be adopted by all manufacturers who purchase their own raw materials and by commission processors with the cooperation of their clients.

Economics
The costs of analytical testing are in the range from EUR 130 to EUR 250 per sales lot (e.g. example from the Figure 4.9: AUD 421.63 for 1,929 kg of wool (10 bales) = AUD 0.22/kg of raw wool). [115, AWTA Ltd 2018]

Driving force for implementation

- Economics (lower costs for effluent treatment and sludge disposal, lower costs for lanolin purification).
- Environmental legislation (environmental quality standards for direct discharges)

Example plants

Plants from the data collection that check the incoming wool for pesticides: CZ016 (by measurements), CZ017, BE010 (by measurements), IT088, UK128 (checking with EU Pesticide database) and UK129 (by measurements).

Reference literature

[48, COM 2014], [51, ENco 2001], [106, Russell 2009], [107, AWTA 2018]

Organochlorine ectoparasiticides may still be used, legally or illegally, for the treatment of sheep in some countries. The OCs are toxic in the environment, persistent and bioaccumulative. They are likely to have long-range effects and as such are the most hazardous ectoparasiticides found on wool. Several OCs are also suspected of having endocrine disrupting effects.

OCs are not used for sheep treatment in the mainstream wool producing and exporting countries. Wool from these countries may, however, contain OC pesticides at the trace levels consistent with contamination from background sources. Secondary sources of wool supply, from which OCs have not been eliminated, include Argentina, the Czech Republic, France, Spain, Turkey and the former Soviet States. At the present time the geographic source of the fibre is therefore the most reliable guide to its likely OC pesticide content.

A number of organisations maintain information on the pesticide content of greasy and scoured wool. Manufacturers can use this information to avoid processing suspect wool unless an analytical certificate showing its OC content to be less than 1 mg/kg is provided by the owner of the wool. In this way, the market for contaminated wool will be undermined and those wool producers still using OCs for sheep treatment will desist. In the absence of information, samples should be assayed to confirm their pesticide content, but this option entails higher costs for the manufacturer.

In wool dyehouses, the wool scouring process removes a significant proportion of the OCs present on greasy wool as these compounds partition with the wool grease into solid and liquid wastes arising from the scouring process (see Sections 2.3.1.2 and). Scoured wool thus contains less than 10 % of the original greasy wool pesticide burden.

Wool which is scoured to a low residual grease content would be expected to contain the lowest levels of OCs. There are, however, practical limits to the efficiency with which wool can be scoured and in some cases it is desirable to retain some lanolin on the fibre to aid further mechanical processing. Scoured wool with a residual grease content of between 0.4 and 1.0 % is generally regarded as optimal. Fibre with a residual grease content significantly higher than 1 % is unlikely to have passed through an efficiently operated scour and manufacturers should avoid using such materials, even as a small proportion of a blend, unless the pesticide content can be confirmed by analysis.

Operational data

The occurrence of OCs in mill waste water depends on the mix of fibre being processed at any given time and is therefore likely to be highly irregular. In the majority of cases concentrations will be below the limit of reliable analytical detection. Analysis of mill effluents is, therefore, unlikely to provide a realistic estimate of releases. Monitoring of raw materials for the presence
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of OCs would provide a more realistic means of controlling inputs and hence outputs from the process stream.

At the present time individual batch testing of small fibre lots is not viable. However, information is available from a number of sources on the average OC content of wools from different geographic locations. Manufacturers should monitor the underlying trends in these data to avoid processing potentially contaminated wool.

Cross-media effects

Effects on all media are expected to be positive.

Applicability

This technique can be applied by all manufacturers who purchase their own raw materials and by commission scouring and finishing mills with the co-operation of their clients.

However, if mills are to be required to turn away business, they must be assured of a level playing field, i.e. that the measure will be adopted and enforced throughout the European Union.

UK mills currently minimise their release of the organochlorine compounds known to be present on wool from some sources by selective purchase or, if the source is suspect, by certification. This strategy has proved successful, particularly in the case of companies who purchase their own raw materials. Although further down the supply chain, commission companies are able to regulate their incoming material quality by requesting data from suppliers.

Economics

Substituting one supply source for another on the basis of pesticide content may have major cost implications for the industry. Maintaining a profitable business partially depends on striking a balance between these two factors and purchasing wool with the correct technical specification (fibre diameter, fibre length, colour, etc.) at the most economic price.

For merchants and topmakers the cost of sampling and analysing a wool batch of, say, 10 tonnes would be approximately 200 euros or 0.02 euros/kg. There would possibly be expensive logistical problems for wool batches which tested above the limit. The solution for the importer would be to insert appropriate conditions into his contract and to have the wool sampled and analysed before export from the country of origin. Quality assured sampling, analysis and certification would be essential.

This cost would eventually reduce to zero, as the technique has its effect in discouraging the use of OCs for sheep treatment in wool-producing countries and it becomes possible to assume that fewer and fewer sources are producing wools potentially contaminated with OCs.

Driving force for implementation

The driving forces are prevention of aquatic pollution and long-range effects, an increase in the probability that sludge can safely be disposed of to agriculture, and a reduction of OCs in wool grease.

Reference-plants

The selective processing and purchase of wool to control OC emissions is already practised by UK wool scouring companies and wool dyers.
CSIRO in Australia is promoting testing and certification schemes in order to allow European processors to purchase Australian wool with confidence.

Reference literature

[51, ENeo 2001 ], [ 49, INTERLAINE 1999 ], [97, CSIRO, 2000], [202, Ian M. Russel, 2000].

Minimising residues of organophosphate and synthetic pyrethroid ectoparasiticides in the raw material by substitution

From ex-Section 4.2.8

Description

Other compounds, typified by the OPs and SPs used legally in animal husbandry, are more difficult to manage by substitution than OCs. The occurrence of OP and SP pesticides in mill waste water will depend on the mix of fibre being processed at any given time and as such is likely to be highly irregular. Waste water concentrations may be below the limit of reliable analytical detection. Monitoring of raw materials for the presence of OPs and SPs would provide a more realistic means of controlling inputs and hence outputs from the process stream.

Wool from some minor sources is known to be essentially free of OP and SP residues, either because these materials are not available in those countries or because the climate or local practice dictates that they are not used. The quantities of fibre available from these sources are small and opportunities to increase production to meet global market demand is limited. Widespread substitution using wool from these sources is not considered viable.

In mainstream wool producing countries the competent bodies responsible for wool production and marketing have recognised the importance of minimising OP and SP residues by good flock management, controlled application procedures and the use of recommended withholding periods between sheep treatment and wool harvesting. At the time of writing, co-operation programmes with leading grower countries have resulted in a progressive reduction of the mean OP and SP residues on wool. The industry continues to develop these strategies, which may in time lead to the widespread availability of low pesticide wool lots, perhaps supported by certification.

Manufacturers should encourage the development of low pesticide residue wool by continued dialogue with the major producer countries.

Main achieved environmental benefits

Emissions of OPs and SPs in waste water from dyeing and finishing operations and from sewage works receiving textile effluents will be reduced. The environmental concentrations of these compounds in surface waters receiving treated effluent will also fall, likewise the concentrations in sewage sludge.

Operational data

At the present time there is no widespread selection of wool on the basis of OP and SP pesticide content. It could be said, therefore, that there is no direct operational experience at the time of writing [32, ENeo, 2001]. However, the sector acting through trade associations and wool promotion bodies has influenced the wool production industries of major producing countries to the extent that the majority now have in place pesticide reduction programmes, which are progressively reducing average clip concentrations.

A low residue certification scheme is, for example, currently promoted by CSIRO Textile and Fibre Technology in Australia.
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The resources required to achieve a reduction in average clip concentration are considerable, but the effectiveness of this strategy can be illustrated by reference to data on the average OP and SP content of the Australia and New Zealand wool clip in recent years (see figures below).

Figure 4.10: Residues on Australian fleece wool 1996 to 1999
[202, Ian M. Russel, 2000]

Figure 4.11: Average pesticide residues in New Zealand greasy wool 1994 to 2000
[32, ENeo, 2001]

Cross-media effects

Effects on all media are expected to be positive.

Applicability

These measures can be adopted by all manufacturers who purchase their own raw materials and by commission processors with the cooperation of their clients.

Economics

Wool price has a very significant influence on the overall economics of yarn production. Yarn manufacturers (both sales yarn spinners and integrated mills) select wool on both technical merit and price. Maintaining a profitable business partially depends on striking a balance between these two factors and purchasing wool with the correct technical specification (fibre diameter, fibre length, colour, etc.) at the most economic price. Substituting one supply source for another on the basis of pesticide content may have major cost implications for the industry [32, ENeo, 2001].

Reference literature

[32, ENeo, 2001], [97, CSIRO, 2000], [202, Ian M. Russel, 2000].

4.1.5.2.2 Control of biocides on cotton fibres

Description

The content of biocides in the incoming cotton fibres or fabrics is regularly monitored and does not exceed the predefined acceptance threshold.

Technical description

Biocides (e.g. pesticides, fungicides and insecticides) may be present on the cotton fibre applied during growing, harvesting, transport or storage, in order to protect the fibre and preserve its quality.

In terms of cotton production, different types of cotton are available, in order of decreasing use of pesticides in cotton production: conventional, integrated pest management (IPM) and organic cotton [48, COM 2014], [195, Dodd et al. 2014]. These types of production and the cotton produced are checked and verified for compliance by certified independent control bodies in conformity with appropriate regulations (e.g. Regulation (EC) No 834/2007, Regulation No 1920/2003) or international standards (UN FAO or government IPM or Integrated Crop Management (ICM) programme, Global Organic Textile Standard - GOTS).

Some test methods used to verify the content of pesticides on the raw cotton fibre are: US EPA 8081 B (organochlorine pesticides, with ultrasonic or Soxhlet extraction and apolar solvents (iso- octane or hexane)), US EPA 8151 A (chlorinated herbicides, using methanol), US EPA
8141 B (organophosphorus compounds) and US EPA 8270 D (semi-volatile organic compounds). In Germany, test methods §64 LFGL L 00.00-34 (GC/MS) and §64 LFGL L 00.00-114 (LC/MS/MS) are used. [194, GOTS 2017].

The tests can be done upstream of the supply chain (e.g. by the farmer or seller) and the certificates with information on the pesticide content can accompany the cotton bale when delivered to the operator.

The acceptable residual pesticides thresholds are given in international standards such as the Oeko–Tex standards [201, OEKO-TEX 2017] and the EU Ecolabel for textile products [48, COM 2014].

Different certification schemes are used to track the origin and the content of pesticides in cotton at all stages of the production cycle. For example, GOTS issues; [194, GOTS 2017]

- ‘transaction certificate’ to track the organic cotton passed from one producer to another in the production chain;
- ‘scope certificate’ to ensure that the operator is qualified to produce textiles based on organic cotton so that the products remain free of hazardous substances.

By using this dual (parallel) system (certifying the material and the operator), traceability and quality throughout the supply and production chain (from the plant to the final product) are ensured.

**Achieved environmental benefits**
Reduced pesticide loads in the effluents and waste water treatment sludge from wet processing (pretreatment, dyeing, finishing) of cotton fibre.

**Environmental performance and operational data**
The EU Ecolabel and OEKO-TEX Standard-100 threshold concentration for the sum of pesticides for organic cotton is 0.5 ppm (mg/kg). [48, COM 2014], [201, OEKO-TEX 2017].

Possible pesticides (residues) detected in the cotton products include chlorpyrifos, malathion, profenofos and cypermethrin. [193, Attallah et al. 2017]

**Cross-media effects**
None identified.

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of this technique.

**Economics**
No information provided.

**Request to TWG: please provide information**

**Driving force for implementation**
- Economics (lower costs for effluent treatment and sludge disposal).
- Environmental legislation (environmental quality standards for direct discharges).

**Example plants**
Plants from the data collection that check incoming cotton raw materials for pesticides: BE010 (with measurements), FR133 (measurements for Oeko-Tex Standard-100 compliance), FR134 (with measurements), IT088 and PT117.

**Reference literature**
[193, Attallah et al. 2017], [48, COM 2014], [194, GOTS 2017], [195, Dodd et al. 2014], [201, OEKO-TEX 2017].
4.1.5.2.3 Control of residues and impurities on synthetic fibres

Description
The content of impurities and residues on the incoming (undyed) synthetic fibres (yarns) or untreated (greige) fabric (knit or woven) is regularly monitored so that it does not exceed the predefined acceptance threshold.

Technical description
Impurities and residues from fibre production found on synthetic fibres are:

- polymer synthesis by-products (e.g. residual non-reactive monomers, low-molecular-weight oligomers, residual catalyst);
- additives to facilitate processing (e.g. antistatic agents, lubricants, humectants);
- residual solvents and others.

Examples of residues from fibre production are: antimony oxide catalyst used on polyester fibres, caprolactam on polyamide 6 fibres, cyclic dimers on polyamide 6,6 fibres, N,N-dimethylformamide (DMF) and N,N-dimethylacetamide (DMAc) solvents on polyacrylonitrile and elastane fibres. For more details, see Sections 2.1.1.1 to 2.1.1.8.

The impurities and residues can have a considerable environmental impact; therefore their content is controlled by analytical testing or by checking of documentation (e.g. certificates) of incoming fibre, to minimise their load in pretreatment and dyeing effluents. [48, COM 2014]

Achieved environmental benefits
Reduced amount of hazardous or hardly or non-biodegradable substances in the effluents.

Environmental performance and operational data
As examples of the controls carried out on incoming textile fibres, Plants BE007, BE009, BE010 and BE011 from the data collection check incoming polyamide, rayon (viscose) and polyester fibres for residues of halogenated and organic solvents by measurements performed by an Oeko-Tex and GuT accredited laboratory.

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
No information provided.

Driving force for implementation
- Economics (lower costs for effluent treatment and sludge disposal).
- Environmental legislation (environmental quality standards for direct discharges).

Example plants
Plants BE007, BE009, BE010 and BE011 from the data collection.

Reference literature
[48, COM 2014]
4.1.5.2.4 Control of mineral oils and sizing agents on incoming fibre and fabric

Description
The content of mineral oils and sizing agents on the untreated (greige) incoming fibre, yarn and fabric (knit or woven) is regularly monitored so that it does not exceed the pre-defined acceptance threshold.

Technical description
Preparation agents for production and processing of synthetic fibres, and yarns or fabric from synthetic fibres can contain mineral oils (e.g. in coning, spooling oils, knitting lubricants, etc.). For more details, see Sections 4.1.5.1.1 and 8.2. Sizing agents used for warp yarn production can be responsible for high COD/BOD loads in pretreatment effluents. For more details, see Section 4.3.1.2.1.

As a consequence of pretreatment operations (e.g. washing, heat-setting), the auxiliaries used during fibre, yarn and fabric production find their way into the waste waters and gases of the textile finishing plants.

These agents can have a considerable environmental impact; therefore their content is controlled by analytical testing and certification of the incoming fibre, to minimise their release in pretreatment/dyeing effluents. [48, COM 2014]

Achieved environmental benefits
Reduced emissions to water and air.

Environmental performance and operational data
Information on add-on preparations used in fibre, yarn or fabric production is needed for appropriate treatment and to avoid unwanted pollutant loads in the effluents or waste gases. For emission factors of organic carbon concentrations in off-gases of various preparation agents from heat-setting of synthetic fibres, see Table 4.10.

The effects of this technique are reflected in the data on emissions to water of COD and BOD (see Section 3.4.4 and Section 3.4.5).

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
No information provided.

Driving force for implementation
- Environmental legislation.
- Economics (lower costs for effluent treatment and sludge disposal).

Example plants
Plants from the data collection that check incoming fibre for preparation agents: BE007, BE008, BE009, BE010, BE011, CZ015, CZ016, CZ017, CZ018, CZ020, DE021, DE023, DE025, DE042, DE046, DE050, IT059, IT065, IT088, SE118, UK124 and UK127.
Plants from the data collection that check the incoming elastane (for add-on of preparations): CZ020, IT063, IT073, PT098, PT111, PT114 and PT117.
Plants from the data collection that check incoming fibre for sizing agents: AT003, CZ017, CZ018, DE022, DE026, DE030, DE032, DE042, DE045, DE047, DE049, DE050, FR134, IT059, IT064, IT065, IT068, IT069, IT074, IT077, IT078, PT108, SE118 and UK127.
4.1.5.3 Textile fibres with reduced processing requirements

Textile fibres with inherent characteristics which reduce the need for wet processing are presented in the following sections.

4.1.5.3.1 Pre-dyed man-made fibres

Description
Use of spin- or dope-dyed fibres that do not require dyeing treatment.

Technical description
Pre-dyed man-made fibres are purchased or produced that do not need a dyeing process in their finishing treatment. The dyeing (colouring) of the fibre takes place in a process upstream of fibre production. The dyestuff is added (doped) and mixed into the molten polymer melt or solubilised cellulose solution before its extrusion or spinning into fibre (the combination of dyeing and spinning is called ‘spin-dyeing’). The fibre has good colour consistency, homogeneous hues and colour fastness (withstanding sunlight, laundry washing, abrasion and even bleach). [156, SpinDye 2019], [157, Lenzing 2019]

Achieved environmental benefits
The technique avoids using a conventional dyeing process, which reduces the energy, water, chemicals and dyestuff needed.

Environmental performance and operational data
Spin-dyeing of rayon (modal) fibres uses 50 % less energy, has a 60 % lower carbon footprint and requires 50 % less water than conventional ‘wet’ dyeing of fabric from rayon (modal) fibres. In addition, spun-dyed fabric needs 20 % less pigment [157, Lenzing 2019]. The life cycle analyses show that spin-dyeing is environmentally beneficial compared to the conventional dyeing process [158, Terinte et al. 2014].

Cross-media effects
None identified.

Technical considerations relevant to applicability
The applicability may be restricted by the product requirements.

The technique is applicable to man-made cellulosic and synthetic fibres (e.g. rayon (modal), polyester).

Economics
No information provided.

Driving force for implementation
- Reduced consumption of water, energy, chemicals and dyestuff.
- Reduced effluent treatment.

Example plants
Producers of spin-dyed fibres: Lenzing Modal® BLACK(COLOR fibre (Lenzing AG), SpinDye Stockholm (Sweden).

Reference literature
[156, SpinDye 2019], [157, Lenzing 2019], [158, Terinte et al. 2014]
4.1.5.3.2 Cationic cotton

Description
Reactive dyeing is carried out on cationic cotton, which does not require the use of salts.

Technical description
Cationic cotton is purchased or cotton is pretreated with a cationisation agent, typically CHPTAC (3-chloro-2-hydroxypropyltrimethylammonium chloride), and caustic soda. The cationisation mechanism is shown in Figure 4.12

![Mechanism of cotton cationisation with CHPTAC](source: [140, Nallathambi et al. 2017])

Figure 4.12: Mechanism of cotton cationisation with CHPTAC

The cationisation solution may be applied in different ways (exhaustion, pad-batch, pad-steam, pad-dry or a combination thereof) and to different substrates (fibre, yarn or fabric). The efficiency of the reaction and the resulting degree of cationisation are directly related to the amount of cationisation agent applied and the substrate and process utilised. [139, Cottonworks 2019]

Cationic cotton is dyed with reactive dyes but without the need for salt. gives examples of reactive dyeing mechanisms.
Alternative eco-friendly substances to CHPTAC such as chitosan are under development. [141, Bhuiyan et al. 2014].

**Achieved environmental benefits**
The process avoids salt-laden coloured effluent arising from the dyeing process.

**Environmental performance and operational data**
Dye exhaustion increases with higher concentrations of CHPTAC used for cotton cationisation. For lower concentrations, addition of alkali in the dye bath may be needed to achieve higher dye exhaustion. [143, Acharya et al. 2014]

In [140, Nallathambi et al. 2017], the properties of cationic cotton dyed fabrics were analysed. They showed good dyeing levelness and fastness properties, and increased depth of shade for medium shade and an equal depth of shade for darker shades. The optimum CHPTAC concentration for achieving different depths of shade in the cationised cotton in exhaust method was 40 g/l for medium shades and 80 g/l for darker shades.

Concerning the environmental performance, Table 4.12 below compares the pollutant loads in waste water of conventional dyeing and of dyeing carried out on cationic cotton.
Table 4.12: Emissions to water from different types of dyeing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional dyeing</th>
<th>Dyeing on cotton cationised with CHPTAC</th>
<th>Dyeing on cotton cationised with polyamino chlorohydrin quaternary ammonium compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD (mg/l)</td>
<td>485</td>
<td>25</td>
<td>68</td>
</tr>
<tr>
<td>COD (mg/l)</td>
<td>1 408</td>
<td>119.3</td>
<td>287.6</td>
</tr>
<tr>
<td>TDS (ppm)</td>
<td>15 200</td>
<td>1 803.2</td>
<td>2 365</td>
</tr>
</tbody>
</table>

Source: [145, Ramasamy et al. 2005]

Dyeing on cationic cotton generates a smaller pollutant load because no salt or alkali are added in the dye bath and because the dye fixation is higher, thus reducing the amount of unfixed dyestuff in the effluent.

The cationisation process itself may generate effluent as CHPTAC goes through an intermediate reactive stage and forms 2,3-epoxypropyltrimethylammonium chloride, a hazardous chemical which is carcinogenic and a skin sensitiser. To ensure that all of the epoxy intermediate is used up before being discharged into the environment, the pH of the water is adjusted.

At high temperatures and high pH, the epoxy form of the chemical changes to become biodegradable. [144, Frazer 2002]

Cross-media effects
Emissions to water from the cationisation process.

Technical considerations relevant to applicability
The technique is generally applicable to cotton substrate.

Economics
The technique induces investment costs for the cationisation unit or purchase costs for cationic cotton.

The investment costs for the cationisation units is less than USD 200 000 and the payback time is 2 years. [162, Cotton Incorporated 2009]

Driving force for implementation
Environmental legislation.

Example plants
No information provided.

Request to TWG: please provide information about plants applying this technique.

Reference literature
[140, Nallathambi et al. 2017] [139, Cottonworks 2019] [141, Bhuiyan et al. 2014] [135, RICARDO 2019] [143, Acharya et al. 2014] [144, Frazer 2002] [145, Ramasamy et al. 2005] [162, Cotton Incorporated 2009]

4.1.5.3.3 Composite man-made fibres with flame retardants

Description
Use of fibres with inherent flame-retardant properties (i.e. spin-doped with flame-retardant constituents).
Technical description
The flame retardant (FR) is added (doped) and mixed into the molten polymer melt (matrix) before the extrusion or spinning of the fibre. Such flame-retardant doped fibres can be used to reduce the need for the external application (finish) of flame retardants.

Some examples of such fibres are: PP matrix with 5-10% FR additives (e.g. DBDPE, tris(Tribromoneopentyl) phosphate (TTBNP), or organophosphorus compounds); PA matrix with 1-10% FR additives (e.g. nitrogen-based like melamine cyanurate or brominated such as DBDPE) or PET matrix with 2.5-15% FR additives (e.g. phosphor-based additives: polyphosphonate polymer or phosphinate, or brominated such as DBDPE). [223, Centexbel 2019]

Achieved environmental benefits
The technique avoids using a conventional functional finishing process, which reduces the energy, water and chemicals needed.

Environmental performance and operational data
Spin-doping of fibres uses less energy and requires less water than conventional ‘wet’ finishing of fabric.

Cross-media effects
None identified.

Technical considerations relevant to applicability
The applicability may be restricted by the product requirements.

The technique is applicable to the man-made cellulosic and synthetic fibres (e.g. rayon (modal), polyester).

Economics
No information provided.

Driving force for implementation
- Reduced consumption of water, energy, chemicals and dyestuff.
- Reduced effluent treatment.

Example plants
No information provided.

Request to TWG: please provide information about plants applying this technique.

Reference literature
[223, Centexbel 2019]

4.1.5.3.4 Low-finish elastane and blend yarns of elastane with other fibres

Description
Elastane (so-called low-finish) or blend yarns of elastane and other polymer fibres (e.g. with recycled PET or other synthetic fibres) that contain a reduced amount of preparation agents (e.g. knitting oils, lubricants, silicon oils, detergents, residual solvents).

Technical description
Conventional elastane fibre yarns are replaced by low-finish elastane fibres and multicomponent elastane blend yarns (e.g. blend of elastane and other synthetic fibres spun in the same yarn). Their properties are similar or better than conventional elastane yarns, but the amount of preparation agents needed for their production is much lower.
Conventional elastane fibres’ silicon oil content is 5 % and the residual solvent (DMAc) content up to 3 %. Low-finish elastane fibres and blends containing between 0 % and 2 % preparation agents and of < 1 % residual solvent are used instead, if these yarns can be processed on the equipment (e.g. warp knitting). [ 36, ÖKOPOL 2011 ]

**Achieved environmental benefits**
Reduced pollutant load to the effluent from pretreatment.

**Environmental performance and operational data**
Processing and dyeing of the blend fibres are the same as for conventional PES fibres.

The blend fibres are used especially in the field of stretch denims for their elastic properties. Due to their greater chlorine resistance, they withstand special bleaching and washing techniques which destroy conventional elastane fibres. Tapes with very high washfastness and elastic linings for jackets or trouser waistbands are other applications.

**Cross-media effects**
Possible emissions of antimony in effluent (from PES fibres, as it is used as catalyst in their production).

**Technical considerations relevant to applicability**
The applicability may be restricted by the product requirements.

Blend fibres can be used everywhere where material elasticity is recommended: in particular in the case of denim and low-weight fabrics.

**Economics**
No information provided.

**Driving force for implementation**
- Economics.
- Environmental legislation.

**Example plants**
No information provided.

**Request to TWG: please provide information about plants applying this technique.**

**Reference literature**
[ 36, ÖKOPOL 2011 ]

4.1.5.3.5 **Use of non-carrier dyeable-PES fibres without carriers**

**Description**
Dyeing is carried out on dyeable polyester fibres, such as polytrimethylene terephthalate (PTT), with no carriers needed for dyeing.

**Technical description**
The polymer industry has long shown an interest in the entire series of aromatic polyester polymers made from the homologous series of n-methylene glycols. Among these polymers, PET based polyester fibres are the most important ones in the textile industry. They show excellent mechanical properties and resistance to heat, but their high degree of crystallinity makes them non-dyeable below 100 °C unless dye carriers are applied.
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The environmental concerns raised by the use of these hazardous substances and the proposed techniques to counteract this problem are described in the previous section. An additional option to consider is the use of non-carrier dyeable PES fibres, such as polytrimethylene terephthalate (PTT) polyester fibres (see also Section 2.1.1.1).

Fibres made from polytrimethylene terephthalate can be dyed or printed using standard disperse dyestuffs without the need for any special processing steps or carriers to accelerate the dyeing process. The dyeing process of PTT fibres with disperse dyes is a diffusion-controlled process. Therefore, a higher temperature (e.g. above 80 °C) and longer exhaustion time (e.g. 1 hour) are recommended for dark and full shades like red, navy blue and black.

Polytrimethylene terephthalate remained an obscure polymer for a long time not because it lacked good physical and chemical properties and potential applications, but because Historically the high costs of synthesis of the starting monomer (1,3-propanediol) has prevented wider use of PTT. The resulting fibre, but from being brought to market. PTT polymers are of renewed interest today thanks to Shell’s recent breakthrough in for the past decade a lower-cost synthesis process (e.g. starting monomer (1,3-propanediol) is produced from corn (sucrose-based)) have been developed that have made it more accessible. [36, ÖKOPOL 2011]

Main-Achieved environmental benefits

The following environmental benefits are achieved in the dyeing process compared to standard polyester fibres (PET type):

- Reduced emissions (of carriers) to water, in the workplace and in the environment are completely avoided
- Reduced energy consumption. Lower amount of energy is consumed compared with PET dyed under high-pressure high-temperature (HT) conditions (PTT is dyed atmospherically at 100 °C with excellent dye exhaustion and colourfastness)

Environmental performance and operational data

Disperse dyes are the recommended dye class for light and medium shades for PTT, although some specially developed disperse dyes can be used especially for dark shades as well. Basic dyes may also be used, but only for light shades.

Dyeing equilibrium for a medium shade is obtained in 30 to 60 minutes, depending on the dyes selected. To achieve a good dye utilisation without compromising productivity, 30 to 45 minutes holding time at 100 °C is recommended [178, VITO, 2001].

The recommended dyeing conditions are pH 7 and 100 °C (PTT at 100 °C was dyed with the same or a slightly deeper shade than PET at 130 °C) [178, VITO, 2001].

PTT fibres are not only easy to process, but also easy to manufacture. They can be extruded on all commonly used machinery with minor modifications.

Properties of PTT are similar to those of PET and nylon fibres.

Thanks to their performance, PTT fibres may have extensive applications in carpeting, textiles and apparel, engineering thermoplastics, non-wovens, films and mono-filaments.

Advantages of PTT fibres are soft handling, higher extensibility, higher stability with regard to UV light as well as higher chlorine fastness, which result in their preferred use in underwear, sportswear and swimwear. [36, ÖKOPOL 2011]

According to manufacturers, fibres made from CORTERRA® Polymers demonstrated performance equal to and, in many cases, better than other materials such as polypropylene, nylon and PET. However, due to the difference in structure, their physical and mechanical
properties obviously differ from standard PES fibres (PET type). As a result, they do not cover exactly the same product market and they cannot be regarded to as “substitutes” for PET fibres.

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
The applicability may be restricted by the product requirements.

Economics
The new biomaterial synthesis route pursued by Shell for the manufacturing of the poly(trimethylene terephthalate) has made PTT fibres even more competitive on the market compared to standard PES fibres.

The low dyeing temperature and the broad dyeing pH allowance help to decrease the cost of dyeing. Moreover, the environmental costs associated with the presence of carriers are avoided.

In the carpet industry, the possibility of dyeing PES carpets in pieces at atmospheric conditions without the use of carriers is particularly convenient (due to the high cost of pressurised machinery for dyeing in pieces under HT conditions).

Driving force for implementation
- Environmental legislation (emissions to water).
- Chemical legislation restrictions (for carriers).
- Emission limit values and restrictions on dye carriers that are currently required by environmental legislation and the leading voluntary Ecolabel schemes.

Reference Example plants
A total of 32 plants from the data collection apply this technique. Shell Chemical Company announced the commercial introduction of PTT in 1996 under the trade name of CORTERRA® Polymers.

Reference literature
[178, VITO, 2001], [36, ÖKOPOL 2011]

4.1.6 Chemicals management [Selection/ substitution of chemicals used]

4.1.6.1 Chemicals management system

Description
The chemicals management system is part of the EMS (see Section 4.1.1.1) and is a set of technical and organisational measures to limit the impact of the use of chemicals on the environment.

Technical description
The chemicals management system (CMS) contains the following components:

- management commitment to reduce the use of hazardous chemicals;
- definition of the CMS scope, identification the parts of the plants concerned (if not the entire plant);
- definition of roles and responsibilities for the management of chemicals;
- staff training for the management of chemicals;
Chapter 4

- process chemicals procurement policy to select process chemicals and their suppliers with the aim to minimise the use of hazardous chemicals such as substances of very high concern and to avoid the procurement of excess amount of process chemicals. In order to reduce emissions to air, the selection of process chemicals may be based on emission factors (see Section 4.1.2.4). The selection of chemicals may be based on certification schemes or standards and/or on the emission factors of the chemicals (see Section 4.1.2.4);
- anticipatory monitoring of regulatory changes related to hazardous chemicals and safeguarding compliance with applicable legal requirements;
- systematic identification and documentation of chemicals used and stored at the plant (see more details on chemicals inventory Section 4.1.6.2);
- identification of the process chemicals’ pathways through the plant (from incoming raw material and purchased chemicals to products, waste and emissions);
- traceability of the chemicals used at the plant, including the identification of possible chemical losses;
- verification of compliance with products or production certification schemes, if relevant;
- assessment of the risks associated to the chemicals, based on the chemicals’ hazards, concentrations and amounts. This may include an estimation of their emissions to the environment;
- regular (e.g. annual) check aiming at identifying potentially new available and safer alternatives to the use of hazardous chemicals (e.g. changes of the processes or use of other chemicals with no or lower environmental impacts such as enzymes);
- goals and action plans to reduce the use of hazardous chemicals.
- development and implementation of procedures for the handling, storage, use and disposal of chemicals (see Section 4.1.6.4.1);
- periodic monitoring of the CMS, including internal and external audits;
- periodic management review of the CMS.

Achieved environmental benefits
- Reduction of the use of hazardous chemicals.
- Reduction of emissions of hazardous chemicals to air, water, groundwater and soil.
- Reduction of the amount of hazardous chemicals in waste.

Environmental performance and operational data

The selection of chemicals and chemical suppliers is facilitated by adhesion to voluntary certification schemes, private initiatives or cooperation in which the presence of hazardous chemicals is controlled along the supply chain and chemicals and preparations are regularly screened for compliance against criteria and thresholds of established manufacturing restricted substance lists. Examples of such certification schemes include GOTS, Textile Standard, OEKO-TEX, Bluesign, ZDHC and others.

Effective communication between downstream users and suppliers at all stages in the REACH process also helps to ensure that relevant information is provided in the supply chain. [226, ECHA 2019]

The list of REACH restrictions about the textile products may be consulted at [256, ECHA 2019]

Methodologies and tools for conducting qualitative and/or quantitative chemical risk assessments are available (e.g. REACH Annex I or XII [79, EU 2006] and the European Union System for the Evaluation of Substances (EUSES) software [232, EU 2019]).

Precisely estimating the quantities of chemicals/preparations needed in formulations for treating the textiles (production planning) lowers the quantities of leftover chemicals. To release the storage space and reduce the risks of chemical expiry (and potential risks and costs of treating them as waste), the unused chemicals (in their original packaging) are preferably returned to the supplier before their expiration date, for possible resale and use. This is achieved especially by using innovative business models like chemical leasing, closed-loop chemicals management, etc.
The information on unwanted hazardous substances in the purchased chemicals/preparations and the quantities of returned unused leftover chemicals/preparations is also used in overviews of material flows through the installation (see Sections 4.1.1.1 and 4.1.1.2).

More details about the operational data of some components of the CMS may be found in Sections 4.1.6.2 to 4.1.6.7.

Information about substitution of hazardous chemicals is given in Section 4.1.6.8 and in the process-specific sections of Chapter 4 (Sections 4.2 to 4.7).

**Cross-media effects**
None reported.

**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 CMS will be related to the nature, scale and complexity of the installation, and the range of hazardous chemicals it may use.

**Economics**
No information provided.

**Driving force for implementation**
The driving forces for the implementation of a CMS include:

- improved environmental performance;
- compliance with regulations and/or certification schemes;
- optimised consumption of hazardous chemicals.

**Example plants**
In total, 51 plants from the data collection apply a CMS.

**Reference literature**
[ 215, ZDHC 2015 ], [ 217, OEKO-TEX 2019 ], [ 27, Derden et al. 2010 ], [ 202, Rodríguez 2018 ], [ 226, ECHA 2019 ], [ 79, EU 2006 ], [ 232, EU 2019 ], [ 256, ECHA 2019 ]

### 4.1.6.2 Chemicals inventory

**Description**
Chemicals inventory and tracking system to elaborate and implement a as part of the CMS.

**Technical description**
Textile plants use a considerable number of chemical products (100-300) for the different processes (pretreatment, dyeing, printing and final finishing).

In order to ensure the availability and completeness of information necessary for responsible chemical management, the relevant data for the chemical auxiliaries and process chemicals used are entered, collected and managed in one dedicated computer-based inventory. From this inventory, a tailored information can be generated.

The chemicals inventory and tracking system is computer-based and contains information about:

- the identity of the process chemicals;
- the quantities and location of the process chemicals procured, stored, used and returned to suppliers;
Chapter 4

- the characteristics of process chemicals including properties with adverse effects on the environment and/or human health

The main and commonly used sources of data used for the different chemical products are the Safety Data Sheets (SDS) and to some extent the Technical Instruction Sheets. In order to facilitate evaluations, it is important to link the inventory to a comprehensive modern production planning and control system.

The inventory may be used for the following purposes:

- Identification of chemical products with acute and chronic aquatic and sediment toxicity [227, ECHA 2019].
- Identification of chemical products which are readily, inherently or non-biodegradable in waste water treatment.
- Qualitative and/or quantitative risk assessment of the chemical substances.
- Identification of all combustible/flammable products and those which can decompose (thermally or by reaction with other chemicals).
- Planning the use of consumption and implementing adequate storage and handling. This also allows the reduction of the risks of chemicals’ expiry (and potential risks and costs of treating them as waste) and for the unused chemicals to be returned to the supplier before their expiration date, for possible resale and use (see Section 4.1.6.1).
- Assessing compatibility of substances and storing the substances accordingly (see Section 4.1.6.4.1).
- Compilation of data relevant for communication and reporting (with competent authorities or customers) and/or certification purposes (e.g. OEKO-TEX STeP, GOTS).
- Cross-verification with manufacturing restricted and/or positive substances lists (e.g. ZDHC Manufacturer restricted substances list, Bluesign system substances list), specific customer restricted substances lists or other lists (e.g. list of substances of very high concern).

Concerning emissions to air from stenters, a reference may be made to the product-specific emission factors for chemical products used for finishing on these machines (see Section 4.1.2.4).

Figure 4.14 and Figure 4.15 show examples of useful information regarding chemicals which can be included in the chemicals inventory. More examples may be found in [215, ZDHC 2015] and [216, Textilbündnis 2019].
### Figure 4.14: Example of useful information related to the substances and mixtures used in a textile plant

| Source: [212, HAZBREF 2019] |

<table>
<thead>
<tr>
<th>Substances and Mixtures</th>
<th>Information</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pesticide 1</td>
<td>Description</td>
<td>Notes</td>
</tr>
<tr>
<td>Pesticide 2</td>
<td>Description</td>
<td>Notes</td>
</tr>
<tr>
<td>Pesticide 3</td>
<td>Description</td>
<td>Notes</td>
</tr>
</tbody>
</table>

**Table Example:**

- **Column 1:** Substances and Mixtures
- **Column 2:** Information
- **Column 3:** Remarks

**Row Examples:**

<table>
<thead>
<tr>
<th>Substances and Mixtures</th>
<th>Information</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pesticide 1</td>
<td>Description</td>
<td>Notes</td>
</tr>
<tr>
<td>Pesticide 2</td>
<td>Description</td>
<td>Notes</td>
</tr>
<tr>
<td>Pesticide 3</td>
<td>Description</td>
<td>Notes</td>
</tr>
</tbody>
</table>

**Description:**

- Pesticide 1: Details of the substance, its uses, and potential hazards.
- Pesticide 2: Further details including handling and storage instructions.
- Pesticide 3: Additional information regarding its impact on health and the environment.

**Notes:**

- Notes on the specific conditions under which each pesticide is used.
- Remarks on safety measures to be taken in handling these substances.

**Table Example:**

<table>
<thead>
<tr>
<th>Substances and Mixtures</th>
<th>Information</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pesticide 1</td>
<td>Description</td>
<td>Notes</td>
</tr>
<tr>
<td>Pesticide 2</td>
<td>Description</td>
<td>Notes</td>
</tr>
<tr>
<td>Pesticide 3</td>
<td>Description</td>
<td>Notes</td>
</tr>
</tbody>
</table>

**Description:**

- Pesticide 1: Details of the substance, its uses, and potential hazards.
- Pesticide 2: Further details including handling and storage instructions.
- Pesticide 3: Additional information regarding its impact on health and the environment.

**Notes:**

- Notes on the specific conditions under which each pesticide is used.
- Remarks on safety measures to be taken in handling these substances.
### Proposal for the content of the chemical inventory

<table>
<thead>
<tr>
<th>Data source</th>
<th>Product information</th>
<th>Product 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOS 1.1</td>
<td>Product name</td>
<td>name</td>
</tr>
<tr>
<td>SOS 1.3</td>
<td>Suppliers name</td>
<td>name</td>
</tr>
<tr>
<td>SOS 9.1</td>
<td>Physical form</td>
<td>description</td>
</tr>
<tr>
<td>SOS 2.1</td>
<td>Mixture classification (if applicable)</td>
<td>classification</td>
</tr>
</tbody>
</table>

### Uses of product

<table>
<thead>
<tr>
<th>Use 1</th>
<th>Use 2</th>
<th>Use n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifier for workplace/process step in company</td>
<td>Description</td>
<td>Description</td>
</tr>
<tr>
<td>Technical purpose of product</td>
<td>Description</td>
<td>Description</td>
</tr>
<tr>
<td>Amount used per day</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>Fate of residues after use (air, wastewater, waste)</td>
<td>Description</td>
<td>Description</td>
</tr>
</tbody>
</table>

### Conformity check with REACH ES for use 1

<table>
<thead>
<tr>
<th>Own data</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contributing activities in ES match onsite use of product</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Conditions of use in ES match onsite conditions</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Safe amount per site in ES &gt; use amount on site</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
</tbody>
</table>

### Conformity check with REACH ES for use 2

<table>
<thead>
<tr>
<th>Own data</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contributing activities in ES match onsite use of product</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Conditions of use in ES match onsite conditions</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Safe amount per site in ES &gt; use amount on site</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
</tbody>
</table>

### Ingredients information

<table>
<thead>
<tr>
<th>Substance 1</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substance name</td>
<td>name</td>
<td>name</td>
</tr>
<tr>
<td>Technical function</td>
<td>description</td>
<td>description</td>
</tr>
<tr>
<td>CAS or EC</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>Concentration %</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>Classification</td>
<td>description</td>
<td>description</td>
</tr>
<tr>
<td>Vapour pressure</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>Biodeg.</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>DNEL</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>OEL</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>PNEC</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>EDS</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>Regulatory flag</td>
<td>Info relevant to substance 1</td>
<td>Info relevant to substance 1</td>
</tr>
</tbody>
</table>

### Release fractions from use 1

<table>
<thead>
<tr>
<th>Own data/ES</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>% incorporated as such to article</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% consumed/reacting during use</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% release to waste water</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% related to air</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% disposed of as waste</td>
<td>Number</td>
<td>Number</td>
</tr>
</tbody>
</table>

### Onsite treatment and effectiveness for substance 1

<table>
<thead>
<tr>
<th>Own data/ES</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>% incorporated as such to article</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% consumed/reacting during use</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% release to waste water</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% related to air</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% disposed of as waste</td>
<td>Number</td>
<td>Number</td>
</tr>
</tbody>
</table>

### Release fractions from use 2

<table>
<thead>
<tr>
<th>Own data/ES</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>% incorporated as such to article</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% consumed/reacting during use</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% release to waste water</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% related to air</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% disposed of as waste</td>
<td>Number</td>
<td>Number</td>
</tr>
</tbody>
</table>

### Onsite treatment and effectiveness for substance 1

<table>
<thead>
<tr>
<th>Own data/ES</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>% incorporated as such to article</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% consumed/reacting during use</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% release to waste water</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% related to air</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% disposed of as waste</td>
<td>Number</td>
<td>Number</td>
</tr>
</tbody>
</table>

### Release fractions from use n

<table>
<thead>
<tr>
<th>Own data/ES</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>% incorporated as such to article</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% consumed/reacting during use</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% release to waste water</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% related to air</td>
<td>Number</td>
<td>Number</td>
</tr>
<tr>
<td>% disposed of as waste</td>
<td>Number</td>
<td>Number</td>
</tr>
</tbody>
</table>

Source: [257, Pillet et al. 2019]

Figure 4.15: Example of the inventory entry for a chemical product used in a textile plant

Achieved environmental benefits
Reduced risks associated with the storage and handling of hazardous substances.

Reduction of chemical leftovers.

The systematic identification of substances with undesirable environmental and toxicological (adverse) properties allows risk-driven prioritisation of management actions and abatement of emissions to air and to water.

**Environmental performance and operational data**

The data from the 16 sections of the respective SDS (as defined in CLP Regulation (EC) No 1272/2008 [47, EU 2008] and Annex II to REACH Regulation No 1907/2006 [79, EU 2006]) are systematically inserted into the database, enabling different evaluation options:

- Section 1: Identification of the substance/mixture and of the company/undertaking;
- Section 2: Hazards identification;
- Section 3: Composition/information on classified ingredients;
- Section 4: First aid measures;
- Section 5: Firefighting measures;
- Section 6: Accidental release measure;
- Section 7: Handling and storage;
- Section 8: Exposure controls/personal protection;
- Section 9: Physical and chemical properties;
- Section 10: Stability and reactivity;
- Section 11: Toxicological information;
- Section 12: Ecological information;
- Section 13: Disposal considerations;
- Section 14: Transport information;
- Section 15: Regulatory information;
- Section 16: Other information.

With regard to environmental protection, information on the chemical composition of the respective chemical products (Section 3 of the SDS), information on handling and storage (Section 7 of the SDS) as well as the exposure values (e.g. Predicted No Effect Concentration (PNEC) reference values of aquatic systems in Section 8 of the SDS) and ecological information (from which PNECs have been derived in Section 12 of the SDS) are the most relevant in practice. The downstream user may acquire additional environmental information from the formulator of hazardous mixtures, e.g. the SDS may be extended with attached information (annexes) on exposure scenarios and release rates for the hazardous substances in the mixture. For more information see [233, ECHA 2019].

Concerning emissions to air from stenters, the emission factors for the various products are not contained in the SDS but are provided separately by the suppliers (for more information see 4.1.2.4). Thus, updating information on emission factors for the products concerned requires regular contact with chemical suppliers. To date, only one German company has established a laboratory stenter to determine the emission factors for the chemical products.

The software application for the establishment and implementation of the inventory and associated evaluation tools can be obtained by a range of providers available on the market (as part of an integrated business or stand-alone applications) or can be developed in-house.

**Cross-media effects**

None identified.

**Technical consideration relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

**Economics**
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The investment and operating costs for a chemical inventory depend on the level of sophistication intended. Estimates put the investment costs in the range of EUR 20 000 to EUR 50 000. Savings usually arise from streamlined stocks, improved management of surplus chemicals, simplification or automation of procedures/processes (e.g. by using chemical inventory software) as well as indirectly from reduced environmental management costs based on the gradual substitution of hazardous chemicals and emissions to the environment.

**Driving force for implementation**
- Reduction of chemical leftovers.
- Certification schemes.

**Example plants**
Plants from the data collection: IT082 and IT097. [ 213, EIPPCB 2019 ]

**Reference literature**

4.1.6.3 **Selection of textile dyes, dyestuffs, pigments, finishing agents and auxiliaries: chemicals according to their waste water relevance**

**Description**
Use of screening tools based on restricted substance lists and environmental labelling to reduce the amount or presence of hazardous substances or to find alternative chemicals and preparations containing substances with a lower environmental impact (e.g. toxicity, biodegradability/eliminability).

**Technical description**
Restricted substances are chemical substances whose use and/or presence has been banned or otherwise restricted by organisations, authorities or producers. In order to avoid using dyestuffs or chemicals that contain these substances, the textile plants can use products that are labelled or certified as appropriate for use in a certain labelling scheme (e.g. Type I, II or III product labels according to ISO 14 020). There are various voluntary labelling (restriction) schemes like EU Ecolabel, and schemes provided by ZDHC, OEKO-TEX, Bluesign, GOTS, AFIRM, GUT, etc.

EU Ecolabel contains a list of restricted substances that are to be avoided or limited in the textile products certified according to this label. [ 48, COM 2014 ]

The ZDHC (Roadmap to Zero Programme) is a coalition of fashion brands, value chain affiliates and associates dedicated to enabling the global textile, leather, apparel and footwear production chains to substitute hazardous chemicals for safer ones. [ 203, Stichting ZDHC Foundation 2019 ]

The International Association for Research and Testing in the Field of Textile and Leather Ecology (OEKO-TEX Association) is a union of 18 independent textile research and test institutes in Europe and Japan and their worldwide representative offices. The member institutes are responsible for the joint development of test methods and limit values which form the basis of the product labels (e.g. OEKO-TEX STANDARD 100, MADE IN GREEN) as well as the production site certifications (e.g. SteP - Sustainable Textile Production) and the chemical management tool DETOX TO ZERO. They are also entitled to carry out the corresponding laboratory tests and site audits. Additional services of the OEKO-TEX Association are the MySteP database for supply chain management and the ECO PASSPORT certification for the verification of chemicals and auxiliaries. [ 204, OEKO-TEX Association 2019 ]
The Global Organic Textile Standard (GOTS) label was developed in 2006 through collaboration by leading carpet producers with the aim of defining requirements that are recognised worldwide and that ensure the organic status of textiles from harvesting of the raw materials through environmentally and socially responsible manufacturing all the way to labelling in order to provide credible assurance to the consumer. [205, GOTS 2019]

Bluesign sustainability labels and certifications, are set by a private company (founded in 2000) for the production of textiles with a particular focus on chemical safety. It relates to both the companies supplying chemicals and the textile industry in order to avoid hazardous chemicals along the manufacturing process. The company also provides their members with services in chemicals management (e.g. substitution of chemicals, inventories, through the Bluesign SYSTEM). [206, bluesign technologies ag 2019]

AFIRM is private company aiming to reduce the use and impact of harmful substances in the apparel and footwear supply chain by managing the restricted substance lists for its members (e.g. brands). [207, AG AFIRM Group 2019]

European carpet manufacturers founded the Association of Environmentally Friendly Carpets e.V. (Gemeinschaft umweltfreundlicher Teppichboden) – GUT - in 1990 in Aachen (Germany). The aim of GUT is to continuously improve all environmental and consumer protection aspects throughout the life cycle of a textile floor covering (from production to installation, to use phase and recycling). In cooperation with officially recognised European testing institutions, GUT-registered products are regularly controlled on the basis of GUT’s test criteria. Also, regular annual inspections of production sites are conducted. [209, GUT 2019]

The above-mentioned entities (ZDHC, OEKO-TEX, GOTS, Bluesign, AFIRM, GuT) carry out certification/labelling according to their restriction schemes (Restricted Substance Lists – RSL). If the product is to be labelled/certified according to these schemes, certain restricted substances must be absent or present in limited concentrations from the manufacturing inputs (raw materials) and outputs (e.g. emissions, effluents) or from the finished textile products.

Substances are restricted for various reasons: due to environmental concerns, health and safety concerns for workers or consumers, or due to legislation. A substance restriction (in the RSL scheme) is usually accompanied by a test (standard) method to be used to verify if a chemical is present and, if so, to ensure the chemical is below the restricted level. These labelling schemes can also be used to select raw materials and chemical suppliers (see Sections 4.1.5.1 and 4.1.6.1).

Some chemical screening tools for finding suppliers of alternative chemicals or mixtures (without restricted substances) are available online (e.g. Marketplace [208, ChemSec 2019]).

In addition to these screening tools, the regulatory context of a given substance may be verified by using the ECHA search tool. [227, ECHA 2019]

In some EU Member States schemes have been developed in cooperation with industry in order to support the permitting process and lower the pollutant loads of hazardous substances to waste waters. They may help in the selection process as screening tools. During the past 15 years, various schemes have been developed for ecotoxicological assessment and classification. These schemes include the Dutch General Assessment Methodology in the Netherlands (RIZA Concept), the SCORE System in Denmark, the BEWAG Concept in Switzerland and the TEGEWA scheme developed in Germany by industry in collaboration with authorities.

Three of these schemes—the TEGEWA scheme, the SCORE System and the Dutch General Assessment Methodology—have been proposed by the German, Danish and Dutch TWG members, respectively, as techniques to be considered in the determination of BAT. All Three methods are presented in Chapter 13 (extracts of submitted documents).
Main-Achieved environmental benefits
Reduced pollutant loads to the effluents from textile processing.

Environmental performance and operational data
The change of chemicals may affect the number, scope and technological parameters of various operation steps, which would need to be adapted to ensure the required product specifications. Also, it can affect the waste water treatment needed, because it may need to be adapted for a different pollution load. Also, it is possible that alternative chemicals are needed in higher quantities and require special treatments and accommodation of production processes – all of these could affect the environmental impact.

All three sources regard the proposed schemes are useful tools that allow the user to select textile dyes and auxiliaries for ecotoxicological aspects. Indirect benefits for water quality are therefore expected, although difficult to quantify/evaluate.

According to TEGEWA, the introduction of the method in Germany in 1998 has produced a reduction in the consumption of Class III products (products with “High relevance to waste water, according to TEGEWA classification scheme). This is shown in the table below.

<table>
<thead>
<tr>
<th>Year</th>
<th>Class I</th>
<th>Class II</th>
<th>Class III</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>2821</td>
<td>1499</td>
<td>460</td>
<td>4780</td>
</tr>
<tr>
<td>1998</td>
<td>3020</td>
<td>1485</td>
<td>417</td>
<td>4922</td>
</tr>
<tr>
<td>1999</td>
<td>3242</td>
<td>1358</td>
<td>358</td>
<td>4958</td>
</tr>
<tr>
<td>2000</td>
<td>3164</td>
<td>1258</td>
<td>297</td>
<td>4719</td>
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<tr>
<td></td>
<td>98446</td>
<td>29972</td>
<td>27574</td>
<td>155992</td>
</tr>
<tr>
<td></td>
<td>105983</td>
<td>23830</td>
<td>150235</td>
<td>159235</td>
</tr>
<tr>
<td></td>
<td>102578</td>
<td>102341</td>
<td>116130</td>
<td>135715</td>
</tr>
</tbody>
</table>

Figure 4.16: Textile auxiliaries sold in Germany from 1997 to 2000: number, quantity and percentage of textile auxiliaries in classes I, II, III, according to TEGEWA [26, UBA, 2001]

Cross-media effects
None identified believed likely according to both sources. However, some considerations are worth mentioning:

- EU/OSPAR have set criteria for the selection and prioritisation of chemicals. The conclusions of the EU/OSPAR criteria may be not fully in agreement with the conclusions derived from the proposed classification schemes.
- A hazard assessment considers only product-specific properties and not the actual risk or total effluent load. It is crucial to differentiate between hazard and risk. Risk is a function of hazard and exposure. If either of these factors is zero then the risk is also zero. Conversely, a less hazardous product can pose a higher risk than a more hazardous product, if the exposure is high (e.g. quantity, frequency of use, degree of exhaustion, etc.). Hazard and exposure are the integral parts of risk assessment (which is taken into account by EU policy). Correct evaluation of the control of risks arising from the use of chemicals can only be achieved by performing a risk assessment [102, ETAD, 2001].
- It is important that the steps of the process and the information that supports the allocation of a product to a given class of hazard remain transparent in order to allow a critical evaluation of the results by the users (both industry and authorities).

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

From the user/textile finisher point of view, the implementation of the TEGEWA method does not require particular resources to be spent because the chemical producers already classify their products.
Conversely, the implementation of the Danish SCORE System implies that the authorities and the companies allocate the necessary man-hours to set up the system. Once the company has joined the system, approximately 25–50 man-hours a year are needed for maintenance of the system [42, Danish EPA, 2001].

The broad applicability of this kind of tool at the European level depends on the degree of acceptance of the method by the parties involved (i.e. industry and national authorities).

Economics
It is possible that alternative chemicals are more expensive, needed in higher quantities and require special treatment – all of these could affect the economic costs of production. According to the sources, no major economic problems have been encountered in Germany or in Denmark, where the two proposed classification tools are already applied.

Driving force for implementation
Demanded from authorities [42, Danish EPA, 2001].
- Environmental and chemical regulation (e.g. Ecolabel, REACH).
- Market demands (customer pressure).

Example Reference plants
Many plants from the data collection reported using labelling and certification schemes (e.g. 47 use Oeko-Tex, 13 use ZDHC, 6 Bluesign, and many others). The TEGEWA scheme has been applied in Germany since 1998, while the implementation of the SCORE System is part of the environmental permits for the clothing and textile industry in Ringkøbing in Denmark.

Reference literature
[42, Danish EPA, 2001], [37, TEGEWA, 2000], [26, UBA, 2001], [48, COM 2014], [203, Stichting ZDHC Foundation 2019], [204, OEKO-TEX® Association 2019], [205, GOTS 2019], [206, bluesign technologies ag 2019], [207, AG AFIRM Group 2019], [209, GUT 2019], [227, ECHA 2019].

with reference to:

“Lepper, 1996”
Lepper, P.; Schönberger, H.
Konzipierung eines Verfahrens zur Erfassung und Klassifizierung von Textilhilfsmitteln
Abschlussbericht FKZ 10901210 zu einem Forschungsvorhaben im Auftrag des Umweltbundesamtes (1996) – nicht veröffentlicht

“TEGEWA, 1999”
Noll, L.; Reetz, H.
Gewässerökologisch orientierte Klassifizierung von Textilhilfsmitteln
Mellian Textilberichte 81 (2000) 633-635

“TVI-Verband, 1997”
Verband der deutschen Textilveredlungsindustrie, TVI-Verband, D-Eschborn
Official and published self-commitment concerning the classification of textile auxiliaries according to their waste water relevance, dated 27.11.1997 (1997)

4.1.6.4 Optimisation of chemical [use]-consumption

From ex-Section 4.1.1

Description
The techniques (organisational and technical measures) are applied to reduce the consumption of chemicals in the finishing processes. These include control of chemical consumption, low-liquid application technology, liquid removal and recovery techniques.
Chapter 4

Technical description

In general, the overall strategy for the minimisation/optimisation of the chemicals used should consider the following steps:

1. Where it is possible to achieve the desired process result without the use of chemicals, then avoid their use altogether.
2. Where this is not possible, adopt a risk-based approach to selecting chemicals and their utilisation mode in order to ensure the lowest overall risk.

That said, some of the chemical-saving techniques to consider possible measures of general applicability are as follows:

a) Reducing the need for process chemicals
   - Regularly revising the recipes in order to identify unnecessary chemicals (dyes, auxiliaries) so that they can be avoided.
   - Giving preference in the selection of auxiliaries and chemicals to products with a high degree of biodegradability/bioeliminability, low human and ecological toxicity, low volatility and low smell intensity (see Sections 4.3.1 and 4.3.2).
   - Optimising the process by improving the control of process parameters such as temperature, chemical feed, dwell times, moisture (for dryers), etc. (see Section 4.1.1.3).
   - Avoiding or reducing the use of chemicals to prevent side effects caused by the presence of impurities (e.g. complexing agents) in process waters by using high-quality water (e.g. water demineralised by ion exchange, membrane filtration or other techniques). (where needed) in wet processes in order to
   - Avoiding or minimising any kind of surplus of applied chemicals and auxiliaries (e.g. by automated dosing and dispensing of chemicals - see Section 4.1.6.6).
   - Optimising scheduling in production (e.g. in dyeing: dyeing dark shades after pale shades reduces water and chemical consumption for machine cleaning).

b) Low liquid application techniques
   - Giving preference to low add-on devices for chemicals (machine selection) such as transfer rollers (e.g. engraved, lick-, kiss-), pad transfer (padding), spraying and foam application for continuous processes.

c) Liquid removal techniques
   - Removing liquors (chemicals) from the textile substrate leaving the process bath by mechanical extraction (e.g. squeeze rollers, vacuum extractors, suction or blowing/ejection of liquid by compressed air) to recover chemicals (e.g. sizes, bleaching chemicals, finishing agents like fluorocarbons, resins, softeners, pigments) and reuse them in the process; (see also Sections 4.1.3.3 and 4.1.4.4).

d) Recovery techniques
   - Recovering and reusing mother baths (e.g. overestimated surplus amounts), leftover chemicals (e.g. from emptying pipes or package) whenever possible.
   - Recovering vapour during delivery of volatile substances.
   - Filling of tanks with volatile compounds using the following precautions:
     - Use of vapour balancing lines that transfer the displaced vapour from the container being filled to the one being emptied.
     - Bottom loading to avoid splashing (for larger tanks).

Achieved environmental benefits

The consumption of chemicals is reduced and therefore the pollutant load in the effluents, emissions to air and amounts of waste are reduced.

Environmental performance and operational data

For data on decreasing the amounts of leftover chemicals, reflecting precise planning and controlled consumption of chemicals, see Section 3.7.7.
Regarding low liquid application techniques, specifically spray dyeing, the liquor (bath) volumes as low as 90 liters (versus 10,000 - 50,000 liters of conventional slasher dyeing) are achieved for indigo dyes; and 45 liters (versus 1200 - 4000 liters by using conventional boxes) for sulphur dyes. [245, ROTASPRAY 2019] [133, Swedish EPA 2019]

Cross-media effects
Some techniques for reducing the consumption of chemicals require energy, so energy consumption may increase.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of these techniques.

Economics
In existing plants, investment in new equipment and infrastructural modifications (e.g. for the segregation of streams) is necessary.

Driving force for implementation
- Environmental legislation.
- Reduced consumption of chemicals.

Example plants

Reference literature
[27, Derden et al. 2010], [133, Swedish EPA 2019], [135, RICARDO 2019], [245, ROTASPRAY 2019]

4.1.6.4.1 Treatments with enzymes

Description
Enzymes are used to activate or catalyse the reactions with fibres in wet processing and lower the consumption of chemicals for those purposes.

Technical description
Enzymes are proteins that act as biocatalysts activating and accelerating chemical reactions. Their excellent substrate selectivity allows milder process conditions compared to conventional processing.

Various enzyme-based solutions have been developed for different textile pretreatment and finishing processes. Typical enzymes used in these processes are amylases, cellulases, catalases, laccases, lipases, pectinases and proteases for textile wet-processing applications like desizing, bio-polishing, denim finishing, bleach clean-up, scouring, anti-felting of wool and others. The application of cellulases for denim finishing and lactases for decolourisation of textile effluents and textile bleaching are the most recent commercial advances.

Similarly, esterases, lipases, and cutinases can replace sodium hydroxide in improving the softness and moisture absorption characteristics, as well as surface softness and reduced pilling of polyethylene terephthalate (PET) fabrics.
For more information on the application of enzymes in pretreatment processes see Section 4.4.2.

For more information on the application of enzymes in soaping after dyeing see Section 4.5.1.4, and for more information on the use of enzymes in softening (biopolishing) cotton see Section 4.7.3.2 and for enzymatic wool anti-felting see Section 6.4.1.

**Achieved environmental benefits**
- Reduced or even avoided use of hazardous and/or hardly biodegradable or bioleminable substances (chemicals).
- Reduced energy consumption (lower processing temperatures).
- Reduced water consumption (reduced number of rinsing steps).

**Environmental performance and operational data**
The process parameters change, depending on the process, substrate and enzymes used. The processing time and consumption of chemicals, water and energy for fabric treatment may be reduced. Enzyme treatments are sensitive to temperature, pH, humidity and contaminants.

**Cross-media effects**
Enzymes contribute to the organic load in the effluent. This means special attention may need to be paid to the operation of the biological waste water treatment plant to treat higher organic loads.

**Technical considerations relevant to applicability**
The use of enzymes in wet processing of textile fibre, fabric and products is limited by the ability to achieve the desired product specifications and their compatibility with other process steps – these treatments are not possible for various types of products and process steps.

**Economics**
No data available.

Apart from additional investments in the equipment that integrating enzyme-based technologies may require, the costs of enzymes can be substantial.

**Driving force for implementation**
- Reduced water, energy and chemicals consumption.
- Reduced waste water treatment.

**Example plants**
19 plants (CZ019, DE022, DE026, DE047, DE049, FR136, IT064, IT065, IT068, IT069, IT077, IT078, IT094, PT108, PT109, PT111, PT114, SE120 and UK127) report using enzymes for desizing (12 amylases).
8 plants (FR136, IT059, IT068, IT069, IT074, IT077, IT091, PT114 and SE120) report using enzymes for scouring of cotton (amylyases and cellulase).
6 plants (DE034, DE049, FR131, IT070, IT097 and PT108) report using enzymes bleeding (2 amylases, 2 catalase, 1 cellulase, 1 other).
3 plants (IT064, IT070 and IT078) report using enzymes for softening and other batch finishing treatment (cellulase and protease).

**Reference literature**
[135, RICARDO 2019], [122, Beton et al. 2014], [161, Saxena et al. 2017], [162, Cotton Incorporated 2009], [163, Cotton Incorporated 2018], [164, Novozymes 2019]

**4.1.6.5 Chemical handling and storage**

**From ex-Section 4.1.2**

**Description**
Techniques are applied to ensure safe storage and prevent leakage and spilling of chemicals during storage and handling. These include:

- optimised storage location of process chemicals to eliminate or minimise the unnecessary transport of process chemicals within the plant (e.g. the transport distances on site are minimised);
- tanks for liquids are located in a suitable secondary containment; its volume is sized to accommodate at least the complete loss of the liquid of the largest tank that is within the secondary containment
- containment of storage and handling areas;
- isolation of tanks and secondary containment (e.g. by closing valves);
- dedicated areas for unloading hazardous process chemicals;
- segregated storage of process chemicals (e.g. depending on their properties);
- the surfaces of the process and storage areas are impermeable to the liquids concerned;
- regular inspection and maintenance of plant and equipment to ensure proper functioning: this includes in particular checking the integrity and/or leak-free status of valves, pumps, pipes, tanks and containments/bunds and the proper functioning of warning systems (e.g. overflow detectors);
- prevention of spillage, leakage and overflows (e.g. by automatic level adjustment of process liquors, double walled tanks);
- segregated drainage system;
- appropriate training of the personnel.

**Technical description**

Each chemical should be stored according to the instructions (e.g. storage precautionary statements) given by the manufacturer in the Material Safety Data Sheet and in accordance with chemicals’ storage compatibility.

All areas where chemicals are stored or spillages are likely to occur should be bunded and it should be impossible for so that spillages do not enter soil, surface waters or sewers. Toxic and dangerous chemicals should be stored separately. More detail on these issues can be found in [192, COM 2006] the horizontal BREF on Storage (which was in preparation at the time of writing).

First aid facilities should be available and evacuation and emergency procedures in place and rehearsed regularly. Records of accidents and incidents (near misses) must be kept.

Transfer of chemicals from storage to machine is often prone to leakage or spillage. Pumps and pipework used for transfer must be regularly inspected (see equipment maintenance in Section 4.1.1.1) and provisions should be made to ensure the safety of manual transfer (including appropriate training of workers, use of buckets with leakproof lids, etc.). For handling and transfer of concentrates to dyeing machines, see also Section 4.7.7.1.

Accurate weighing, dispensing and mixing are fundamental for avoiding/minimising spillages in manual operation. However, an automated chemical dosing and dispensing system offers some important advantages over the manual method (better laboratory-to-dyehouse correlation; minimises the chance of worker injury when handling hazardous chemicals; faster delivery times, etc.). For more details see Section 4.1.6.6.

The training of the staff addresses in particular the understanding and use of the SDS, the preventive environmental and works safety practices, the practices to save chemicals, the regulatory requirements and the use of the chemicals inventory. [215, ZDHC 2015].

**Achieved environmental benefits**
The spillage, leakage (loss) and emissions of chemicals are reduced. Reduced emissions to soil and groundwater.
Environmental performance and operational data

To ensure appropriate storage, chemical segregation charts (see Figure 4.17 for an example from the German Technical Rule for Hazardous Substances TRGS 510 (2013)) are used together with information gathered from the corresponding Safety Data Sheets (SDS).

For example, hydrogen peroxide is stored separately in a dedicated catchment facility and sodium dithionite is stored in a separate dry room.

Source: Technical Rules for Hazardous Substances TRGS 510 in [212, HAZBREF 2019]

Figure 4.17: Storage class compatibility check used in Germany

The following table outlines exemplary measures (common good chemical management practices) for the proper storage and handling of chemical products:
Dedicated unloading area with precautionary measures in case of spillages for liquid bulk chemicals; typically acetic acid, NaOH, KOH, H₂O₂, urea, main surfactants; stormwater drain needs to be connected to the treatment plant.

Double-walled tanks with overfilling prevention and leakage detection for bulk chemicals (NaOH, KOH, H₂O₂, detergents, urea); for H₂O₂, explosion prevention is required (e.g. a safety relief valve and an over-roof pipe).
Single-walled tanks are placed in a catchment area with its volume adjusted to the volume of the tanks.

All IBCs, small tanks and drums are placed on appropriate catchment areas (secondary containments) that are able to contain the proportionate volume of all containers.

Source: [ 212, HAZBREF 2019 ] (Photos: Dr. Harald Schönberger)

Table 4.13: Measures for proper storage and handling of chemical products

**Cross-media effects**
None identified.

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of these techniques. The moving of the storage location may be restricted by the plant layout and space availability for existing plants.

**Economics**
There are no precise figures available for the different measures described. Potential savings arise from reduced risks of uncontrolled reactions and connected costs (losses, damage, insurance costs).
Driving force for implementation
- Environmental and chemical legislation.
- Reduced consumption of chemicals.

Example plants
All techniques are used by many plants from the data collection (e.g. prevention of overflows by 38, prevention of piping leakage by 31, strategic positioning of storage areas by 24, sealing of operational areas by 16, containment and/or bunding by 12).

Reference literature
[67, Benninger et al. 2016], [192, COM 2006], [212, HAZBREF 2019], [215, ZDHC 2015].

4.1.6.6 Handling and storage of packaging containing chemicals

Description
Packaging containing liquid process chemicals is completely emptied by gravity or by mechanical means (e.g. brushing, wiping) without the use of water. Packaging containing process chemicals in powder is emptied using suction. Empty packaging is stored in dedicated area.

Technical description
The packaging types used for textile finishing chemicals include: intermediary bulk containers (IBCs), big bags, 25 kg metal buckets (paste), containers (1000 l), metal recipients (50 kg), plastic or paper bags (up to 25 kg).

IBCs, buckets, containers and recipients
Packaging for chemicals like IBCs, buckets, containers and recipients for ready-to-use solutions, mixtures of active substances, aqueous dispersions or viscous paste is emptied without the use of water: by gravity and by scraping the inner surface when possible. The packaging is not rinsed.

Thereafter, the emptied packaging is stored in an appropriate manner in a dedicated storage area, until it is taken over by a qualified processing company or by the chemicals supplier.

Sacks and big bags
Sacks or big bags with chemicals in powder form are emptied under negative pressure. Thereafter, emptied sacks and big bags are stored in an appropriate manner, until they are taken over by a qualified processing company or by the chemicals supplier. Emptied sacks are packed in polyethylene sacks and sacks and big bags are stored in enclosed conditions.

Achieved environmental benefits
Reduction of water consumption and of generation of waste water.
Reduced emissions to soil and groundwater.

Environmental performance and operational data
Water consumption is limited by emptying the packaging materials without the use of water. This also limits the pollutant load of the waste water. If the chemical leftovers are recovered, the chemical consumption can also be limited. Emissions to air are avoided when sacks of powder-form chemicals are emptied under negative pressure. Emissions of chemicals into waste water and the soil can be prevented by storing chemicals packaging in an appropriate manner. The amount of waste is reduced when reusable packaging is returned to the chemicals supplier.

It is estimated that around 25 litres of chemicals are left behind per 1 000-litre IBC. The chemicals remaining in the packaging can be reduced to a fifth (5 litres) by placing the IBCs on a sloping surface.
Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
If packaging material for chemicals is emptied without the use of water, it is possible to make savings in the purchase of chemicals by recovering a certain quantity. The storage of chemical packaging in an appropriate manner is not accompanied by a cost increase or decrease. However, additional costs will be encountered when disposing of this packaging via a qualified processing company or via the chemicals supplier.

Some examples are given in [27, Derden et al. 2010]:

- The cost for a system where sacks are emptied under negative pressure amounts to approximately EUR 10,000. This price also includes the dust filter.
- The cost for a system where big bags are emptied amounts to EUR 5,000-6,000 (used in major companies).
- The cost for disposing of packaging material amounts to EUR 40 per IBC. This is the cost for rinsing the IBC and bringing the packaging onto the market via a tank cleaning company. However, there must only be maximum 5 l of leftover product in the to-be-cleaned IBC and penalties are paid for higher residue contents.

Driving force for implementation
Savings in chemical purchase.

Example plants
No information provided.

Request to TWG: please provide information about plants applying this technique.

Reference literature
[27, Derden et al. 2010]

4.1.6.7 Automatic systems preparation, dispensing and dosing of chemicals and dyestuffs

From ex-Section 4.1.3

Description
Automatic and semi-automatic weighing, dissolving, measuring and dispensing systems for precise delivery of textile chemicals and dyestuffs to the production machines.

Technical description
Tanks in storage facilities (storage vessels), dispensing units (for weighing, mixing and dissolving the chemicals) and machinery are connected by the pipework equipped with valves, pumps, sensors and meters (e.g. flowmeters, temperature, pressure, level, conductivity, weighting) enabling automated and computerised control and handling of solid and liquid chemicals (basic and auxiliary) and dyestuffs (dyes and printing pastes).

Gravimetric or volumetric distribution systems are used to serve the preparation ranges, pretreatment, dyeing, printing and finishing machines (ranges).
Systems are available for dispensing of chemicals and dyes as either aqueous solutions, powders or pastes. Plants can choose various levels of automation, from quantitative dispensing systems for preparation chemicals and/or dyes to simpler semi-automatic addition systems for manually prepared solutions.

The so-called just-in-time chemical and dyestuff preparation systems are employed in the following areas [67, Benninger et al. 2016]:

- preparation of enzymatic desizing solutions;
- preparation of bleaching and scouring liquors;
- ratio dosing for dyeing with reactive dyestuffs;
- preparation of resin finishing and finishing liquors.

Great improvements have been made in recent years in the automation of traditionally manual process steps, such as the preparation and dosing/dispensing of chemicals (as either aqueous solutions, powder or pastes) and even laboratory operations.

Automated colour kitchens and automated chemicals dosing and dispensing systems are now commonly applied in many companies in the textile industry. Microprocessor-controlled dosing systems meter chemicals automatically according to a variety of profiles, such as constant rate or variable rate.

In the case of highly concentrated padding liquors for pretreatment, dyeing and finishing (continuous and semi-continuous processes), it is of environmental relevance to prevent or to minimise excess liquors. Today, there are automated systems available for just-in-time preparations of liquors. With on-line measurement of the liquor pick-up and of the quantity of processed fabric, the exact amount of liquor can be prepared and added. Liquor surpluses and waste water pollution are therefore minimised.

Moreover, in modern dosing and dispensing systems, the water used for washing the preparation vessel and supply pipes is taken into account when the quantity of liquor to be prepared is calculated. This approach reduces waste water, but still involves premixing of chemicals. Other automated dosing systems are available where the chemicals are not premixed before being introduced into the applicator or dyeing machine. In this case, individual streams are used for each of the products. As a result, there is no need to clean the containers, pumps and pipes before the next step, saving even more chemicals, water and time. This is an important feature in continuous processing lines.

Figure 4.18 shows an example of an automated system for dispensing chemicals for the preparation of pretreatment and finishing liquors (without premixing of the chemicals). Similar devices can be used in semi-continuous (cold pad-batch - see the relevant described technique in Section 10.4.2) and continuous dyeing.

![Diagram of an automated system for dispensing chemicals](image-url)
Figure 4.18: Example of automated systems for dispensing chemicals

In addition to the improvements mentioned above, the most recent developments in dosing systems for carpets and bulky fabrics, although expensive, are still worth mentioning. Concerning carpets and bulky fabrics, the most advanced equipment allows on-line real-time preparation, dosing and application of each of the individual components. The most innovative machines and application systems work on the colour-on-demand principle. There is no longer any need to make measurements; the liquors are injected or applied digitally and quantitatively. As a result, there are no liquor residues at the end of the process.

Important improvements have also been made in laboratory operations. All laboratory operations needed in batch dyeing can now be carried out with fully automated systems with practically no need for manual intervention. These sophisticated systems have been successfully applied in some large dyehouses.

Main-Achieved environmental benefits

- Reduced consumption of chemicals and water.
- Reduced amounts of effluent and pollutant loads in emissions to water.
- Increased productivity (right-first-time performance).

Automation leads to a number of environmental benefits.

First of all, tighter control of the process allows for improved right-first-time performance, which means minimising corrective measures such as reworks, redyes, stripping and shade adjustment.

Secondly, automated systems with just-in-time preparation of liquors and separate dispensing of the different chemicals (i.e. no premixing) allow a significant reduction of waste water pollution and wasted chemicals thanks to the minimisation/avoidance of liquor residues that would otherwise need to be disposed of at the end of the process. This is particularly important in continuous and semi-continuous processing.

Another important issue to consider is a safer and healthier working environment. Eliminating human contact means no workers handling and breathing toxic and hazardous substances.

Environmental performance and operational data

Semi-automatic addition systems are more common, but automatic dispensing systems are used in larger and more modern plants, especially for batch dyeing of yarns and knits.

Coupled with on-line measurement of the liquor pick-up and of the quantity of processed fabric (see Section 4.1.1.3), the exact amount of liquor can be prepared and added. These systems improve the accuracy of material additions and the consistency of production, while reducing waste (surpluses) in dyes and chemicals.

Automation of dyes and chemical dispensing can significantly improve right-first-time performance, as well as lot-to-lot shade reproduction.

In automated systems with separate dispensing of the different chemicals, the resulting environmental benefits are particularly important where chemicals and auxiliaries are used in large amounts in the mill and in long continuous lines (where the dead volume in the distribution system is comparable with the volume in the padder). When the different chemicals are not mixed before the process they can be easily reused for the next run. Separate dispensing of each dye, although technically possible, is very expensive and advantageous only for trichromatic systems where a few dyes are used (maximum nine different dyes) and the volumes recovered are high enough to justify the investment.

Highly automated systems generally require qualified personnel, but usually one person can easily operate the system.

Automated systems for powders are highly sophisticated, especially when very small amounts have to be metered. High precision in dosing is fundamental, especially for powder dyes.
Modern automated dosing systems can dose amounts of powders as small as 0.8 g [289, Comm., 2002].

In Table 4.14 below, data from a textile dyehouse (size dyed textile capacity of 3 500 t/year) show the following improvements before and after the installation of an automated dosing and dispensing system for chemicals.

Table 4.14: Example of savings due to automatic dosing and dispensing system

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
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<tbody>
<tr>
<td>Seconds</td>
<td>1.6 %</td>
<td>0.9 % (43 % reduction)</td>
</tr>
<tr>
<td>Reworks</td>
<td>4.5 %</td>
<td>3.7 % (17 % reduction)</td>
</tr>
<tr>
<td>Chemicals reduced costs</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Labour reduced cost in the dyehouse</td>
<td>NA</td>
<td>10 %</td>
</tr>
<tr>
<td>Increased dye machine efficiency</td>
<td>NA</td>
<td>5 %</td>
</tr>
</tbody>
</table>

NB: NA: Not applicable.
Source: [118, Color Service 2002]

Another example comes from a well-known Italian manufacturer who, due to the installation of an automated dosing and dispensing system for dyes and auxiliaries, no longer needed a sampling operation on the batches and so was able to replace it with an extra daily batch on each machine [289, Comm., 2002] [118, Color Service 2002].

Automated laboratories can reduce reworking to 2-3 % of total production.

Cross-media effects
Compressed air, steam and electricity are needed for the operation of the system. If water used for cleaning of equipment and piping (needed for dosing and dispensing) is not reused, there is additional effluent to be treated.

There are no cross-media effects to be mentioned.

Technical considerations relevant to applicability
Typical automated dosing and dispensing techniques described in this section are applicable to both new and existing installations. However, an exception is made for highly sophisticated systems techniques such as dosing systems based on the colour-on-demand principle and automated laboratories, which are still very expensive and as a consequence more suitable for large installations.

According to information provided by equipment suppliers, the size and the age of the plant do not seem to represent a limitation to the applicability of automated dosing and dispensing systems in general. Examples are available of plants with production capacity ranging from 70 t/day to 5 t/day [289, Comm., 2002].

Space availability may represent an issue in existing companies, especially for the automation of dyes. Whereas liquid chemicals are easy to automate due to the limited number of chemicals used in the process, some companies may regard the high number of dyes as a limitation due to lack of space and the higher investment costs required.

Also, it is not uncommon to find dyehouses with many (e.g. > 150/200) different dyes for various reasons. However, in most cases it should be possible to use a maximum of 15 colours for each fibre, which means 90 dyes for 6 different types of fibre [289, Comm., 2002]. Usually the colourants it is not uncommon that those are used—more frequently used (highest consumption) are selected for automation. A typical situation is the one in which a company uses 60 colourants with a daily consumption of 5-6 kg and 20 colourants in amounts as low as
10 g/day. In such a situation, it is likely that the company will decide to automate the 60 dyes with higher consumption and leave the others for manual dosing and dispensing. Very often this choice encourages the company to give preference to dyes that are automated, gradually reducing the consumption of the other dyes.

For long-distance pipelines, the minimum quantities of liquor needed for the operation of the distribution system (e.g. filling volume of piping and pumps, the so-called dead volume) can exceed the volume of the liquor used in padders or batches (e.g. a 100 m textile good (patternning) requires 30 litres of liquor and the minimum quantity of the dosing/dispensing system is 60 litres), making it uneconomical and environmentally controversial for small batches (lots).

In automated systems with separate dispensing of the different chemicals, the resulting environmental benefits are particularly important where chemicals and auxiliaries are used in large amounts in the mill and in long continuous lines (where the dead volume in the distribution system is comparable with the volume in the padder). When the different chemicals are not mixed before the process they can be easily reused for the next run. Separate dispensing of each dye, although technically possible, is very expensive and advantageous only for trichromatic systems where a few dyes are used (maximum nine different dyes) and the volumes recovered are high enough to justify the investment.

**Economics**

The time for preparation and dispensing of chemicals and dyestuffs is short compared to the overall treatment time. Investment into preparing the treatment range, associated dispensing/distribution and dosing systems is therefore economically viable when larger numbers of machines are served. The cost/utilisation factor is weighted versus a higher quality of treatment (e.g. right-first-time) and productivity.

Investment costs for the automated dosing of liquid chemicals, depending on the number of machines to be served, liquors to be prepared and chemicals to be used, range from EUR 7 000 to EUR 250 000 [36, ÖKOPOL 2011].

Data from a recent study for small and medium enterprises are provided in the Table 4.15 below.

| Table 4.15: Cost and payback periods of automated preparation and dispensing of chemicals in dyeing plants |
|----------------------------------------------------------|----------------------------------------------------------|----------------------------------------------------------|
| **Automatic chemical dispensing system** | **Dye dissolution and distribution** | **Bulk powder dissolution and distribution** |
| USD 150 000-890 000 | USD 100 000-400 000 | USD 76 000-600 000 |
| 1.3-6.2 | 4-5.7 | 3.8-7.5 |

**Source**: [152, Hasanbeigi 2010]

Cost savings can be derived from a reduction of consumption of chemicals and water, increase of reproducibility and decrease in staff costs. Savings of up to 30 % have been reported by [26, UBA, 2001].

Liquid chemicals are the most commonly automated (first option in existing companies) for health and safety reasons, but also due to the relatively low investment needed (limited number of chemicals used in the process) [289, Comm., 2002] [118, Color Service 2002].

**Driving force for implementation**

The main driving forces for implementation are increased reproducibility and productivity along with health and safety requirements defined by legislation.
Example Reference plants
Commonly applied in textile installations (in 51 out of 105 plants from the data collection).

Plants with automated dosing and dispensing systems represent more than 60 % of the existing
dye and print houses in Europe. Automated systems for liquid chemicals are the most common
(70 % of the plants), whereas automated dosing and dispensing for powder dyes and auxiliaries
are present in 20 % of the European installations [289, Comm., 2002 ] [ 118, Color Service 2002 ].
Some examples of installations using automated systems for just in time preparation of liquors are
in Germany:
- Brennet AG, D-79704 Bad Säckingen
- Schmitz Werke GmbH + Co., D-48282 Emsdetten
- Görlitz Fleece GmbH, D-02829 Ebersbach
- Thorey Gera Textilveredelung GmbH, D-07551 Gera.

There are many examples of installations equipped with fully automated in Europe and
worldwide.
Reference literature
[ 26, UBA, 2001 ], [ 19, GuT, 2001 ], [76, ColorService, 2001 ], [289, Comm., 2002 ] [ 118, Color
Service 2002 ], [ 36, ÖKOPOL 2011 ], [ 67, Benninger et al. 2016 ], [ 152, Hasanbeigi 2010 ].

4.1.6.8 Substitution of hazardous substances
4.1.6.8.1 Substitution of alkylphenols and alkylphenol ethoxylates (and other
hazardous surfactants)

From ex-Section 4.3.3

Description
Surfactants that are biodegradable and bioeliminable are used in pretreatment, dyeing, printing
and finishing processes instead of alkylphenols and alkylphenol ethoxylates (AP/APEO).

Technical description
Many surfactants give rise to environmental concerns due to their poor biodegradability, their
toxicity (including that of their metabolites) and their potential to act as endocrine disrupters.

Concerns in the textile sector currently focus on alkylphenol ethoxylates (APEO) and in
particular on nonylphenol ethoxylates (NPE), which are often may be contained in the
formulations of detergents and many other auxiliaries (e.g. softeners, desizing, fixing, wetting
and dispersing agents, emulsifiers, spinning lubricants).

Alkylphenol ethoxylates are themselves believed to be endocrine disruptors and to cause
feminisation of male fish, with a known oestrogenic effect More importantly, however, they
produce metabolites which are believed to be many times more potent as endocrine disruptors
than the parent compounds. The most potent of these are octyl- and nonylphenol. [ 214, Acir et
al. 2018 ]

Nonylphenol is listed as a priority hazardous substance under OSPAR and the EC Water
Framework Directive, which means that any discharge needs to be phased out. Nonylphenol
(NP) and nonylphenol ethoxylates (NPE) are subject to restriction (Annex XVII entries 46 and
46a) under the REACH Regulation [ 79, EU 2006 ]. Their use on textiles and as substances or in
mixtures in concentrations equal to or greater than 0.1 % by weight of the textile article or
mixture is banned.

Legal restrictions for biodegradation of surfactants in detergents are imposed by Regulation
(EC) No 648/2004 on Detergents. The Regulation introduced stricter rules, allowing only the
use of such surfactants in the detergents, which are readily biodegradable (Article 4). Annex VIII to the Regulation defines the test and analytical methods to determine the biodegradability of surfactants [ 155, EU 2004 ].

Alkylphenol ethoxylates may be present in auxiliaries formulations as the main active substances or in small percentages as additives. In both cases substitutes are available. The main alternatives to NPE are (mostly linear) alcohol ethoxylates (AEs). The properties of these non-ionic surfactants can be adjusted by the alcohol selection and by the length of the hydrophilic polyethylene glycol chain. The properties of AEs are affected by the length and the structure of the alkyl chain and the length of the polyoxyethylene chain. The challenge of replacing NPEs with AEs is to balance their good wetting and detergent properties, with sometimes inferior emulsifying and dispersion properties, which are additionally needed in most applications. Selection of appropriate AEs is therefore often a compromise, and not a straight replacement of NPE.

The most effective are AE mixtures comprising AEs of different alkyl chain lengths and single cut alcohols (from C6 to C22). [ 154, Sasol 2019 ].

A recent study [ 210, US EPA 2012 ] has identified the following substances as possible alternatives to be used as detergents:

- C9-11 alcohols, ethoxylated (6 EO);
- C12-15 alcohols, ethoxylated (9EO);
- oxirane, methyl-, polymer with oxirane, mono(2-ethylhexyl ether); Ecosurf EH-9;
- D-glucopyranose, oligomeric, decyl octyl glycosides;
- benzenesulphonic acid, C10-13-alkyl derivatives, sodium salt;
- Sodium lauryl sulphate;
- poloxy(1,2-ethanediyl), alpha-sulfo-omegadecyloxy-, sodium salt;
- sorbitan monostearate.

Their suitability for specific textile treatment needs is unclear. Any chosen alternative obviously needs to be compliant with the regulatory provisions as well as any brand-specific restrictions.

but Other readily biodegradable surfactants have also been developed.

As to other problematic surfactants, substitutes are often available that are readily biodegradable or bioeliminable in the waste water treatment plant and that do not form toxic metabolites.

Tests for biodegradability and bioeliminability are listed in [ 228, ISO 2006 ] and include inter alia the Zahn-Wellens test (ISO-EN 9888:1999 comparable to OECD guideline 302 B). More details on biodegradability are provided in Regulation (EC) No 648/2004 on Detergents.

Substances are considered readily biodegradable if in a 28-day period, with ready biodegradation studies (OECD 301 A-F), the following levels of degradation are achieved:

- for tests based on dissolved organic carbon (e.g. OECD tests 301 A, 301 E): ≥70 % DOC reduction or
- for tests based on oxygen depletion or carbon dioxide generation (e.g. OECD test 301 B): ≥60 % (of theoretical maxima).

Substances are considered bioeliminable if the following levels of degradation are achieved:

- OECD test 302 B DOC reduction ≥70 % in 28 days or
- OECD test 302 B, DOC reduction ≥80 % in 7 days, if an adapted “inoculum” is used in the treatment plant where the substance is treated.

The finisher should be able to may select the less hazardous products based on the information reported by the manufacturer in the Material Safety Data Sheets.
More information on surfactants can be found in Section 8.1.

**Achieved environmental benefits**

The use of APEO-free auxiliaries produces a reduction of the amount of potentially toxic endocrine disrupters in the receiving toxicity of waste waters. Moreover, the substitution of non-bioeliminable surfactants will result in improved treatability and biodegradability of the effluent is improved.

**Environmental performance and operational data**

Sites using exclusively APEO-free auxiliaries report no operational or processing difficulties [51, ENco, 2001].

For the substitution of APEO in detergents, the substituting new washing formulations are reported to be applied in concentrations similar to the conventional ones [43, Spain, 2001].

According to other sources (e.g. [49, INTERLAINE, 1999]), AE are slightly less effective detergents than APEO, which means that higher concentrations and feed rates may be required for equivalent effects. Investigations carried out in the wool scouring sector showed that mills using alkyl phenol ethoxylates used an average of 7.6 g detergent per kg of greasy wool (range 4.5-15.8 g/kg), while the users of alcohol ethoxylates consumed an average of 10.9 g detergent per kg of greasy wool (range 3.5-20 g/kg).

**Cross-media effects**

None identified.

- There are no adverse environmental effects to be mentioned.

The possibility of foaming in rivers exists in cases where sufficient amounts of surfactant pass through sewage treatment works unchanged or as partial metabolites with residual surfactant properties. The formation of foam is, however, typical of many other surfactants, including APEO.

**Technical considerations relevant to applicability**

This technique measure is generally applicable in all new and existing wet processing installations. However, as long as ‘hard’ surfactants containing APEO are used in fibre and yarn preparation agents, a large fraction of potentially hazardous surfactants in wet-processing effluents cannot be controlled by the textile finisher dyehouse.

For APEO, it should be noted that these surfactants also have many dry applications (e.g. as dry spinning lubricants, in the production of viscose for technical uses). In these cases substitution is possible, but it is expensive and it is not a priority. Indeed, here the presence of APEO can be regarded as a less critical problem since the surfactant does not enter the wet processing line.

**Economics**

The costs of AE are 20—25% more expensive than comparable to those of APEO. The fact that they appear to be less effective (in certain uses) can further increase the operating costs over those of APEO, since higher concentrations (amounts) of AE may be needed to achieve the desired effect. However, mills making the change from APEO to AE are more likely to take care to optimise their use [49, INTERLAINE, 1999].

An example is given for a UK scouring mill which made the substitution in 1996. Annual costs for detergent use were estimated to have increased from EUR 84700 to EUR 103600: an increase equivalent to about EUR 1.09 per tonne of wool processed. In the past few years the cost of APEO has been reduced significantly from EUR 1000/tonne (1997/98) to EUR 700/tonne (1999). As a result the increase in costs involved with the use of AE could be even higher [187, INTERLAINE, 1999].

Generally speaking, costs of environmentally optimised formulations are comparable, but in some cases can be significantly higher than conventional products. However, usually the finisher tends to accept the extra costs associated with the use of more environmentally friendly products, especially when the overall environmental balance is considered [179, UBA, 2001].
Driving force for implementation
The enforcement of regulations at national and European level, together with the PARCOM recommendations and the eco-labelling schemes, are the main driving forces. Chemical legislation (REACH).

Reference Example plants
Many plants throughout the world,
A total of 29 plants reported the using APEO-free surfactants (e.g. linear AEs).

Reference literature

4.1.6.8.2 Substitution Selection of phosphorus or nitrogen-containing biodegradable/bioeliminable complexing agents in pretreatment and dyeing processes

From ex-Section 4.3.4

Description
Complexing agents containing phosphorous (e.g. tripolyphosphate) or nitrogen (e.g. polycarboxylic acids such as EDTA, DTPA or NTA) used in the wet processes (e.g. pretreatment, dyeing and finishing) are substituted by biodegradable substances e.g:
• polycarboxylates (e.g. polyacrylates and copolymers of acrylic and maleic acids);
• hydroxy carboxylic acids (e.g. gluconates, citrates);
• sugar-based acrylic acid copolymers.

Technical description
Complexing agents are applied as sequestering agents to mask hardening alkaline-earth cations and transition-metal ions in aqueous solutions in order to eliminate their damaging effect, especially in pretreatment processes (e.g. catalytic destruction of hydrogen peroxide), but also during dyeing operations.

Typical sequestering agents are polyphosphates (e.g. tripolyphosphate), phosphonates (e.g. 1-hydroxyethane 1,1-diphosphonic acid) hydrocarboxylic and amino carboxylic acids (e.g. EDTA, DTPA, and NTA) (see Figure 4.19 below).
The main concerns associated with the use of these substances arise from their N and P content, their often low biodegradability and bioeliminability, their toxicity and their ability to form stable complexes with metals, which may lead to remobilisation of heavy metals (see also Section 8.5).

Softening of fresh water, to remove the iron and the hardening alkaline-earth cations from the process water, and the techniques described in Section 4.4.7.2 are available options for minimising or avoiding the use of complexing agents in various applications (e.g. in hydrogen peroxide bleaching, rinsing after reactive dyeing of cotton).

When complexing agents are used, polycarboxylates or substituted polycarboxylic acids (e.g. polyacrylates and polyacrylate-maleic acid copolymerisates), hydroxy carboxylic acids (e.g. gluconates, citrates) and some sugar-acrylic acid copolymers are convenient alternatives to the conventional sequestering agents. None of these products contain N or P in their molecular structure (see Figure 4.20). In addition, the hydroxy carboxylic acids and sugar-acrylic acid copolymers are readily biodegradable.
The best complexing agent (in a technical, economical and ecological sense) is one that also achieves a good balance of ecological properties and effectiveness and has no detrimental effect on dyeing (demetalisation of dyes).

Effectiveness is measured as the capacity to complex alkaline-earth cations, the dispersing capacity and the capacity of stabilising hydrogen peroxide.

On the ecological side, the following factors are to be considered:

- biodegradability;
- bioeliminability;
- remobilisation of heavy metals;
- nitrogen content (eutrophication potential);
- phosphorus content (eutrophication potential).

A qualitative assessment of the ecological properties of most common classes of complexing agents is given in Table 4.16, while Table 4.17 gives an analysis of the aspects related to their effectiveness.

### Table 4.16: Qualitative assessment of commercially available complexing agents

<table>
<thead>
<tr>
<th>Ecological property</th>
<th>EDTA, DTPA</th>
<th>NTA</th>
<th>Polyphosphate</th>
<th>Phosphonates</th>
<th>Poly-carboxylates</th>
<th>Hydroxy carboxylic acid</th>
<th>Sugar copolymers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodegradability</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bioeliminability</td>
<td>No</td>
<td>Yes</td>
<td>NI</td>
<td>Yes (1)</td>
<td>Yes</td>
<td>NIL</td>
<td>NIL</td>
</tr>
<tr>
<td>N-content</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>P-content</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Remobilisation of heavy metals</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

(1) Under UV photocatalytic degradation is observed.

### Achieved environmental benefits

The substitution of conventional complexing agents with the product mentioned above has the following positive effects:

- reduced eutrophication in the receiving water;
- improved biodegradability of the final effluent;
- reduced risk of remobilisation of the heavy metals from sediments.

### Environmental performance and operational data

Complexing agents are applied in many different fields in textile chemistry. Recipes and application techniques are therefore process-specific. However, the use of the optimised products mentioned above does not imply major differences with respect to conventional complexing agents.

Bioelimination and biodegradation rates for some commercial products that do not contain P and N in their molecular structure are:

- sugar-acrylic acid copolymer: readily biodegradable, (OECD 301 F, mineralisation: 100%; COD: 194 mg/g; BOD₅: 40 mg/g); ("CHT, 2000")
- sugar acrylic acid copolymer: readily biodegradable (OECD 301C; COD: 149 mg/g); ("Stockhausen, 2000")
- hydroxy carboxylic acid: bioeliminable (OECD 302 B, elimination: 92%; COD: 144 mg/g; BOD₅: 51 mg/g) (“CHT, 2000”)
- carboxylates: bioeliminable (OECD 302B, elimination > 90%; COD: 280 mg/g; BOD₅: 125 mg/g) (“Petry, 1998”)
- modified polysaccharide: readily biodegradable (OECD 301E, biodegradability: 80%; COD: 342 mg/g; BOD₅: 134 mg/g) (“Clariant, 2000”).

NTA is biodegradable when treated in waste water treatment plants under nitrifying conditions (OECD 302B, elimination 98% COD: 370 mg/g; BOD₅: 270 mg/g – “BASF, 2000”). Recent studies have shown that NTA plays a minor role, if any, in the remobilisation of heavy metals in aquatic sediments [62, Germany, 2002]. Phosphonates are not biodegradable, but they are bioeliminable and they do not contribute to the remobilisation of heavy metals (see also Section 8.5).

The effectiveness of the various products in different processes has, however, to be considered when replacing conventional complexing agents by more environmentally friendly ones (see table below).

### Table 4.17: Effectiveness of complexing agents

<table>
<thead>
<tr>
<th>Property</th>
<th>EDTA, DTPA</th>
<th>NTA</th>
<th>Poly-phosphate</th>
<th>Phosphonates</th>
<th>Poly-carboxylates</th>
<th>Hydroxy carboxylic acid</th>
<th>Sugar copolymers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softening</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Dispersing</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Stabilisation of peroxide</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>++</td>
<td>0</td>
<td>-</td>
<td>+ (special products)</td>
</tr>
<tr>
<td>Demineralisation</td>
<td>++</td>
<td>+</td>
<td>0</td>
<td>++</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

NB: Effectiveness increases in the following order -, 0, +; ++.

Source: [26, UBA 2001]

### Cross-media effects

Taking as a reference the application of conventional complexing agents, there are no cross-media effects of concern. With polyacrylate-based complexing agents, the residual monomer content in the polymer should be taken into account (note that acrylates are also widely used in large volumes in other sectors as detergent builders, thus overloading the waste water treatment plants more significantly than textile effluents do).

### Technical considerations relevant to applicability

The complexing agents described in this section can be used in continuous and discontinuous processes.

The applicability may be restricted by the product requirements.

### Economics

Costs for N- or P-free compounds, especially for sugar-acrylic copolymers, are comparable to other N- and P-free products, although higher quantities may be necessary in some cases, [26, UBA 2001].

Costs for sugar-acrylic copolymers are about 30-50% higher than using amino carboxylic acids like EDTA, DTPA or NTA because of the higher quantities needed (for the same effect) and higher costs. [36, ÖKOPOL 2011]

### Driving force for implementation

The enforcement of regulations at national and European level, together with the PARCOM recommendations and the ecolabelling schemes, are the main driving forces.

### Reference/Example plants
N- and P-free complexing agents are applied in many plants worldwide. Consumption of polycarboxylates is significantly higher than for sugar-acrylic copolymers and hydrocarboxylic acids [26, UBA 2001].

Plant SE119 reported using saccharides instead of EDTA and UK127 uses NTA-free complexing products.

Reference literature
[46, L. Bettens, 1999], [48, European Commission, 2001], [26, UBA 2001], [36, ÖKOPOL 2011] with reference to:

“CHT, 1999”
Chemische Fabrik Tübingen, D-Tübingen
Material Safety Data Sheet (1999)

“CHT, 2000”
Chemische Fabrik Tübingen, D-Tübingen
Product information (1999)

“Clariant, 2001”
Clariant, D-Lörrach
Material Safety Data Sheet (2001)

“Stockhausen, 2000”
Stockhausen, D-Krefeld
Material Safety Data Sheet (2000)

“Petry, 1998”
Dr. Petry, D-Reutlingen
Material Safety Data Sheet (1998)

4.1.6.8.3 Substitution Selection of mineral oil-based antifoaming agents with improved environmental performance

From ex-Section 4.3.5

Description
Mineral oil-based antifoaming agents used in wet processes (e.g. pretreatment, dyeing and finishing) are substituted by biodegradable substances e.g. silicone-based antifoaming agents.

Technical description
Excessive foaming causes uneven dyeing of yarn or fabric. There is a trend towards higher consumption of antifoaming agents because of the growing preference for high-speed and high-temperature processing, reduction in water usage and the use of continuous equipment/processes. Due to the increasing usage of dosing systems, more pumps and feeding pipes are used, which in turn increases the foam formation by shear forces and high flow rates. Antifoaming agents are commonly applied in pretreatment, dyeing (especially when dyeing in jet machines) and finishing operations, but also in printing pastes. Low foaming characteristics are particularly important in jet dyeing, where agitation is severe.

Antifoaming agents (also called ‘defoamers’) are used in the processes where liquors, formulations or chemicals are handled under high pressure or high velocities. An example of this is dyeing with jet machines, where agitation is severe. Furthermore, foam formation for the most part does not occur in the bath, but during the spraying of liquor on the fabric with air, through the nozzles in the head of the jet machines. If foam formation is not prevented in this (e.g. 8...
Products that are insoluble in water and have a low surface tension are suitable for providing an antifoaming effect. They displace foam-producing surfactants from the air/water boundary layer. Nevertheless, antifoaming agents contribute to the organic load of the final effluent. Their consumption should therefore be reduced in the first place. Possible measures in this respect are:

- using bath-less air-jets, where the liquor is not agitated by fabric rotation (see Section 4.5.1.6.2.1);
- reusing treated baths (see Section 4.5.1.7).

However, these techniques are not always applicable and cannot completely avoid the use of antifoaming agents. Therefore the selection of auxiliaries with an improved ecological performance is important. Antifoaming agents are often based on mineral oils (hydrocarbons). The presence of PAH contaminants must also be taken into account when poorly refined oils are present in the formulation.

Environmentally improved products are free of mineral oils and are characterised by high bioelimination rates.

Typical active ingredients of alternative products are silicones (e.g. silicone glycol copolymers like polydimethylsiloxane (PDMS)), phosphoric acid esters (especially tributylphosphates), high molecular alcohols, fluorne derivatives, and mixtures of these components.

**Main-Achieved environmental benefits**

Thanks to the use of mineral oil-free antifoaming agents the hydrocarbon load in the effluent, which is often limited in national or regional regulations, is minimised. Furthermore, these alternative antifoaming agents have a lower specific COD and higher bioelimination rate than hydrocarbons. For example, a product based on triglycerides of fatty acid and fatty alcohol ethoxylates (COD: 1 245 mg/l; BOD₅: 840 mg/l) has a degree of bioeliminability higher than 90 % (determined in the modified Zahn-Wellens Test, according to OECD 302 B Test method or EN 29888, respectively) [26, UBA, 2001].

For emissions to air, due to the substitution of mineral oil-based compounds, it is possible to reduce VOC emissions during high-temperature processes (caused by the carry-over of antifoaming agents on the fabric after wet operations).

**Environmental performance and operational data**

The mineral oil-free antifoaming agents can be used in a way similar to conventional products. Because silicone products are highly effective, the required amount can be considerably reduced.

The treatment of the effluents containing silicones requires additional abiotic pretreatment (i.e. prior to biological treatment).

If antifoaming agents based on silicones are used there is a risk of silicone spots on the textile and silicone precipitates in the machinery [26 UBA, 2001]. Thin films are formed on the tank walls which cannot be removed by 'normal' rinsing leading to spots in downstream processes. Furthermore, problems occur in practice in the wetting behaviour in downstream processes by using antifoaming agents based on silicones [36, ÖKOPOL 2011].

**Cross-media effects**

Account must be taken that:

- Antifoaming agents contribute to the organic load of the final effluent; therefore, their consumption should be reduced.
- silicones are eliminated only by abiotic processes in waste water. Furthermore, above certain concentrations, Effluents containing silicone oils (silicones) above certain concentrations may hinder the efficiency of biological waste water treatment (e.g. lowering the transfer/diffusion of oxygen into the activated sludge).
• Odour emissions (e.g. from using tributylphosphates are odour intensive and strongly irritant and high molecular-weight alcohols are odour intensive and cannot be used in hot liquors.)

Technical considerations relevant to applicability
There are no particular limitations concerning the application of mineral oil-free formulations. However, the effectiveness of the various alternative products has to be borne in mind [26, UBA, 2001]. The applicability may be restricted by the product requirements. Restrictions in the use of silicones in some sectors have to be considered. For example, in the automotive industry restrictions have been put in place which forbid the use of silicones in automobiles and textiles for this industry.

Economics
The cost of mineral oil-free products is comparable to the cost of conventional ones [26, UBA, 2001].

Driving force for implementation
Minimisation of hydrocarbons in the effluent is the main reason for substituting mineral oil-containing antifoaming agents.

Reference Example plants
Many plants in Europe. There are various suppliers for antifoaming agents free of mineral oils. Plants IT064, IT 068, IT069, IT077 and IT091 report using silicone antifoaming agents instead of antifoaming agents with mineral oils.

Reference literature
[26, UBA, 2001], [36, ÖKOPOL 2011]. with reference to:

“Dobbelstein, 1995”
Optimierung von Textilhilfsmitteln aus ökologischer Sicht. Möglichkeiten und Grenzen
Nordic Dyeing and Finishing Conference 20.05.1995, F-Hämeenlinna

“Petry, 1999”
Dr. Petry GmbH, D-Reutlingen
Material Safety Data Sheet

4.1.7 Prevention and reduction of emissions to water
This section contains techniques used in the textiles sector to prevent, reduce or control the emissions to water.

This section only covers those techniques most relevant to the textiles sector. These techniques have already been described and analysed in the CWW BREF [24, COM 2016]. For this reason, it is not intended in this section to provide a complete analysis of each of the different techniques. Instead, only a short description of the techniques is given as well as examples of plants from the data collection where these techniques are applied.

4.1.7.1 Waste water management and treatment strategy
Description
Integrated waste water management and treatment strategy that includes an appropriate combination of process-integrated techniques, techniques to recover and reuse process liquors and treatment techniques is implemented.
Technical description
The strategy for waste water management and treatment is based on the information provided by the inventory of waste water streams (see Section 4.1.1.2). The effluents from textile processes are characterised and the pollutants present in them are evaluated.

Based on this information the appropriate treatment options are selected. Usually the goal is to find a cost-effective combination of treatment methods offering an optimum environmental performance. Special pretreatment may be needed to remove the compounds that are insufficiently abated during biological treatment (e.g. toxic compounds, hardly or non-biodegradable and/or bioelminable organic compounds, organic compounds that are present in high concentrations, or metals) and to protect the biological waste water treatment plant (e.g. against inhibitory or toxic compounds).

An appropriate choice normally requires treatability and/or pilot studies. Many ‘local’ factors, varying from site to site, may influence the selection: e.g. plant location, size and layout of the processes, type of discharge (direct, indirect), quality of the receiving water body, limitations and constraints on an installation imposed by other legislation.

Source reduction options and/or special pretreatment considered for hazardous and hardly or non-biodegradable and/or non-bioelminable substances present in the effluents (waste water streams) will be selected by considering the options for:

- reduction at the source (e.g. by use of process-integrated techniques, choice of raw materials, auxiliary chemicals, etc.);
- collection (drainage) system (e.g. suitable for segregation and separate pretreatment of different tributary waste water streams);
- treatment methods (e.g. suited to abate a specific pollutant or generic, suitable for abatement of many pollutants).

Examples of effluents from textile treatments which may need to be pretreated include [27, Derden et al. 2010]:

- Washing water from yarns and/or textiles when preparing dyeing processes.
- Rinsing water from washed, dyed and/or printed textile materials.
- Residues of (concentrated) process baths (e.g. residual baths and residual pastes from dyeing, printing and finishing, responsible for 1-2% of the total waste water volume). These may also be handled as hazardous liquid wastes, see Section 4.1.7.2).
- Exhausted process baths in discontinuous process (dyeing).
- Rinsing water from cleaning the process baths (e.g. rinsing water from dye baths, responsible for 1-2% of the total waste water volume).

Descriptions of individual treatment techniques are given in Section 4.1.7.3 and examples of typical configurations or combinations of these techniques used for waste water treatment in textile plants are given in Section 4.1.7.2.

Achieved environmental benefits
Reduction of waste water volume.
Reduced pollutant loads sent to waste water treatment plant.
Reduction of emissions to water.

Environmental performance and operational data
Physico-chemical treatments are commonly used before biological treatment in textile plants (see Section 3.4 for textile plants from the data collection) to ensure appropriate abatement levels.

In the case of indirect discharge, it is ensured that the level of emission of the remaining pollutants in the effluent leaving the textile plant does not have a negative impact on the
downstream WWTP or on the efficiency of this downstream installation at treating those remaining pollutants.

The following table summarises data on the applicability/efficiency of certain waste water treatment techniques to remove certain pollutants of concern from textile effluents.

Table 4.18: Overview of applicable waste water purification techniques for the removal of NP/NPE, PAH, deca-BDE and/or HBCD, Sb$_2$O$_3$, and PFOS and/or PFOA

<table>
<thead>
<tr>
<th>Waste water treatment technique</th>
<th>Parameter/pollutant</th>
<th>NP/NPE</th>
<th>PAH</th>
<th>Deca-BDE/HBCD</th>
<th>Sb$_2$O$_3$</th>
<th>PFOS/PFOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic treatment</td>
<td></td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Biological (active sludge)</td>
<td></td>
<td>0</td>
<td>x</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Active carbon dosage in biological treatment (PACT)</td>
<td></td>
<td>(x)</td>
<td>x</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Membrane bioreactor (MBR)</td>
<td></td>
<td>ND</td>
<td>(x)</td>
<td>x</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Chemical precipitation (with coagulation-flocculation)</td>
<td></td>
<td>ND</td>
<td>x</td>
<td>x</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Microfiltration, ultrafiltration</td>
<td></td>
<td>ND</td>
<td>x</td>
<td>(x)</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Nanofiltration, reverse osmosis</td>
<td></td>
<td>(x)</td>
<td>x</td>
<td>(x)</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Sand filtration</td>
<td></td>
<td>ND</td>
<td>x</td>
<td>x</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Adsorption (e.g. active carbon filtration)</td>
<td></td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Chemical oxidation</td>
<td></td>
<td>(x)</td>
<td>x</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Ozonisation</td>
<td></td>
<td>ND</td>
<td>(x)</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Evaporation</td>
<td></td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Incineration</td>
<td></td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

NB:
- x: Parameter (group) removed.
- (x): Parameter (group) possibly / potentially partly removed.
- 0: Parameter (group) not removed.
- ND: No data.

Source: [27, Derden et al. 2010]

Typical environmental performance of the plants using appropriate combination of waste water treatment techniques is given in the following Table 4.18.
Table 4.19: Overview of the environmental performance (emission concentration ranges for direct discharge) achieved with appropriate combination of waste water treatment techniques

<table>
<thead>
<tr>
<th>Substance/Parameter</th>
<th>Activities / processes</th>
<th>Concentration range (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adsorbable organically bound halogens (AOX) ((\cdot))</td>
<td>All activities / processes</td>
<td>0.1–0.5</td>
</tr>
<tr>
<td>Chemical oxygen demand (COD) ((\cdot))</td>
<td>Pre-treatment and/or dyeing of polyester</td>
<td>40–120 ((\cdot))</td>
</tr>
<tr>
<td>Hydrocarbon oil index (HOI)</td>
<td>Finishing with flame retardants using antimony trioxide</td>
<td>1–10</td>
</tr>
<tr>
<td>Metals / metalloids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antimony (Sb)</td>
<td>Pre-treatment and/or dyeing of polyester</td>
<td>0.1–0.4</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>Dyeing with chromium-containing dyes</td>
<td>0.01–0.3</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>All activities / processes</td>
<td>0.03–0.4</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td></td>
<td>0.01–0.5</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td></td>
<td>0.04–0.5</td>
</tr>
<tr>
<td>Sulphide, easily released (S(^2)-)</td>
<td>Dyeing with sulphur dyes</td>
<td>0.3–1</td>
</tr>
<tr>
<td>Total nitrogen (TN)</td>
<td></td>
<td>5–20 ((\cdot))</td>
</tr>
<tr>
<td>Total organic carbon (TOC) ((\cdot))</td>
<td></td>
<td>13–40</td>
</tr>
<tr>
<td>Total phosphorus (TP)</td>
<td>All activities / processes</td>
<td>0.4–5</td>
</tr>
<tr>
<td>Total suspended solids (TSS)</td>
<td></td>
<td>5–45</td>
</tr>
</tbody>
</table>

**Cross-media effects**
See the CWW BREF [24, COM 2016].

**Technical considerations relevant to applicability**
See the CWW BREF [24, COM 2016].

**Economics**
See the CWW BREF [24, COM 2016].

**Driving force for implementation**
- Environmental legislation (reducing and effectively abating the pollutant load).
- Economics (savings due to lower discharge fees).

**Example plants**
Many textile plants treat waste waters with physico-chemical treatment before biological treatment.

**Reference literature**
[24, COM 2016], [27, Derden et al. 2010]

### 4.1.7.2 Pretreatment of waste waters containing poorly biodegradable compounds

**Description**
Waste water streams containing high loads of toxic and/or hardly or non-biodegradable and/or bioeliminable compounds (e.g. spent process baths and rinsing waters) are pretreated before discharging.
Technical description
The treatment is carried out as part of an integrated waste water management and treatment strategy (see Section 4.1.7.1) and is generally necessary to:

- protect the biological waste water treatment against inhibitory or toxic compounds;
- remove compounds that are insufficiently abated during biological waste water treatment (e.g. toxic compounds, poorly biodegradable organic compounds, organic compounds that are present in high concentrations, or metals);
- remove compounds that could otherwise be stripped to air from the collection system or during biological waste water treatment (e.g. sulphide);
- remove compounds that have other negative effects (e.g. corrosion of equipment; unwanted reaction with other substances; contamination of waste water sludge).

Spent padding dyeing liquors, spent printing pastes and spent padding finishing liquors with high pollutant loads are collected separately and pretreated or disposed as waste. While in the case of residual printing pastes this is easy to achieve, separating residual padding liquors from dyeing and finishing requires additional efforts as the residual padding liquor has to be pumped from the padder to an intermediate bulk container (IBC) or another type of appropriate container. This can either be done automatically by controlling valves or manually by pumping residues out of the padder and the padding liquor preparation tank.

The various treatment options are indicated in Table 4.20.

Table 4.20: Technical options for treatment and disposal of spent padding liquors and printing pastes

<table>
<thead>
<tr>
<th>Type of residue</th>
<th>Technical options for treatment and/or disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual dyeing padding liquor</td>
<td>The residual dyeing padding liquor is oxidised (at least to fragments which are biodegradable) by means of a wet oxidation process (see Section 4.1.7.4.1). This is possible for all relevant groups of dyestuffs such as reactive, direct, vat, sulphur and disperse dyestuffs.</td>
</tr>
<tr>
<td></td>
<td>In the case of reactive dyestuffs, the dyestuffs can be precipitated/flocculated by means of an organic cationic flocculant. The sludge formed is separated by dewatering (e.g. in a chamber filter press) and disposed of by incineration.</td>
</tr>
<tr>
<td></td>
<td>In the case of sulphur dyestuffs in their oxidised form as well as in case of vat dyestuffs, the dyestuffs can be separated by precipitation/flocculation by means of a combination of inorganic precipitating agents (iron or aluminium salts) and a polyelectrolyte. The sludge is separated by dewatering (e.g. in a chamber filter press) and disposed of by incineration.</td>
</tr>
<tr>
<td>Residual printing paste</td>
<td>In the case of pigment printing paste, inorganic precipitating agents can be used. The sludge formed is separated by dewatering (e.g. in a chamber filter press) and disposed of by incineration. The residual pigment printing paste may also be incinerated directly.</td>
</tr>
<tr>
<td></td>
<td>Residual paste containing reactive dyestuffs can be fed to an anaerobic digester as most (but not all) reactive dyestuffs are azo dyestuffs, which can be cleaved in anaerobic conditions. However, the resulting aromatic amines are non-biodegradable and may therefore ultimately end up in the environment. (See Section 4.1.7.4.5.)</td>
</tr>
<tr>
<td>Residual finishing padding liquor</td>
<td>There are many different chemical compounds used and each has its individual chemical properties. In general, it is best to directly incinerate the residual final finishing padding liquors unless the compounds exclusively consist of readily biodegradable compounds such as fatty acid esters applied as softeners.</td>
</tr>
</tbody>
</table>

Source: [212, HAZBREF 2019]
Achieved environmental benefits
Reduction of the load of non-biodegradable compounds in the disposed waste water.
Reduced emissions to water.

Environmental performance and operational data
Figure 4.21 and Figure 4.22 show two examples of collection of spent padding liquor.

Figure 4.21: Example 1 - Padder (left) and IBC (right) equipped with a pump and pipes to manually empty the padder

Figure 4.22: Example 2 - Automated system for the collection of spent padding liquor (left) and IBC receiving the spent padding liquor (right)

The waste water load is limited and the operation of the waste water treatment plant is not disrupted if rinsing waters from process baths containing deca-BDE, HBCD, Sb$_2$O$_3$, PFOS and/or PFOA are collected and reused. Indirectly, this may also reduce the use of products (e.g. chemicals) needed to operate the WWTP.

When those separate waste water streams are treated before being indirectly discharged, the removal efficiency or biodegradability of the COD/TOC content of the waste water sent to biological treatment is at least 80 %. (as required in some Member States, e.g. DE, BE). [ 27, Derden et al. 2010 ] [ 36, ÖKOPOL 2011 ]

Cross-media effects
Chapter 4

The technique leads to a higher volume of hazardous waste.

As the spent padding liquors and printing pastes are incinerated (possibly after precipitation/flocculation), this generates emissions to air. However, in general the benefits of proper incineration easily outweigh the relatively limited cross-media effects.

It is nevertheless important that the quantity of residues is minimised prior to disposal. [ 212, HAZBREF 2019 ]

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
For a padder, the investment costs for an automated system for the separate collection of residual padding liquors (valves, tank below the padder from where the residual padding liquor is pumped to an IBC) are in the range of EUR 20 000-30 000. Investment costs for the manually operated separation system (flexible pipes and a flexible pump) are around EUR 5 000. Operating costs are negligible.

The costs for the treatment of residual printing pastes and residual padding liquors depend on the techniques applied and may be in the range of a few euro per tonne (in the case of anaerobic treatment) to EUR 300-500/t in the case of direct incineration. [ 212, HAZBREF 2019 ]

Driving force for implementation
Environmental legislation.

Example plants
Cilandrea AG, Herisau, Switzerland (direct incineration of residual padding liquors). Textilvereinigung an der Wiese (Plant DE047) and Laufenmühle, both located in Lörrach, Germany (anaerobic co-fermentation of residual dyeing padding liquors in the municipal anaerobic digester).

Plants from the data collection:
Plants DE024, DE030, DE039, DE40 and FR133 handle spent dye baths as waste.
Plants DE025, DE032 and DE049 handle spent printing pastes as waste.

Reference literature
[ 212, HAZBREF 2019 ], [ 27, Derden et al. 2010 ], [ 36, ÖKOPOL 2011 ]

4.1.7.3 Individual waste water treatment techniques

This section introduces the individual waste water treatment techniques as described in [ 24, COM 2016 ]. It is not exhaustive; instead, only a short descriptions relevant for the textile sector and examples of plants from the data collection applying these techniques are given.

4.1.7.3.1 Equalisation / Buffer storage

Description
Balancing of flows and pollutant loads by using tanks, basins or other management techniques.

Technical description
Equalisation and buffering facilities ensure reasonably constant conditions of certain parameters, especially pH, hydraulic load (or flow rate) and contaminant loads/concentrations for the effective operation of downstream waste water treatment plants (WWTPs).
Achieved environmental benefits
This technique enables downstream treatment techniques to operate at the optimum efficiency. It makes use of mixing effects to offset extremes of important WWTP operating parameters (e.g. temperature, pH).

Environmental performance and operational data
The retention times of equalisation tanks in the textile sector are typically 12-24 hours; in adverse climatic or other local conditions the retention times may be even longer.

Cross-media effects
Excessive retention of waste water in the equalisation tank may lead to odour emissions.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to applicability of this technique.

Economics
The cost of constructing and operating an equalisation tank needs to be compared with the savings associated with the smooth operation of the downstream treatment techniques and compliance with environmental standards.

Driving force
- Compliance with environmental standards.
- Protection and proper operation of downstream treatment techniques.

Example plants
Equalisation tanks are widely used in the textile sector [196, TWG 2019]

Reference literature
[24, COM 2016], [196, TWG 2019].

4.1.7.3.2 Neutralisation

Description
Neutralisation is the process by which the pH of the incoming waste water is adjusted to the neutral pH 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) are used to decrease the pH. The precipitation of some substances may occur during neutralisation.

Achieved environmental benefits
Neutralisation avoids the effects of strongly acidic or alkaline waste waters, e.g. corrosion or lowering of the efficiency of biological treatment downstream.

Environmental performance and operational data
The neutralisation of process waste water requires a tank of sufficient volume to assure the appropriate hydraulic retention time. The mixing capacity should be sufficient to keep the tank completely mixed.

The CO₂ from flue-gases is often introduced to neutralise waste waters with a high pH in the textile sector.

Cross-media effects
Increased concentration of salts in the waste waters (as a result of chemical neutralisation) and the solid waste generated (e.g. precipitate) may need to be disposed of.
Technical considerations relevant to applicability
Generally, there are no technical restrictions to applicability of this technique.

**Economics**
No information provided.

**Driving force**
Compliance with legal requirements to limit pollution to a receiving water body.

**Example plants**
Neutralisation is widely used in the textile sector [196, TWG 2019]. Plants from the data collection [196, TWG 2019] using CO₂ as a neutralising agent: IT059, PT099, PT109 and SE118.

**Reference literature**
[24, COM 2016] [196, TWG 2019].

### 4.1.7.3.3 Insoluble contaminants / mechanical separation

#### 4.1.7.3.3.1 Screening

**Description**
Screening is the mechanical separation/removal of insoluble contaminants such as fibre and fluff from textile effluent by coarse or fine screens.

**Technical description**
Screening devices are classified based on the size of the material they remove (the screenings). Fine screens (with openings as small as 100-200 μm) typically used for textile effluents are: fixed parabolic (curved), rotary drum, rotary disk. Fine screens can be either movable or fixed in a vertical, inclined or horizontal position and must be cleaned by rakes, teeth or brushes.

**Achieved environmental benefits**
Reduced suspended solids and BOD/COD emission levels.

**Environmental performance and operational data**
The use of fine screens produces effects similar to primary sludge removal in primary sedimentation. Fine screens are capable of removing 20-35% of suspended solids and BOD₅.

The screens must be mechanically cleaned; the cleaning of oils and grease from fine screens may cause some difficulties.

**Example plants**
Plants from the data collection using screening: BE009, DE030, IT084, PT099, PT110, PT110, PT114, PT115, UK129 [196, TWG 2019].

**Reference literature**
[24, COM 2016], [196, TWG 2019].

#### 4.1.7.3.3.2 Grit separation

**Description**
[24, COM 2016]
Grit separation is the removal of sand and gravel from rainwater. Grit chambers are part of the WWTP and are usually situated immediately downstream of the screen installed as protection for downstream techniques (equipment) from coarse and fibrous material.

**Example plants**

Plants from the data collection using grit separation before other waste water treatment techniques: BE008, CZ015, DE032, FR134, FR135, FR136, IT084, PT110, UK129. [196, TWG 2019]

**Reference literature**

[24, COM 2016], [196, TWG 2019].

4.1.7.3.3 Hydrocyclone

**Description**

[24, COM 2016]

A hydrocyclone is used to separate suspended solids with a diameter of 5 μm to 1,000 μm that are likely to sink and resistant to shearing forces. It separates the particles by using the centrifugal force generated as the liquid enters the cyclone tangentially at high speeds and is accelerated by the conical middle section. This creates a liquid vortex in the cyclone. The smaller the diameter of the cyclone, the greater the centrifugal force that will be generated as the liquid is forced to turn sharply. Light components leave the hydrocyclone through the top, while heavier components are collected at the bottom.

**Example plants**

According to the data collection [196, TWG 2019], Plant UK129 is using a hydrocyclone.

**Reference literature**

[24, COM 2016], [196, TWG 2019].

4.1.7.3.4 Oil-water separation

**Description**

[24, COM 2016]

An oil-water separator is a piece of plumbing equipment designed to intercept most greases (by gravitation) before they enter the biological waste water treatment.

The typical oil-water separators are: the American Petroleum Institute (API) separator (an open rectangular basin and a flight scraper), the parallel plate interceptor (PPI) (equipped with plates parallel to the current to enlarge the active surface area and oil skimming device) and the corrugated plate interceptor (CPI) (equipped with corrugated plate packs placed countercurrently and an oil skimming device). The skimmer device has to be regularly maintained. Skimmed oil is handled as waste.

**Example plants**

Plants from the data collection: DE022, PT099, PT109, SE120 and UK129 [196, TWG 2019].

**Reference literature**

[24, COM 2016], [196, TWG 2019].

4.1.7.3.5 Coagulation and flocculation

**Description**

WORKING DRAFT IN PROGRESS
Coagulation occurs in successive steps which are intended to overcome the forces stabilising the suspended particles, allowing particle collision and growth of floc.

Coagulation is the first step. It aims at destabilising the particles’ charge by neutralising their electrical surface charge. This is carried out by adding coagulants with charges opposite to those of the suspended solids to the waste water. This allows the particles to stick together into slightly larger particles.

Flocculation is a gentle mixing stage which aims at increasing the particle size. Collisions of microfloc particles cause them to bond to produce larger floc. This occurs in the presence of inorganic (formed by the coagulant) or added organic polymers. Contact times for flocculation range from 15 or 20 minutes to an hour or more.

Once the floc has reached the optimum size and strength, the waste water can be brought to sedimentation (see Section 4.1.7.3.3.6).

Example plants
Plants from the data collection using coagulation and flocculation are BE009, BE011, CZ020, DE025, DE032, DE051, IT075, IT076, IT084, PT110, PT114, UK124, UK128 and UK129. [196, TWG 2019].

Reference literature

4.1.7.3.3.6 Sedimentation

Description
Sedimentation, or clarification, is the separation of suspended particles and floating material by gravitational settling.

The settled solids are removed as sludge from the bottom, whereas floated material is skimmed from the water surface. When the particles cannot be separated by simple gravitational means, e.g. when they are too small and their density is too close to that of water or they form colloids, special chemicals are added to cause the solids to settle, such as: aluminium sulphate (alum); ferric sulphate; ferric chloride; lime; polyaluminium chloride; polyaluminium sulphate; cationic organic polymers.

Example plants
Plants from the data collection using sedimentation: BE009, CZ015, CZ020, DE025, DE032, IT067, IT075, IT076, IT082, IT084, IT092, IT096, IT097, PT098, PT110, PT111, PT114, SE118. [196, TWG 2019].

Reference literature

4.1.7.3.3.7 Flotation

Description
Flocculation is a process in which solid or liquid particles or particulates are separated from the waste water phase by attaching to fine gas bubbles, usually air. The buoyant particles accumulate at the water surface and are collected with skimmers. Flocculant additives, such as aluminium and ferric salts, activated silica and various organic polymers, are commonly used to
support the flotation process. Their function, besides coagulation and flocculation, is to create a surface or a structure able to absorb or entrap the gas bubbles.

There are three methods of flotation: vacuum flotation, induced gas flotation (IGF)/induced air flotation (IAF) and dissolved gas flotation (DGF)/dissolved air flotation (DAF).

Example plants

Plants from the data collection using flotation: AT006, BE009, IT076, UK124, UK129. [196, TWG 2019].

Reference literature
[24, COM 2016], [196, TWG 2019].

4.1.7.3.3.8 (Sand) filtration

Description
[24, COM 2016]
Filtration is the separation of solids from waste water effluents passing through a porous medium. In the case of sand filtration this medium is sand (or a similar granular medium). This technique is rarely used as a stand-alone treatment and is generally combined with the sedimentation of solids (see Section 4.1.7.3.3.6) or flotation (see Section 4.1.7.3.3.7).

Example plants

Plants from the data collection using sand filtration: BE007, BE009, BE011, DE032, PT098, PT108, PT111, PT114. [196, TWG 2019].

Reference literature
[24, COM 2016], [196, TWG 2019].

4.1.7.3.3.9 Microfiltration and ultrafiltration

Description
[24, COM 2016]
Microfiltration (MF) and ultrafiltration (UF) are membrane processes that retain certain substances contained in waste waters on one side of the membrane. The liquid that permeates through the membrane is referred to as the permeate. The liquid that is retained is referred to as the concentrate. The driving force of the process is the pressure difference across the membrane. Both are special and elaborate filtration techniques using ‘pore-type’ membranes which operate like sieves. The solvent and particles of molecular size can pass through the pores, whereas suspended particles, colloidal particles, bacteria, viruses, and even larger macromolecules are held back.

Example plants

According to the data collection [196, TWG 2019], Plant BE009 uses microfiltration and Plant UK129 uses ultrafiltration.

Reference literature
[24, COM 2016], [196, TWG 2019].

4.1.7.3.4 Soluble non-biodegradable or inhibitory contaminants / physico-chemical treatment
Chapter 4

4.1.7.3.4.1 Chemical oxidation Treatment of selected and segregated, non-biodegradable waste water stream by chemical oxidation

From ex-Section 4.10.7

Description

[24, COM 2016]
Chemical oxidation is the conversion of pollutants by chemical oxidising agents other than oxygen/air or bacteria into similar but less harmful or hazardous compounds and/or to short-chained and more easily degradable or biodegradable organic components. Chemical oxidation is used for the treatment of selected segregated waste water streams containing non-biodegradable/bioeliminable substances (i.e. with high COD loads) which might disturb the biological process in a downstream biological WWTP, or which have properties which are too harmful to allow them to be released into an ordinary sewer.

Chemical oxidising agents include:

- chlorine;
- sodium or calcium hypochlorite;
- chlorine dioxide;
- permanganate;
- ozone (with or without UV light);
- hydrogen peroxide;
- hydroxyl radicals generated by hydrogen peroxide (known as the Advanced Oxidation Process) in combination with:
  - ferrous salts (Fenton’s agent); see [24, COM 2016] for a detailed description of an oxidation technique involving hydrogen peroxide and a ferrous ion catalyst;
  - ozone;
  - UV light;
  - pressure;
  - temperature.

A special type of chemical oxidation is wet oxidation (WO). It is the reaction of oxygen in the aqueous phase at a high pressure and temperature, and is used to increase the solubility of oxygen in water.

Highly concentrated waste water streams result from various processes in the textile finishing chain:

- desizing baths with COD concentrations up to 20000 mg/l can be observed. (depending on the efficiency of the washing machines (water consumption) and load of sizing agents on the fabric);
- exhausted dye baths have with COD concentrations between 1000 and 15000 mg/l (depending on the class of dyestuffs, are possible);
- residual padding liquors from dyeing and finishing and residual printing pastes show even higher COD concentrations.

Desizing baths with non-biodegradable sizing agents and exhausted dye baths can be treated by oxidation in a special reactor at 100—130 °C and about 3 bars pressure (max. 5 bars). The main oxidising agent is molecular oxygen. Hydrogen peroxide only initiates the oxidation reaction and keeps it running (delivering 1/5 of the reactive oxygen). Iron(II)-salt is added as catalyst in acid medium. With COD of the feed of more than 2500 mg/l, the reaction is exothermic. The process is called "Thermal Fenton Process". The figure below shows the reactor and reaction conditions. More information about Advanced Oxidation Processes and the Fenton reaction is reported in [24, COM 2016] Section 14.
Main achieved Environmental performance
COD removal efficiencies of 70 – 85 % are achieved, depending on retention time, applied temperature and pressure and chemical properties of the compounds in the effluent to be treated.

Residual COD is largely biodegradable, because of modification of the compounds during the oxidation process. Given that the effluent is in most cases submitted to subsequent biological treatment (normally in the municipal waste water treatment plant), high COD removal efficiencies (95 % or higher) are achieved. This removal is real mineralisation, that is complete break-down of organic compounds. De-colouration is more than 90 % and treated exhaust dye baths are practically colourless.

Operational data
Waste water streams from different processes (different compounds and concentrations) are treated in sequence to minimise running costs. The treatment is performed continuously and is fully automated. It needs low manpower for operation.

Although recycling of the iron catalyst is possible, it is not always necessary; for example, where subsequent treatment in a waste water treatment plant uses iron for phosphate removal or at least for sludge dewatering.

Typical dosage of chemicals for the oxidation process is (e.g. for COD = 8500 mg/l):
- 13 l H₂O₂-solution (35 %)/m³ waste water (1.53 l H₂O₂-solution/m³ and 1000 mg/l)
- 35 ml H₂SO₄ (30 %)/m³ waste water
- 120 g Fe²⁺/m³ waste water.

Cross-media effects
The operation of the oxidation reactor requires electricity and chemicals, but the amount is not significant.

applicability
The oxidation technique is applicable to both new and existing installations.

Segregation of the selected streams (preferably automatically) is required, along with the necessary pipe-work and equalisation tanks. The space requirement for an oxidation reactor and chemicals feed tanks is not significant and does not represent a limitation.

Economics
Investment cost for a reactor with a flow of 4 – 5 m³/h (including reactor, dosing system for hydrogen peroxide and catalyst, heat exchanger, catalyst preparation unit, automated control and pipe work) is about 230000 euros. Operation cost, including above-mentioned dosage of chemicals, maintenance, labour and electricity, is about 3 euros/m³. It should be emphasized that this number is for the treatment of the selected high-loaded waste water streams and not for the whole of the mixed waste water.

Driving force for implementation
Difficulty in complying with standards set by municipal waste water treatment plant in terms of COD-load, biodegradability and toxicity.

Reference-Example plants
One plant that has been in operation at Schoeller Textil AG, CH-9475 Sevelen since 1996; the flow is 4 – 5 m³/h. A second and third plant are under construction for Tintoria di Stabio SA, CH-6855 Stabio and Givaudan Vernier SA, CH-1214 Vernier [26, UBA, 2001].

According to the data collection [ 196, TWG 2019 ], Plants BE009, BE011 and UK123 are using chemical oxidation.

Figure 4.23: Scheme of the reactor for treatment by catalytic oxidation with O₂/H₂O₂ of some segregated highly concentrated streams; on the left, illustration of the reactor at Schoeller AG, CH-Sevelen in operation since 1996 [ 26, UBA, 2001]
In particular, at Plant UK123, boiling of effluent with caustic soda is used to destroy the permethrin.

Reference literature
[45, OSPAR, 1994], [26, UBA, 2001] [24, COM 2016], [196, TWG 2019]

4.1.7.3.4.2 Chemical reduction

Description
[24, COM 2016]
Chemical reduction is the conversion of pollutants by chemical reducing agents into similar but less harmful or hazardous compounds. Common chemical reducing agents include: sulphur dioxide; sodium hydrogen sulphite/metabisulphite; ferrous sulphate; sodium sulphide and sodium hydrogen sulphide; urea or amidosulphonic acid (at low pH).

These chemicals are brought into contact with the waste species under appropriate pH and concentration conditions. Chemical reduction normally results in products that can be treated more easily in downstream treatment facilities such as a chemical precipitation unit.

Example plants
According to the data collection [196, TWG 2019], Plant BE009 is using chemical reduction.

Reference literature
[24, COM 2016], [196, TWG 2019].

4.1.7.3.4.3 Phosphorus removal by chemical precipitation

Description
[24, COM 2016]
The chemical precipitation of phosphorus is accomplished by the addition of the salts of multivalent metal ions that form precipitates of sparingly soluble phosphates. The multivalent metal ions most commonly used are calcium (Ca$^{2+}$), aluminium (Al$^{3+}$) and iron (Fe$^{3+}$).

Chemical addition occurs in primary clarifiers (when present) or in the secondary process, in the aeration basin or upstream of the secondary clarifiers, or in tertiary clarifiers or other treatment processes. Feeding chemicals to the primary clarifiers usually requires less chemical than feeding to the secondary or tertiary process. Feeding chemicals at both the primary and secondary clarifiers results in less chemical use than feeding to the secondary process alone, allowing some phosphorus to be removed in the primary clarifiers and polishing to occur in the secondary process. The resulting chemical precipitate will settle to the tank bottom where it can be removed as a sludge.

Example plants
According to the data collection [196, TWG 2019], Plant BE010 is using chemical precipitation by FeCl$_3$ for phosphorus removal.

Reference literature
[24, COM 2016], [196, TWG 2019].

4.1.7.3.4.4 Nanofiltration (NF) and reverse osmosis (RO)

Description
[24, COM 2016]
A very specific membrane filtration process is the permeation of a liquid through a membrane, to be segregated into permeate that passes through the membrane and concentrate that is retained. The driving force of this process is the pressure difference across the membrane. Nanofiltration (NF) and reverse osmosis (RO) membranes can hold back all particles down to the size of organic molecules and even ions. Provided that the feed is particle-free, these membranes are mainly used when complete recycling of permeate and/or concentrate is desired.

A large proportion (e.g. more than 90 %) of waste waters from the textile industry can be recycled by using this technique, thereby improving the overall life cycle impact of textiles [122, Beton et al. 2014 ].

Example plants
According to the data collection [196, TWG 2019 ], Plant BE011 is using nanofiltration and Plants BE009 and IT092 reverse osmosis.

Reference literature
[24, COM 2016 ], [196, TWG 2019 ].

4.1.7.3.4.5 Adsorption

Description
[24, COM 2016 ]
Adsorption is the transfer of soluble substances (solute)s from the waste water phase to the surface of solid, highly porous particles (the adsorbent). The adsorbent has a finite capacity for each compound to be removed. When this capacity is exhausted, the adsorbent is ‘spent’ and has to be replaced by fresh material. The spent adsorbent either has to be regenerated or incinerated.

Potential adsorbents for adsorptive waste water purification are activated carbon, lignite coke, γ-aluminium oxide and adsorber resins.

Example plants
According to the data collection [196, TWG 2019 ], Plants IT082 and PT114 are using adsorption.

Reference literature
[24, COM 2016 ], [196, TWG 2019 ].

4.1.7.3.4.6 Evaporation

Description
[24, COM 2016 ]
Evaporation of waste water is a distillation process where water is the volatile substance, leaving the concentrate as bottom residue to be handled (e.g. recycled or disposed of). The aim of this operation is to reduce the volume of waste water or to concentrate mother liquors. The volatile steam is collected in a condenser and the condensed water is, if necessary after subsequent treatment, recycled.

There are many types of evaporators: natural circulation evaporators; short-tube vertical evaporators; basket-type evaporators; falling film evaporators; agitated thin film evaporators.

Example plants
According to the data collection [196, TWG 2019 ], Plants CZ016, DE022 and FR133 are using evaporation.
4.1.7.3.4.7 Distillation/rectification

**Description**  
[24, COM 2016], [29, COM 2018]
Distillation or rectification is the separation of waste water from its contaminants by transferring them into the vapour phase. The enriched vapour phase is condensed afterwards.

Waste water distillation or rectification has a limited application. It is often used as a process-integrated measure to recover starting material and/or product from mother liquors. As a waste water treatment operation, it is applied for the following reasons:

- to recover solvent after waste water extraction;
- to recover solvent from waste water, e.g. separation of alcohols from methyl cellulose production;
- to treat oil emulsions;
- as a pretreatment to remove the main contaminant content from the waste water stream in order to recover it and afterwards discharge the waste water to further downstream treatment;
- to recover organics from scrubbing liquors.

**Example plants**
According to the data collection [196, TWG 2019], Plant BE013 is using distillation for ammonia recovery from mercerization with ammonia.

**Reference literature**  
[24, COM 2016], [29, COM 2018], [196, TWG 2019].

4.1.7.3.4.8 Stripping

**Description**  
[24, COM 2016], [29, COM 2018]
Waste water stripping is an operation in which waste water is brought into contact with a high flow of a gas current in order to transfer volatile pollutants from the water phase to the gas phase.

Stripping is applied to separate volatile contaminants from water, e.g.:

- chlorinated hydrocarbons, such as trichloroethene, perchloroethene, trichloromethane, dichloroethane, trichloroethane;
- ammonia and hydrogen sulphide; their volatility is strongly dependent on temperature and pH, thus pH control is essential (pH > 9.5 with ammonia, pH 2-3 with hydrogen sulphide);
- organic solvents, petrol, diesel fuel, lower aromatics, phenol, mercaptans.

**Example plants**
According to the data collection [196, TWG 2019], Plants CZ016 and IT074 are using stripping for treatment of effluents from dry cleaning.

**Reference literature**  
[24, COM 2016], [29, COM 2018], [196, TWG 2019].
4.1.7.3.5 Soluble biodegradable contaminants / biological treatment

Description
Biological treatment processes have repeatedly been shown to be effective for the elimination of biodegradable organic compounds, nitrogen compounds and phosphorus. In contrast to other treatment techniques, biological treatment makes use of microorganisms that can react to the manifold boundary conditions of their existence and are therefore able to adjust optimally to the compounds that are to be degraded (adaptation).

4.1.7.3.5.1 Aerobic treatment

Description
Aerobic treatment is the biological oxidation of dissolved organic substances using the metabolism of microorganisms. In the presence of dissolved oxygen – injected as air or pure oxygen – the organic components are converted (mineralised) into carbon dioxide, water or other metabolites and biomass (i.e. the activated sludge).

Aerobic waste water treatment generally represents the final biological step. It offers the advantage of a high rate of sludge growth which not only enables the handling of the various components of toxic waste water but also provides a COD removal efficiency that is normally superior to that of anaerobic treatment.

Aerobic biological treatment techniques commonly used in the textile sector are the activated sludge process and the membrane bioreactor process. Less commonly used aerobic biological treatment techniques are the trickling or percolating filter process, the expanded-bed process and the fixed-bed biofilter process.

The complete mix process is operated with several variants, depending on the amount of waste water, the availability of space, the requirements for emissions to air, etc. Examples of variants are:

- the oxidant agent: air or pure oxygen, the latter having the advantage of fewer stripping effects and a reduced odorous release, because less gas is blown through the waste water, and of faster and more effective biological reaction;
- the aeration chamber: a more or less flat tank or a tower, the latter taking into account the higher degradation efficiency because of smaller air bubbles ascending in a high column of waste water and thus considerably increasing the air/waste water mass transfer;
- the clarification step: sedimentation or membrane filtration (membrane bioreactor, see below), the latter requiring less space, the former probably supported by a final flotation stage.

In general, the complete mix activated sludge process is applicable to all biodegradable waste water streams, be it as a high-load pretreatment of tributary streams or as the main part of a central WWTP.

Example plants
Plants from the data collection using the activated sludge process or a membrane bioreactor are listed in Sections 4.1.7.3.5.4.1 and 4.1.7.3.5.4.2, respectively.
Plant UK124 uses an aerobic biofilter treatment.
4.1.7.3.5.2 Anaerobic treatment

**Description**

[24, COM 2016], [29, COM 2018]

Anaerobic waste water treatment converts the organic content of waste water, with the help of microorganisms and without entry of air, to a variety of products such as methane, carbon dioxide, and sulphide.

Anaerobic waste water treatment is essentially used only as a pretreatment for waste water which is characterised by a high organic load (> 2 g/l) and a more or less constant quality. It is applicable mostly in sectors with effluents with consistently high BOD loads.

The biogas consists of about 70 % methane and 30 % carbon dioxide and other gases such as hydrogen and hydrogen sulphide, the quantity of which depends on the sulphate content in the waste water. The process is carried out in an airtight stirred tank reactor, and the microorganisms are retained in the tank as biomass (sludge).

There are several reactor types available. The most commonly used are:

- anaerobic contact reactor;
- upflow anaerobic sludge blanket (UASB);
- fixed-bed reactor;
- expanded-bed reactor.

Anaerobic bioreactors are used to treat textile effluents with a high COD concentration and dyestuff pollutants (high colour).

**Environmental performance and operational data**

An anaerobic bioreactor combined with an activated sludge system (with tilted plate separators) removes nearly 90 % of COD as well as most of the colour and toxicity. [185, TenCate 2015], [186, Paques 2019]

**Example plants**

According to the data collection [196, TWG 2019], Plants CZ019 and FR134 use anaerobic treatment.

**Reference literature**

[24, COM 2016], [29, COM 2018], [196, TWG 2019].

4.1.7.3.5.3 Nitrogen removal by nitrification / denitrification

**Description**

[24, COM 2016], [29, COM 2018]

Nitrogen, or more precisely ammonium, is removed by a special biological treatment that consists of two steps:

- Aerobic nitrification, where special microorganisms oxidise ammonium (NH$_4^+$) to the intermediate nitrite (NO$_2^-$) which is further converted to nitrate (NO$_3^-$). Ammonium can also be oxidised to nitrite without further conversion to nitrate.
- Anoxic denitrification, where microorganisms convert nitrate into nitrogen gas.

Nitrification may not be applicable in the case of high chloride concentrations (i.e. around 10 g/l) and when the reduction of the chloride concentration prior to nitrification would not be justified by the environmental benefits. Nitrification is not applicable when the temperature of the waste water is low (e.g. below 12 °C).
Example plants
Plants from the data collection using nitrification / denitrification: BE007, BE010, BE011, BE014, CZ019, CZ020, DE032, DE034, IT067, IT075, IT076, IT082, IT092, IT096, IT097. [ 196, TWG 2019 ].

Reference literature
[ 24, COM 2016 ], [ 29, COM 2018 ] [ 196, TWG 2019 ].

4.1.7.3.5.4 Combinations of biological waste water treatment techniques

Recent developments of process variants and combinations are based on detailed knowledge and control of microbiological, hydraulic and aeration conditions (biotic and abiotic), which significantly increase the efficiency of microorganisms’ activity. The processes that may be used for textile effluent treatment are as follows:

- Simultaneous nitrification/denitrification (also called biological double-efficiency process) is possible due to the control of the dissolved oxygen concentration at a very low level (at an average of 0.3 mg/l), and the formation of an oxygen concentration gradient across the flocs of bacteria. The nitrification occurs at the surface of the activated-sludge flocs (aerobic zones) and denitrification occurs within the flocs (anoxic zones). A high sludge concentration with a low food to microorganisms (F/M) ratio, results in smaller sludge flocs that maintain just sufficient aerobic conditions. The process can work at a carbon to nitrogen (C/N) ratio as low as 0.17. Such conditions are achieved in a single basin (treatment tank). [ 189, US EPA 2013 ], [ 190, BDP Envirotech 2016 ], [ 191, BDP Envirotech 2016 ]
- Multistage treatment is based on the establishment of the food chain of biota (from microorganisms to worms and insects) in different compartments of the reactor where different compounds of the effluent are degraded. Typically the reactor has 8-12 compartments with different conditions – aerobic (for nitrification) or anoxic (for denitrification). Due to the establishment of a food chain, the amounts of sludge are significantly reduced. [ 188, US EPA 2013 ]

The most commonly used combinations of biological waste water treatment techniques used in the textile sector are presented below.

4.1.7.3.5.4.1 Activated sludge system with a low food to microorganisms ratio (F/M) Treatment of textile waste water in a

From ex-Section 4.10.1

Description
The increase of the biodegradability of hardly biodegradable substances in the effluents by the use of activated sludge systems with a low food to microorganisms (F/M) ratio.

Technical description
Aerobic biological treatment techniques are widely used to treat mixed textile waste water. In most cases, complete mix activated sludge systems are used. The description and performance of this type of technique is treated in detail in another BREF ([196, EIPPCB, 2001]). [ 24, COM 2016 ], [ 29, COM 2018 ]

In the activated sludge process the microorganisms are maintained as suspension in the waste water and the whole mixture is mechanically aerated. The activated sludge mixture is sent to a separation facility from which the sludge is recycled to the aeration tank. The separation facility can be: a sedimentation or settling tank (see Section 4.1.7.3.3.6); an air flotation facility (see Section 4.1.7.3.3.7); or a MF or UF membrane (see Section 4.1.7.3.3.9; more common for a membrane bioreactor).
The complete mix process is operated with several variants, depending on the amount of waste water, the availability of space, the requirements for emissions to air, etc. Operational variations concern the following:

- the oxidant agent: air or pure oxygen, the latter having the advantage of fewer stripping effects and a reduced odorous release, because less gas is blown through the waste water, and of faster and more effective biological reaction;
- the aeration chamber: a more or less flat tank or a tower, the latter taking into account the higher degradation efficiency because of smaller air bubbles ascending in a high column of waste water and thus considerably increasing the air/waste water mass transfer;
- the clarification step: sedimentation or membrane filtration (membrane bioreactor, see next technique below), the former probably supported by a final flotation stage and the latter requiring much less space.

In general, the complete mix activated sludge process is applicable to all biodegradable waste water streams, be it as a high-load pretreatment of tributary streams or as the main part of a central WWTP.

Textile waste water is a mixture of many different chemical compounds which can roughly be classified into easily biodegradable, hardly biodegradable (recalcitrant) and non-biodegradable compounds. In activated sludge systems, easily biodegradable compounds are mineralised, whereas hardly biodegradable compounds need special conditions, such as low food to microorganisms ratios (F/M) (< 0.15 expressed in kg BOD5 per kg of MLSS (mixed liquor suspended solids) per day, or even < 0.05 for mineralisation below optimum temperatures), adaptation (when the compounds are discharged very regularly) and a temperature higher than 15 °C (which is normally the case for textile waste water).

F/M is the most relevant design parameter. If they remain under the mentioned F/M value, For example, hardly biodegradable chemicals, such as nitrilotriacetate (NTA) (“GDCh, 1984”), m-nitrobenzene sulphonate and its corresponding amine (“Kölbener, 1995”), polyvinyl alcohol (PVA) (“Schönberger, 1997”) and phosphonates (“Nowack, 1998”) are degraded and mineralised in such conditions. [26, UBA, 2001]

The low F/M ratio conditions in an activated sludge treatment can be achieved not only by increasing the hydraulic retention time. Other methods are applicable, such as but also for example by:
- removing the food from the activated sludge, (like for example see the technique described in Section 4.1.7.4.1);
- reducing the load by pretreatment of selected concentrated streams (see Section 4.1.7.3.4.1);
- increasing the biomass in the activated sludge system (e.g. bio-membrane reactor, bio-flotation).

Today, many activated sludge systems meet these system conditions (see the following examples in Table 4.21), which also enables almost complete nitrification. In these conditions, both readily and hardly biodegradable compounds can be degraded. On the In contrast, effluents containing non-biodegradable compounds should be treated/pretreated at the source (see Section 4.1.7.3.4.1), but this is done only in a few mills. In most cases, in addition to activated sludge further treatment steps are carried out, such as flocculation/precipitation, coagulation/adsorption/precipitation, adsorption to activated carbon and ozonation.

Other techniques combine the biological degradation process with physical adsorption, coagulation and advanced oxidation processes. These techniques are described in Section 4.10.3.

Plant 1:
The treatment plant receives municipal waste water and effluent from four large textile finishing mills. The textile waste water is equalised and then mixed with primarily treated municipal waste water. The textile waste water accounts for about 45% of the hydraulic load and about 60% of the COD load. After primary treatment and equalisation, there is a biological treatment, including nitrification/denitrification and flocculation with FeCl₃ as final step (FeCl₃ has the disadvantage of introducing additional chloride ions in the system, which are a source of corrosion problems). The system can be seen from Figure 4.34 while Figure 4.35 shows the daily measured average COD concentration of the final effluent. The values vary within a significant range, reflecting fluctuations during the week, rainy days (because storm water enters the same sewer) and holiday time (very low values are recorded at the end of August which is the holiday time for companies).

**Figure 4.34**: Plant 1—combined treatment of textile effluent and municipal waste water [179, UBA, 2001]

**Figure 4.35**: Daily average COD concentration measured on the final effluent from Plant 1 in the year 2000 [179, UBA, 2001]

**Plant 2:**

In this big plant, waste water from two cities and some villages is treated together with textile waste water from four large textile finishing industries which accounts for about 40% of the hydraulic load and about 65% of the COD load. Municipal waste water and textile waste water are already mixed in the public sewer. Figure 4.36 shows the layout of the plant. The tanks for primary treatment are also used for equalisation of the incoming waste water. After the activated sludge treatment, no additional treatment is applied for further reduction of organic compounds and colour. The daily variation of the COD load at the outlet of the plant can be seen from Figure 4.37. There are high peaks which result from high flows of storm water. In such conditions, retention time is reduced and removal efficiency is therefore also reduced. As in example Plant 1, during holiday time in the industry (August), residual COD load is significantly lower.

**Figure 4.36**: Plant 2—combined treatment of textile effluent and municipal waste water [179, UBA, 2001]

**Figure 4.37**: Daily average COD load measured on the final effluent from Plant 2 in 1999 [179, UBA, 2001]

**Plant 3:**

This example also features combined treatment of municipal and textile waste water. The layout of the plant is shown in the next figure. The neutralised and equalised waste water of a big textile company is discharged to the treatment plant by a separate sewer. The water is specially pretreated in a high-loaded activated sludge system with F/M 1.1 kg BOD₅/kg MLSS · d. Under these conditions, PVA, which is present at high concentration in the textile waste water, is not degraded at all. More than 90% PVA removal is achieved in the subsequent (second) activated sludge stage having F/M 0.05 kg BOD₅/kg MLSS · d.

Ozonation of textile waste water reduces colour significantly, but COD is reduced only very slightly (<10%) because of low ozone dosage (about 50 g/m³). However, it is postulated that biodegradability is increased. Activated carbon treatment is added only where the standards are
breached, which has not happened in the past three years. Flocculation/filtration as a polishing step reduces COD to 10–20% and removes some colour as well.

Figure 4: Plant 3—combined treatment of textile effluent and municipal waste water [179, UBA, 2001]

Plant 4:
This large plant is for the treatment of waste water from about 150 textile units. Textile waste water accounts for about 55% of the hydraulic load, municipal waste water for about 23% and infiltration and storm water for the remainder. The layout of the plant is shown in the following figure.

After biological treatment including nitrification/denitrification, the mixed waste water is precipitated/flocculated for further COD reduction. The effluent is subsequently treated with ozone in order to remove colour and recalcitrant surfactants. The F/M ratio is higher than 0.15 kg BOD$_5$/kg MLSS · d, which means that complete nitrification cannot be achieved and hardly degradable compounds may not be removed to as high an extent as with a lower F/M ratio.

Figure 4: Plant 4—combined treatment of textile effluent and municipal waste water [179, UBA, 2001]

Plant 5:
In plant 5, the waste water from one textile finishing industry is treated. In this example, the company plant mainly finishes cotton fabric, including pretreatment (desizing, scouring, bleaching), dyeing (cold pad-batch and exhaust dyeing), printing (mainly with pigment printing pastes) and finishing. About 5% of the treated waste water is recycled for washing and cleaning operations (floor washing, cleaning of printing equipment such as pumps, pipes, squeegees and screens). The retention time in the activated sludge system is very high. Decolourisation is achieved through reductive cleavage of azo groups of dyestuffs by an iron(II)-salt. Figure 4.24 shows the layout of the waste water treatment plant.
Achieved environmental benefits
Reduction of emissions of hardly biodegradable pollutants to water.

Environmental performance and operational data
Achieved emission levels
Chapter 4

The table below shows the influent and effluent values and F/M ratios of the six described treatment plants. In some cases of combined treatment, textile waste water and municipal waste water are discharged to the plant via different sewer lines. For these plants, the influent values are presented separately. Where textile and municipal waste water are already mixed in the sewer, the influent values are given under the heading ‘influent (textile ww).’

F/M ratios below 0.15 kg BOD₅/kg MLSS·d enable almost complete nitrification (residual ammonia concentrations lower than 0.5 mg/l).

Plant 4 has a F/M ratio of 0.2, resulting in higher ammonia concentrations and a lower BOD₅ removal efficiency.

Table 4.21: Characteristics of waste water parameters (input and output) for six treatment plants

<table>
<thead>
<tr>
<th>Aspect/component</th>
<th>unit</th>
<th>Plant 1</th>
<th>Plant 2</th>
<th>Plant 3</th>
<th>Plant 4</th>
<th>Plant 5</th>
<th>Plant 6</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Annual average values for 2000</td>
<td>Annual average values for 1999</td>
<td>Annual average values for 2000</td>
<td>Annual average values for 1999</td>
<td>Annual average values for 2000</td>
<td>Annual average values for 2000</td>
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<tr>
<td>Total flow</td>
<td>(m³/d)</td>
<td>8377±1431</td>
<td>47770±24500</td>
<td>6690</td>
<td>25000</td>
<td>2070</td>
<td>38750±16790</td>
</tr>
<tr>
<td>Municipal ww flow</td>
<td>(m³/d)</td>
<td>4562±2018</td>
<td>NI</td>
<td>4865</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Textile ww flow</td>
<td>(m³/d)</td>
<td>3685±1431</td>
<td>NI</td>
<td>1825</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Food to microorganisms ratio (F/M)</td>
<td>kg BOD₅/(kg MLSS·d)</td>
<td>0.1</td>
<td>0.1</td>
<td>1.1 and 0.05</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Influent (municipal ww)</td>
<td></td>
<td>8±0.4</td>
<td>8.1</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>9.2±0.8</td>
<td>8.4±0.4</td>
<td>8.7</td>
<td>n.a.</td>
<td>9 - 9.5</td>
<td>NI</td>
</tr>
<tr>
<td>COD</td>
<td>(mg O₂/l)</td>
<td>443±200</td>
<td>336</td>
<td>NI</td>
<td>NI</td>
<td>278±86</td>
<td>NI</td>
</tr>
<tr>
<td>BOD₅</td>
<td>(mg O₂/l)</td>
<td>114±50</td>
<td>144</td>
<td>NI</td>
<td>NI</td>
<td>138±49</td>
<td>NI</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>(mg N/l)</td>
<td>30±14</td>
<td>31</td>
<td>NI</td>
<td>NI</td>
<td>12.5±4.8</td>
<td>NI</td>
</tr>
<tr>
<td>N-org</td>
<td>(mg N/l)</td>
<td>18±7</td>
<td>15.9</td>
<td>NI</td>
<td>NI</td>
<td>n.a.</td>
<td>NI</td>
</tr>
<tr>
<td>P total</td>
<td>(mg P/l)</td>
<td>6±2</td>
<td>6.2</td>
<td>NI</td>
<td>NI</td>
<td>3.7±1.2</td>
<td>NI</td>
</tr>
<tr>
<td>Influent (textile ww)</td>
<td></td>
<td>7.2±0.2</td>
<td>8.2±0.3</td>
<td>7.4</td>
<td>n.a.</td>
<td>7.8 - 8.6</td>
<td>6.8 - 7.5</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>59±16</td>
<td>46±23</td>
<td>54</td>
<td>60 - 110</td>
<td>90 - 110</td>
<td>11±1.3</td>
</tr>
<tr>
<td>COD</td>
<td>(mg O₂/l)</td>
<td>3±2</td>
<td>4.4±3.8</td>
<td>3</td>
<td>10 - 40</td>
<td>&lt;5</td>
<td>3±0.7</td>
</tr>
<tr>
<td>BOD₅</td>
<td>(mg O₂/l)</td>
<td>0.14±0.2</td>
<td>0.2±0.9</td>
<td>0.12</td>
<td>5 - 15</td>
<td>0.3 - 1.6</td>
<td>0.4±0.3</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>(mg N/l)</td>
<td>2.9±1.9</td>
<td>3.6±1.1</td>
<td>5.4</td>
<td>1 - 10</td>
<td>&lt;2</td>
<td>6.8±1.0</td>
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<tr>
<td>N-org</td>
<td>(mg N/l)</td>
<td>1.7±0.5</td>
<td>n.a.</td>
<td>n.a.</td>
<td>8 - 15</td>
<td>5 - 10</td>
<td>n.a.</td>
</tr>
<tr>
<td>P total</td>
<td>(mg P/l)</td>
<td>0.2±0.2</td>
<td>0.9±0.7</td>
<td>0.6</td>
<td>n.a.</td>
<td>1 - 2.5</td>
<td>0.15±0.015</td>
</tr>
<tr>
<td>AOX</td>
<td>(mg Cl/l)</td>
<td>0.06 - 0.08</td>
<td>0.06 - 0.1</td>
<td>n.a.</td>
<td>n.a.</td>
<td>&lt;0.04 - 0.15</td>
<td>n.a.</td>
</tr>
<tr>
<td>PVA</td>
<td>(mg/l)</td>
<td>0.6 - 7.8</td>
<td>n.a.</td>
<td>3</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
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<td>SAC (435 nm)</td>
<td>(1/m)</td>
<td>8.3±3</td>
<td>n.a.</td>
<td>2.4</td>
<td>0.02</td>
<td>5 - 7</td>
<td>0.42±0.08</td>
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<td>SAC (525 nm)</td>
<td>(1/m)</td>
<td>6.8±2.9</td>
<td>n.a.</td>
<td>0.9</td>
<td>n.a.</td>
<td>1.5 - 5</td>
<td>0.31±0.08</td>
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<td>SAC (620 nm)</td>
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<td>0.9</td>
<td>n.a.</td>
<td>1 - 3.5</td>
<td>0.18±0.05</td>
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<td>Removal efficiencies</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>(%)</td>
<td>90±4</td>
<td>84.4</td>
<td>89</td>
<td>91</td>
<td>92.5</td>
<td>96</td>
</tr>
<tr>
<td>BOD₅</td>
<td>(%)</td>
<td>97±2</td>
<td>96.2</td>
<td>98</td>
<td>93.5</td>
<td>99</td>
<td>98</td>
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<tr>
<td>Nitrogen</td>
<td>(%)</td>
<td>88±6</td>
<td>88</td>
<td>78</td>
<td>77</td>
<td>82</td>
<td>47</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>(%)</td>
<td>96±3</td>
<td>79</td>
<td>88</td>
<td>n.a.</td>
<td>90</td>
<td>96</td>
</tr>
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</table>

NB: No information, n.a.: Not applicable.
Source: [26, UBA, 2001]
Cross-media effects
None identified.

Treatment in activated sludge under low F/M conditions as such is not sufficient for removing the fraction of COD represented by non-biodegradable hazardous chemicals. Other or additional treatment are necessary to transform or better transform these substances.

Technical considerations relevant to applicability
Activated sludge systems with low F/M ratios are applicable to both new and existing plants for all kinds of textile waste water. They can also be applied to municipal waste water treatment plants with low and high percentages of textile waste water as well as to purely industrial plants in which the waste water of one or more finishing mills is treated.

Economics
When low F/M ratio conditions are achieved by increasing the retention time, this means bigger aeration tanks, resulting in higher investment costs. Broadly speaking, the size of activated sludge systems is inversely proportional to the F/M ratio. Precise data on investment costs are not available. Additional cost for additional aeration is about 0.30 euros/m$^3$.

Driving force for implementation
Environmental legislation.

Example plants
Plants from the data collection using the activated sludge process: BE007, BE010, BE011, BE014, CZ019, CZ020, DE032, DE034, IT067, IT075, IT076, IT082, IT092, IT096, IT097. [196, TWG 2019].

Reference literature
[26, UBA, 2001], [24, COM 2016], [29, COM 2018], [196, TWG 2019].

4.1.7.3.5.4.2 Membrane bioreactor

Description
The membrane bioreactor process, as a combination of biological activated sludge treatment and membrane separation, is a biological treatment process used for urban and industrial waste water (see the CWW BREF [24, COM 2016] for more details on membrane bioreactors). The different variations of this process are:

- an external recirculation loop between the activated sludge tank and the membrane module;
- immersion of the membrane module in the aerated activated sludge tank, where the effluent is filtered through the hollow fibre membrane, and the biomass remains in the tank; this variant consumes less energy and results in a more compact plant.

These variants together with the conventional activated sludge process are shown in Figure 4.25.
Figure 4.25: Variants of membrane bioreactor, compared with a conventional activated sludge

Example plants
According to the data collection [196, TWG 2019], Plant IT076 is using a membrane bioreactor (IT075 plans to invest in one in 2020).

Reference literature
[24, COM 2016], [29, COM 2018], [196, TWG 2019].
Chapter 4

4.1.7.4 Combinations of waste water treatment techniques in the textiles industry

4.1.7.4.1 Adsorption and advanced oxidation treatment integrated with activated sludge treatment. Biological, physical and chemical treatment of mixed waste water effluent

From ex-Section 4.10.3

Description
Adsorption and advanced oxidation treatment are integrated with activated sludge treatment to degrade or destroy the non-biodegradable compounds in textile waste waters.

Technical description
After biological treatment, e.g. treatment in activated sludge systems under low food to microorganism (F/M) ratio conditions (Section 4.1.7.3.5.4.1), enables the degradation of both readily and hardly biodegradable substances. However, this technique is not sufficient for degrading or eliminating non-biodegradable compounds. Effluents containing non-biodegradable compounds should undergo additional treatments to remove or destroy these substances.

Such treatments should preferably be carried out before the final biological treatment (see Section), but in practice this is done only in a few mills.

In most cases additional sequential treatments are carried out after the activated sludge such as flocculation/precipitation, coagulation/adsorption/precipitation, ozonation. However, ozonation, when applied at the end of the treatment process, mainly has the effect of degrading the chemicals into intermediate degradation by-products, whereas the other treatments listed ultimately just transfer to sludge the substances that escape bioelimination.

Another approach for improving the performance of the activated sludge treatment is represented can be complemented by integrating adsorption on powdered activated carbon (PAC) treatment and advanced oxidation treatment of the sludge produced by adsorption. This consists in combining the different technologies (biological, physical, chemical), thus allowing simultaneous biodegradation, adsorption and coagulation. The process was introduced in the early seventies and industrialised with the commercial name of PACT and PACT® systems.

In the PACT3+ system, powdered activated carbon is added to the aerobic aerator together with iron, which is used as a coagulant to precipitate phosphate and increase the binding of dyes into the sludge. Activated carbon and bacteria are maintained in aerobic/anoxic conditions, thus allowing simultaneous biodegradation, adsorption and coagulation. Treatment process for symbiotic activity [292, US Filter Zimpro, 2002]. In the PACT® system,

The excess sludge (a mixture of spent powdered carbon, iron and biomass) from generated in the aerobic aerator is treated (regenerated) by means of advanced oxidation: either a hydrothermal treatment (wet oxidation) or oxidation with hydrogen peroxide at low temperature (below 130 °C) which is referred to as ‘catalytic active carbon wet peroxidation’.

This wet oxidation is a liquid phase reaction in water using dissolved oxygen (or air) to oxidise soluble and suspended oxidisable contaminants in the aqueous environment. When air is used as the source of oxygen the process is referred to as ‘Wet Air Oxidation’ (WAO). The oxidation reaction is carried out at moderate temperatures of 150-315 °C and at pressures from 10 bar to 207 bar. The process destroys the large molecules in waste water, converting them predominantly to carbon dioxide, water and short-chain organic acids, which are highly biodegradable and more suitable for biological treatment. This regeneration process provides continual reuse of the activated carbon and ensures high levels of waste treatment. [ 184, Zimpro 2019 ]
The reactivation of the spent sludges containing powdered carbon and iron, is carried out at low temperature (below 130°C) if hydrogen peroxide is used (a process referred to as “catalytic active carbon wet peroxidation”). Advanced oxidation using hydrogen peroxide destroys concentrated or adsorbed substances by creating the conditions for the Fenton reaction (H₂O₂, Fe²⁺ at pH 3). The principle of this process is described in [24, COM 2016]. Both the reactivated carbon and the iron are recycled back to the aerobic system.

A first application of the PACT® system in the European textiles industry appeared in 1975 (Desso in Belgium). The process was later improved by integrating it with simultaneous coagulation treatment (the system is called PACT+, a cryptic term to indicate a first improvement). A second improvement (the so-called PACT++) could only be achieved by changing and extending the conventional activated sludge process with a nitrification/denitrification step followed by a filtration of the effluent to retain suspended solids. Another technique is the PACT3+ system. This concept is a combination of different available techniques, with the aim of improving performance, flexibility and economy of scale of the PACT® system.

Main Achieved environmental benefits
Reduction of emissions of hardly and non-biodegradable pollutants to water.

Environmental performance and operational data
The pretreatment techniques described improve the performance of the activated sludge treatment.

The addition of the adsorbent (activated carbon) and coagulant can be done at any point where the utilisation is most effective (cost, performance) and do not necessarily need to be added directly in the aerobic aerator; this is because the countercurrent flow from coagulation, adsorption and filtration has the effect of returning to the biological system the adsorbent and coagulant containing the substances removed from the water.

Reactivation of powdered carbon using hydrogen peroxide allows the reuse of carbon and iron. The technique is most interesting for pretreating hot concentrates and for reactivating sludges from biological, physical and coagulation processes (somewhat comparable with chemical oxidation described in Section 4.1.7.3.4.1, but simpler because there is no need to inject oxygen gas).

The main advantages of these treatments being integrated with the biological step over sequential tertiary treatments applied after the biological system are:

- the production of excess sludge in biological treatment is reduced (by recirculation through chemical oxidation treatment);
- substances that are potentially hazardous (non-biodegradable, accumulatable, toxic) are preferentially removed and destroyed;
- the activated sludge system is better protected against shock loading, and, as the adsorbed material is degraded, the risk of displacement of dyes and other adsorbed substances is much lower than it appears to be with post-adsorption (e.g. granular activated carbon);
- the excess solids produced are dense and retain the remaining substances, which can therefore be sent to easier dewatering (anaerobic) and incineration;
- mineralisation of the organic pollutants is improved;
- energy use in aeration is lower.

With PACT® and PACT++ treatments, good filtration is very important in order to efficiently separate the sludge from the treated effluent. The following additional equipment is needed:

- dosing systems for powdered carbon and iron sulphate;
• dosing system for peroxide;
• microfiltration;
• reactor for reactivation of concentrated streams.

Consumption of powdered activated carbon dosage is less than 100 g/m$^3$ of waste water of mixed effluent is needed, when reactivation of the activated carbon is carried out.

Hydrogen peroxide is consumed in stoichiometric amounts to transform the concentrated substances into bioeliminable substances (under conditions of optimal pH and temperature).

Iron is added as iron sulphate. It is introduced as a coagulant but it also serves as a catalyst, nutrient and precipitant for sulphides and phosphates.

**Cross-media effects**
The chemical oxidation treatment requires electricity and chemicals.

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of this technique.

The technique is applicable to existing and new installations where a biological treatment is available and where solids are fully retained in the clarification system. A microfilter is to be added when there is a risk that solids could escape with the effluent.

**Economics**
Investment and operational costs for additional treatments could be offset in the long term by savings in sludge treatment and energy costs and due to the increased efficiency of biological treatment. Special types of activated carbon are known to give the best performance. Cost depends on the

**Driving forces for implementation**
Environmental legislation.
PARCOM Recommendations 94/5, after critical review of the PACT process, supports the implementation of the PACT3+ concept as one of the most promising upcoming technologies (based on advanced oxidation processes, technologies for the nineties).

**Reference/Example plants**
Different PAC® processes to treat dyestuff-containing effluents are in place worldwide.
The PAC® system has been in operation since 1980 for textile effluents in the city of Vernon.
The PACT+ system has been implemented by Desso, who has also evaluated the PACT++ system (no info about future directions).
PACT3+ is a concept that combines existing applied techniques.

**Reference literature**

**4.1.7.4.2 Waste water treatment by [flocculation] / precipitation / coagulation / flocculation [and incineration of the resulting sludge]**

<table>
<thead>
<tr>
<th>From ex-Section 4.10.8</th>
<th>From ex-Section 4.10.5</th>
</tr>
</thead>
</table>

**Description**
A combination of precipitation, coagulation and flocculation is used to degrade or destroy the non-biodegradable compounds in textile waste waters.
**Technical description**

Treatment of textile waste water by precipitation/flocculation in order to reduce organic load and especially colour has been performed for more than 100 years. However, today there are techniques that minimise the quantity of sludge produced and reduce negative effects associated with its disposal. Instead of landfill disposal, the sludge can be incinerated using state-of-the-art technology.

Dissolved heavy metal compounds (e.g. dyestuffs) and other non-biodegradable substances (e.g. organic thickeners, binders, fixation agents from pigment pastes) are removed from textile waste waters by a combination of precipitation, flocculation and coagulation. These processes can take place simultaneously in the same step either before or after biological treatment.

For precipitation, aluminium and iron sulphate are used. Although at high concentrations (> 500 mg/l) sulphates become aggressive against concrete, the use of sulphates is preferred to chlorides. Sulphates are easier to remove from water than chlorides. Moreover, the use of sulphate avoids the introduction of chlorides in the waste water and in the sludge to be incinerated [101, Belgium, 2002].

Iron sulphate is equally effective for the removal of COD and can also be considered as a coagulant (e.g. it is particularly effective for removing acrylates and other substances from pigment printing waste water). The introduction of iron has advantages (it is responsible for the activation of redox processes, it can be recycled, etc.), but it forms coloured complexes that remain in the solution, giving it a yellowish or brownish tint [101, Belgium, 2002].

In modern plants, the precipitate is separated from the aqueous phase not just by sedimentation, but also by dissolved air flotation, flocculation, coagulation or filtration (e.g. micro- or ultrafiltration). Precipitation, flocculation and/or coagulation agents are specifically selected in order to maximise COD and colour removal, and to minimise sludge formation. In most cases, the best performance is obtained with a combination of aluminium sulphate (precipitation), cationic organic flocculant and very low amounts of an anionic polyelectrolyte (also used for flocculation).

Membrane filtration techniques (e.g. micro-, ultra-, nanofiltration) can be used to separate the precipitate from the waste water.

For more detailed descriptions of coagulation and flocculation Section 4.1.7.3.3.5 and for filtration see Section 4.1.7.3.3.9 and 4.1.7.3.4.4

**Main Achieved environmental benefits**

Reduction of emissions of non-biodegradable substances like heavy metals, COD and colour (dyes and pigments) to water.

**Environmental performance and operational data**

Before precipitation, flocculation and coagulation, the textile waste water is equalised. However, the equalisation time can be shorter (about 12 hours) than with biological treatment. Fibres are removed by a sieve.

The dosage of precipitation agent and flocculants (e.g. for a mixed textile effluent with a COD of around 1,000 mg/l) is about:

- aluminium sulphate: 400-600 mg/l;
- cationic organic flocculant: 50-200 mg/l;
- anionic polyelectrolyte: 1-2 mg/l.

Typically COD removal is only about 40-50 %. When the effluent has a high content of water-insoluble compounds (e.g. in waste water from pigment printing sections), COD removal is higher. Decolouration is more than 90 %.
The quantity of sludge produced is about 0.7–1 kg of dry matter/m³ of treated waste water. Usually, the sludge is dewatered in a chamber filter press to reach a dry matter content of about 35–40% (3 kg of sludge are therefore produced for 0.5 kg of COD removed). The sludge is fully mineralised in an incineration plant.

Cross-media effects
- Additional energy and chemicals are consumed for these waste water treatments.
- Aerobic sludge generated in these treatments could be considered hazardous waste and needs appropriate handling.

A considerable amount of organic compounds is shifted from the aqueous phase to the sludge. However, the sludge is incinerated and thus mineralised.

Energy is consumed for dewatering, transport and incineration.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

The technique is applicable to both new and existing installations.

Economics
No information provided. For more information see [24, COM 2016].

Driving force for implementation
Environmental legislation.

Example plants
See Section 4.1.7.3.3.5.

Reference literature
[24, COM 2016], [101, Belgium, 2002]

Treatment and recovery of waste water containing pigment-paste

Description
This technique refers to membrane treatment of waste water containing pigment printing pastes with full reuse of the resulting permeate.

In the example described here, waste water comes from the printing paste preparation kitchen (mainly resulting from cleaning operations of stirrers, drums etc.). The pigment pastes contain organic dye pigments, organic thickeners (usually polyacrylates), organic binders (co-polymers), fixation agents (organic resins), catalysts and softening agents.

Treatment (see flow sheet in the figure) consists of the following steps:
- coagulation to de-activate the organic dyes, binders and fixation agents (polyaluminium chloride sulphate is added)
- precipitation of the resulting coagulates with bentonite at pH 6
- microfiltration of the precipitate. The applied membranes consist of polypropylene and have a cut off of 0.2 μm. Suspended solids in the concentrate are removed in a tube settler by dosage of a floeculant.

The sludge is sent to physico-chemical treatment offsite. It is planned to send it to incineration in the near future. The permeate is totally free of suspended solids and can be reused for cleaning operations.

Figure 4.45 indicates that, beside the waste water from the pigment paste preparation station, the effluent from the scrubbers (treatment of off-gases from three stenters) is also sent to the
membranes. The core of the plant are two micro-filtration modules consisting of 400 spiral membrane tubes each.

Figure 4.26: Layout of a plant for treatment and recycling of waste water from pigment printing paste preparation kitchen (water from scrubbers is treated in the same plant) [179, UBA, 2001]

Main achieved environmental benefits

More than 90% of the water is recycled. Non-biodegradable compounds, such as organic thickeners, binders and fixation agents, are completely removed and can then be mineralised by incineration (incineration is not yet done in the example referred to in this section, but it is planned for the near future). It should be noted, however, that due to the presence of chlorides, there is a potential for the production of hazardous substances (dioxins and furans) when the sludge is incinerated [281, Belgium, 2002]. Catalytic and high temperature incinerators are now available to prevent these emissions.

Operational data

COD of input water to the treatment plant varies between 4000 and 10000 mg/l. COD in the permeate is about 600 mg/l, which means a removal efficiency of about 90%.

Coagulation has to be carried out and controlled very carefully because of organic binders and fixation agents. If these compounds became completely inactivated, they would lead to scaling of the membrane and would block it within a short time.

The pressure difference of microfiltration is about 1 bar.

Cross-media effects

Energy is required for waste water treatment and recycling [179, UBA, 2001]. No data were made available regarding consumption levels.

Applicability

The technique is applicable to existing and new installations preparing pigment pastes for coating or printing operations.

Economics

The described plant with a flow of 2.5 m³/h (comprising the two waste water streams mentioned) needed investment of 180000 euros. Operating cost, including external disposal of the concentrate (which is the major part) is about 4 euro/m³.

Driving force for implementation

The company considered in this example is discharging the waste water to a municipal waste water treatment plant with strong limitations imposed on flow and COD.

Reference plants

A plant for 1.25 m³/h has been operating since 2001 at van Clewe GmbH, D-46495 Dingden, where combined treatment with scrubbing water from purification of stenter off-gas takes place (additional 1.25 m³/h).

Reference literature

[179, UBA, 2001]
4.1.7.4.3 Waste waster treatment of segregated streams in a membrane biological reactor

Description
The effluents containing hardly biodegradable compounds (e.g. polyvinyl alcohol (PVA) removed from fabric during desizing) are treated in a membrane biological reactor.

Technical description
PVA is only biodegradable under certain conditions. These include a waste water temperature of more than 15 °C, a food to microorganisms ratio of less than 0.15 kg BOD₅/kg MLSS x d and adaptation of the biomass [212, HAZBREF 2019]. If in an industrial or municipal biological waste water treatment plant these conditions cannot be maintained over the entire year (e.g. due to very low waste water temperature in winter or very high in the summer), additional treatment is required.

A membrane biological reactor (MBR) (see Section 4.1.7.3.5.4.2) equipped with an ultrafiltration membrane, preventing residual PVA from leaving the reactor, can be used for treatment at unfavourable temperatures by using adapted microorganisms. The membrane can either be separately installed or directly submerged in the activated sludge tank.

Achieved environmental benefits
The emission of PVA to water bodies is drastically minimised over the entire year, including winter time with low waste water temperatures.

Environmental performance and operational data
Figure 4.27 shows a waste water treatment plant with PVA containing streams originating from desizing machines. The waste water streams are then segregated by automated valves and directed to an equalisation tank from where the streams are fed to the tube flocculator and subsequently to the membrane bioreactor (MBR). The food to microorganisms ratio is about 0.2 kg BOD₅/kg MLSS x d. PVA is degraded between 95% and 98%, even at temperatures of 40 °C. To still enable biodegradation, the PVA-degrading microorganisms have been adapted to elevated temperature levels.
Cross-media effects

Compared to the treatment in a conventional activated sludge system or in a municipal waste water treatment plant, biological treatment in a MBR requires additional energy as the energy consumption of a MBR plant is higher than that of conventional activated sludge systems.

Technical consideration relevant to applicability

The technique is applicable to both new and existing plants. However, in existing plants, sufficient space for equalisation tanks and the MBR plant is a prerequisite. Furthermore, in existing plants additional waste water pipes have to be retrofitted to enable proper segregation of the different waste water streams. It can be expected that low waste water temperatures (where PVA degradation is low) usually only occur in colder parts of Europe (e.g. central and northern Europe).

Economics

The investment costs for the plant shown in Figure 4.27 were around EUR 1.5 million. The treatment costs are about EUR 1-1.5/m³.

Driving force for implementation

- Environmental regulation (emission limit values).
- Reduction of waste water fees (in the case of indirect discharge).

Example plants

Cilander AG, Herisau/Switzerland.

Reference literature

[ 212, HAZBREF 2019 ]
4.1.7.4.4 Optimised waste water recycling and reuse [Recycling of textile waste water by treatment of selected streams with]

From ex-Section 4.10.4

**Description**
Effluents are treated with a combination of filtration techniques (e.g. micro-, ultra-, nanofiltration, reverse osmosis) and/or evaporation. The permeate is recycled in the processes, the concentrate is either reused or further treated to recover auxiliary chemicals (e.g. sizing agents, dispersants, acids, salts) which can be reused in textile treatment processes.

**Technical description**
Membrane techniques are applied in various combinations for the treatment of segregated streams to allow water reclamation and reuse closely integrated with the process. Two case studies are presented. Typical segregated effluents for which membrane techniques are applied to effluents come from desizing and dyeing operations, especially from the washing steps. These case studies, however, are examples only. Membrane techniques can also be applied to other types of effluents, such as, for example, the desizing effluents (see Section 4.5.1), including those resulting from the enzymatic desizing of fabrics treated with starch and modified starch sizes [192, Danish EPA, 2001].

The concentrates from treatment with the membrane techniques can be further treated with evaporation and/or crystallisation to further separate the water content for reuse and the remaining concentrated liquids (e.g. acids or alkalis) or solid substances (e.g. salts) for reuse in the processes (e.g. in dyeing). The combination of techniques used depends on the load and nature of the pollutants in the waste water effluent. The combinations of these kinds of treatment are also known as the zero liquid discharge (ZLD) approach. [135, RICARDO 2019], [231, Telgmann et al. 2019]

**Plant A** [26, UBA, 2001]
The company treats woven fabric, mainly consisting of cotton. The process sequence includes pretreatment, dyeing (cold pad batch), pigment printing and finishing (application of softeners or fluorocarbon resins). Rinsing operations account for most of the waste water produced.

The next figure shows the flow sheet of the treatments applied to the segregated streams. Membrane techniques applied include ultrafiltration, nanofiltration and reverse osmosis.

**Figure:** Treatment of selected segregated waste water streams using a series of membrane techniques (ultrafiltration, nanofiltration and reverse osmosis) – the cut-offs are expressed in Dalton (D) [179, UBA, 2001]

Not all waste water is recycled. Waste water from pretreatment (scouring and bleaching) and finishing (residual padding liquors) is not treated in the membrane plant but is discharged, after neutralisation, to the municipal waste water treatment plant.

In order to assess the potential for reuse, the single process streams have been carefully analysed and segregated according to their suitability for treatment with membranes. For instance, streams containing pigment pastes cannot be treated with membranes because the binders would lead to irreversible scaling of the equipment. Moreover, some process modifications have been necessary. For example, use of water glass in cold pad batch dyeing had to stop because silicates would also block the membranes.

The first membrane step is an ultrafiltration tubular ceramic module, which is needed in order to remove all residual particles and polymers.
About 90% of the feed can be recycled for most processes. However, the reuse of the treated water has to be carefully assessed. For example, fresh water and not recycled water is used for the preparation of bleaching, dyeing and finishing liquors.

Plant B) [192, Danish EPA, 2001]

The second example is also of a company finishing cotton fabric. The measures include:
- reclamation and reuse of dye bath and first rinsing water after reactive dyeing by treating the highly coloured and salted water with activated carbon; the carbon retains the dyestuff and other organic chemicals and delivers clear, hot water with sodium chloride and sodium hydroxide for reuse
- reclamation and reuse of rinsing water after dyeing by membrane filtration (with nanofiltration or reverse osmosis).

**Main-Achieved environmental benefits**
- Reduced discharge of waste water.
- Reduced water consumption.
- Recovery of auxiliary chemicals (e.g. sizes, salts, dispersion agents).

**Environmental performance and operational data**

*Plant A* went into operation at the end of 1995. To avoid membranes scaling and fouling, many problems had to be tackled, especially the removal of fibres and particles (e.g. dust from singeing) need to be removed (e.g. by upstream sieving). Also, the identification of chemicals that were causing scaling of the membranes need to be neutralised. In the case of ultrafiltration, the step had to be changed from spiral modules are much less sensitive to scaling than ceramic tubular modules. Polymer membranes have proven a life time of 2-3 years. [36, ÖKOPOL 2011]

As a filter cake is produced that needs to be cleaned, self-cleaning membranes are preferred (e.g. transverse current filtration).

Waste water is circulated over membranes, producing a coating on the surface of the membrane where the transverse flow of waste water takes place. The coating can be kept a specific thickness by regulating the transverse current or by backflushing. [36, ÖKOPOL 2011]

The filtrate/permeate amount depends on the pressure and on the thickness of the coating on the membrane. Waste water is circulated into the system according to the amount of drained-off filtrate. The reference data for permeate fluxes achieved by membrane techniques are:

- ultrafiltration (UF), cut-off around 50 daltons: 85-130 l/m² x h;
- nanofiltration (NF), cut-off around 200 daltons: 12-17 l/m² x h;
- reverse osmosis (RO), cut-off around 50 daltons: 11-17 l/m² x h.

A reduction in water consumption and waste water discharge of about 60% is reported in a plant Fa. van Clewe A [26, UBA, 2001]. The COD load in the effluent discharged to the municipal treatment plant is reduced by about 50%. Similar reductions in water consumption and discharge of chemicals (especially salt) are also claimed in the second example plant [42, Danish EPA, 2001].

For ZLD configurations, combinations of different types of evaporators are used including agitated thin-film, falling-film, forced-circulation, mechanical vapour recompression, multiple-effect, etc. The ZLD systems can achieve water recycling rates of more than 98% and recovery rates for salt from dyeing effluents of up to 90%. [135, RICARDO 2019], [231, Telgmann et al. 2019]

The use of different combinations and/or variations of waste water treatment (WWT) techniques to improve recycling and reuse of waste waters is an important area of research and
development in the textile sector. Examples of recent LIFE, Eco-innovation and Horizon 2020 projects demonstrating these approaches are presented in the Table 4.22 below:

### Table 4.22: Examples of LIFE, Eco-innovation and Horizon 2020 projects on recycling and reuse of textile waste waters

<table>
<thead>
<tr>
<th>Project name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BATTLE - Best Available Technique for water reuse in TextiLE SMEs</td>
<td>The demonstration plant was the medium-sized textile finishing plant Stamperia di Martinengo (IT) – with 500 m$^3$/day of effluent treated of which 374 m$^3$/day were recovered/reused. The treatment technique was membrane UF. A high recovery rate was enabled by an innovative water management system, which integrated online effluent characterisation, stream segregation, final effluent treatability evaluation and impact control, reclaimed water reusability and cost analysis. [234, ENEA 2019]</td>
</tr>
<tr>
<td>PROWATER - Sustainable water management in the textile wet industry through an innovative treatment process for waste water reuse</td>
<td>The demonstration plants were 4 textile finishing plants from Prato (IT). The effluent recycling system was composed of a sequence of treatments: physico-chemical pretreatment (coagulation + lamellar sedimentation or flotation), cross-flow ultrafiltration and ozonation. The removal efficiency of surfactants was 62 % and of colour 98 %. Operating costs in 4 demonstration plants were in a range between EUR 0.78 and EUR 2.37 per m$^3$. Fresh water consumption was reduced by 40 % on an industrial scale. [235, Tecnotessile 2019]</td>
</tr>
<tr>
<td>PURIFAST - Advanced Purification Of Industrial And Mixed Waste Water By Combined Membrane Filtration And Sonochemical Technologies</td>
<td>Pre-industrial-scale prototype of advanced waste water treatment system based on ultrafiltration (UF) and an ultrasonic Advanced Oxidation Process (AOP) on textile and mixed waste waters. For textile waste waters, a reduction efficiency of more than 90 % was achieved for colour and around 80 % for COD and TSS. As much as 60 % of textile effluent has proven to be reusable. An ex-post study revealed that the technique was not implemented on demonstration sites (in IT, and DE) due to the large capital investments needed. [236, Next Technology Tecnotessile 2019]</td>
</tr>
<tr>
<td>Water-Saving Processes for Textile Production (WASATEX)</td>
<td>A combination of techniques like a membrane bioreactor, nanofiltration, filtration (resin bleaching and softener), reverse osmosis and UV chemical oxidation was implemented in Benetton Tekstil company in Osijek (HR). A reuse/recycling rate of 62 % (1 000 out of 1 600 m$^3$/day of fresh water) was achieved in the plant (theoretically up to 90 % is possible). The energy recovery reduced the natural gas consumption for heating the fresh water. The brine recovery reduced the NaCl consumption. The estimated return on investment (ROI) was 5 years. [237, ASPEL 2019]</td>
</tr>
<tr>
<td>European consortium to demonstrate EColoRO concept for waste water reuse in the textile industry</td>
<td>Waste water treatment by electrocoagulation followed by membrane filtration (ultrafiltration and reverse osmosis) allowed the reuse of up to 90 % of textile waste waters. The electrocoagulation removes 93-96 % of dyes and pigments. The technology was demonstrated on an industrial scale in textile plants in BE and IT. [238, S-ISPT 2019]</td>
</tr>
</tbody>
</table>
Aquatfite4use – The project for sustainable water use in industry

The combination of treatment techniques tested in plants in SI (Tekstina, Svilanit) and CZ (Inotex) included: flocculation, membrane bioreactor (MBR), ultrafiltration, nanofiltration (NF), evapoconcentration and AOP (UV/H\textsubscript{2}O\textsubscript{2}). The textile effluent streams were segregated and treated separately based on their pollution level. The highly concentrated streams were treated by evapoconcentration (COD removal 96-98%). The low-medium concentrated streams were treated by MBR/AOP or MBR/NF (COD removal 93-98%, conductivity removal 70-80%, turbidity removal 99%). Mixed textile waste waters were treated with flocculation/biological treatment/AOP (UV/H\textsubscript{2}O\textsubscript{2}) as end-of-pipe treatment without any effluents segregation. [239, TNO 2019]

ElectroChemical technique combined with UV irradiation for the treatment and reuse of dyeing textile waste waters: Industrial marketing (ECUVal)

Photo(UV)-electrochemical treatment is used for degradation of dyes contained in the textile effluents. The salts in the effluent serve as electrolyte. Residual dyes are removed by the addition of chemical reagents. The final effluent contains salt and can be reused for dyeing. Water consumption for dyeing process was reduced by 70-100%, dye removal > 90%, lower salt consumption (15-60%). Industrial pilot and scale-up in plants in ES. [240, UPC 2019]

The plant treats about 900 m\textsuperscript{3}/week waste water (which is about 70% of the overall waste water flow) and recovers about 800 m\textsuperscript{3}/week water which can be used for all washing/rinsing operations.

The plant is operated batch-wise. The concentrate is physico-chemically treated in an external plant. For further optimisation, plans are in hand to treat the concentrate by evaporation (in order to achieve 15% water content) and then send it to incineration.

The experience with Plant B reported by Denmark was a semi-full scale test. The dimensioning parameters from the activated carbon test plant were a retention time of 2 hours and a capacity of 4 kg carbon/kg dyestuff. The carbon type used was F400 from Chemviron Carbon. A full-scale plant can consist of two columns connected in series and with reversible flow, so that there is capacity for recharging when they reach dye breakthrough point.

Test dyeings showed that reusing warm, saline and decoloured dye baths was possible with no adverse effects on fabric shade or fastness.

The dimensioning parameters of the membrane treatment from the test plant based on spiral wound elements were an average production of 25 l/m\textsuperscript{2}h at 25 °C and 7-10 bar. The selected elements in use were 50 mil Duratherm elements from OSMONICS DESAL.

Cross-media effects
- Increased energy consumption (e.g. for pumps and evaporation).
- Solid or liquid waste generated (e.g. remining impurities and liquid concentrates).

Energy consumption seems to be significant. For plant A, the energy consumption of the membrane plant is reported to be about 20 kWh/m\textsuperscript{3} treated waste water. Moreover, since membrane treatment is a separation technique, correct disposal of the concentrate is a crucial point.

No consumption data are reported for the second case study.
Technical consideration relevant to applicability
The membrane techniques are applicable to all textile plants finishing industries, provided that proper waste water segregation is practised and membrane-compatible single waste water streams are selected for treatment. Recipes have to be checked in terms of membrane compatibility and have to be changed if necessary (see Description above).

Additional piping and buffer tanks connecting waste water recovery units with process machines are needed. In existing installations space availability may be limited. Structural changes for additional pipelines are needed in existing mills for waste water segregation. Additional tanks (space demand) for interim storage have to be installed.

For salt reuse (plant B), since the salt will be in the water from the very start, the so-called “all-in” dyeing method has to be applied. This is opposite to the normal way where the dyestuff is evenly distributed before salt is added (see Section 2.7.3 “Reactive dyes”).

Economics
The investment for the a 10 m³/h membrane bioreactor (Plant A) is about EUR 1 million. Taking into account the capital cost and operating costs (labour, energy, chemicals for membrane cleaning, maintenance and concentrate disposal), the specific costs are EUR 4.5 euros/m³ of recycled water (capital cost: EUR 1.3 euros/m³, operating cost: EUR 3.2 euros/m³) [179, UBA, 2001].

In Plant B, payback time is reported as 5 years for reclaiming and reuse of dye bath by treatment with activated carbon and 8 months for membrane treatment and recycling of rinsing water from dyeing [192, Danish EPA, 2001].

Driving force for implementation
- Environmental legislation.
- Savings in water consumption.
- Savings in chemicals.

High costs for fresh water and waste water discharge are the main driving forces.

Reference Example plants
Membrane techniques for treatment of segregated waste water streams are applied in many plants in Europe.
IDEAL Floorcoverings, Wielsbeke, Belgium (BE009) uses filtration (ultrafiltration and reverse osmosis to recycle waste water. [150, EIPPCB 2019]
Plants FR133 and DE022 from the data collection use evapoconcentration to recycle waste water. [196, TWG 2019]
In particular the two examples described here are:
Plant A: Fa. van Clewe GmbH & Co.KG, D-46499 Dingden. with a design flow of 10 m³/h
Plant B: Martensens A/S, DK-7330 Brande

Reference literature
[26, UBA, 2001], [42, Danish EPA, 2001], [36, ÖKOPOL 2011 ], [135, RICARDO 2019 ], [150, EIPPCB 2019 ], [187, Dasgupta et al. 2015 ], [231, Telgmann et al. 2019 ], [196, TWG 2019]

4.1.7.4.5 Anaerobic removal of residual dyestuffs from padding liquors and printing paste residues

From ex-Section 4.10.6
Description
Residual printing pastes and padding liquors for continuous and semi-continuous dyeing, which contain high concentrations of dyestuffs. (see Section 3.3.3.5.4). Residual padding liquors and printing pastes can be treated in anaerobic digesters (see Section 4.1.7.3.5.2), preferably in
co-fermentation with primary and excess sludge from biological treatment. In practice, the residues are fed into anaerobic digesters at municipal waste water treatment plants.

Technical description
When azo dyestuffs are treated under anaerobic conditions, the azo groups (characteristic of this type of dyestuffs) are irreversibly destroyed, causing the dyestuffs to lose their colour. However, the remaining aromatic systems still absorb light, so some slight yellowish colour often remains.

The water-soluble cleavage products (the ones with sulphonic groups) are present in the water phase and reach the activated sludge treatment both as overflow from the anaerobic digester and as filtrate from sludge dewatering. The more substituted Some naphthalene derivatives are hardly biodegradable and may still be present in the final effluent. For this reason, the supernatant needs to be subsequently treated in an activated sludge system.

Main-Achieved environmental benefits
Anaerobic treatments reach colour removal efficiencies of more than 90 % with azo dyes (determined as reduction of spectral absorption coefficients at the wavelengths 436 nm, 525 nm and 620 nm) [26, UBA, 2001].

Also with printing pastes containing natural thickeners, such as alginates or galactomannans, there is a conversion to biogas thanks to degradation of these biopolymers.

Although the quantity of the concentrates mentioned represents a small percentage of the total discharged waste water (only a few tonnes per week even for large mills), there are cases in which the total residual colour in the effluent of treatment plants could be reduced by about 50 %.

Environmental performance and operational data
In order to derive the most benefit from anaerobic treatment, this technique should be applied in combination with process-integrated techniques aimed at minimising padding liquors and printing paste residues. Moreover, it is important to separate at source the residual padding liquors from other streams in order to keep them concentrated.

The dosage of reactive printing paste should not exceed 10 g/kg sludge because of possible inhibition effects on the anaerobic process. Laboratory tests may assist with determination of inhibition effects.

Padding liquors and printing pastes with heavy metal-containing dyestuffs should be separated unless the sludge resulting from the anaerobic treatment is incinerated or disposed of in appropriate landfill (see Landfill Directive 99/31/EC).

Cross-media effects
The reductive cleavage of the azo bonds leads to aromatic amines. As for the potential for release of carcinogenic aromatic amines, investigations carried out so far have not confirmed this fear [26, UBA, 2001] (with reference to “Kolb, 1988”). Moreover, the supernatant from the anaerobic treatment is normally treated with activated sludge.

Technical considerations relevant to applicability
The technique can be applied to both new and existing installations.

Anaerobic treatment is particularly suitable for azo dyestuffs, which represent 50 % of the colourants currently available on the market.

However, other chromophoric systems cannot be treated substantially. Vat dyes for example, are reduced to the colourless form, but this process is reversible.
Pigment printing pastes cannot be treated in anaerobic digesters because all components are non-biodegradable and scaling problems occur because of polymer binders.

In conclusion, even if anaerobic treatments reach efficiencies of 90 % with azo dyes, for companies using a broader range of dyes this technique has an average overall efficiency.

**Economics**
The known cost for anaerobic treatment in municipal anaerobic digesters varies between EUR 30 and EUR 60 per tonne of padding liquor or printing paste [ 26, UBA, 2001].

**Driving force for implementation**
Pressure related to non-Compliance with existing environmental standards for emissions to water (e.g. for colour) in the discharge from treatment plants.

**Example Reference plants**
In Germany, residual printing pastes are treated in the anaerobic digesters of the municipal waste water plants of Ravensburg, D-Ravensburg and Bändlegrund, D-Weil. Residual padding liquors for dyeing are treated in the anaerobic digester of the municipal waste water treatment plant of Heidenheim, D-Heidenheim.

Plants CZ019 (printing and dyeing) and FR134 (dyeing and functional finishing) report using anaerobic treatment for waste water treatment.

**Reference literature**
[ 26, UBA, 2001]

**4.1.7.5 Environmental performance of plants using different combinations of waste water treatment techniques**

**4.1.7.5.1 Direct discharge**

Tables below present the environmental performance (emissions to water) of the plants treating textile effluents with combinations of waste water treatment techniques and directly discharging to the receiving water body. The environmental performance for chemical oxygen demand (COD) is presented in Table 4.23, for total organic carbon (TOC) in Table 4.24, for total nitrogen (TN) in Table 4.25, for total phosphorus (TP) in Table 4.26 and for total suspended solids (TSS) in Table 4.27.
### Table 4.23: Environmental performance of combinations of waste water treatment techniques for chemical oxygen demand (COD) emissions to water

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Associated processes</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Combination of techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT082_w [1]</td>
<td>Dyeing - Singeing - Functional finishing - Thermal treatment - Wool Fulling</td>
<td>12</td>
<td>24.72</td>
<td>43</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Adsorption (e.g. powdered/granular activated carbon, lignite coke, etc.), Other</td>
</tr>
<tr>
<td>IT096_w [1]</td>
<td>Dyeing - Other</td>
<td>29</td>
<td>38.67</td>
<td>49</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Other</td>
</tr>
<tr>
<td>BE010_w [1]</td>
<td>Bleaching - Dyeing - Bleaching - Scouring - Functional finishing</td>
<td>31</td>
<td>45.4</td>
<td>53</td>
<td>Equalisation Activated sludge process, Nitrification/denitrification, Other</td>
</tr>
<tr>
<td>Code</td>
<td>Process Description</td>
<td>Year 1</td>
<td>Year 2</td>
<td>Year 3</td>
<td>Notes</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------------------------</td>
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<td>--------</td>
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<td>------------------------------------------</td>
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<tr>
<td>CZ020_w</td>
<td>Dyeing</td>
<td>21</td>
<td>34.36</td>
<td>65</td>
<td>Sedimentation, Nitrification/denitrification, Neutralisation, Coagulation and flocculation, Activated sludge process</td>
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<tr>
<td>CZ019_w</td>
<td>Bleaching - Dyeing - Printing - Functional finishing - Desizing</td>
<td>NI</td>
<td>71</td>
<td>NI</td>
<td>Equalisation, Neutralisation, Anaerobic treatment, Nitrification/denitrification, Activated sludge process</td>
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<tr>
<td>IT092_w</td>
<td>Dyeing - Other</td>
<td>7.6</td>
<td>23.35</td>
<td>73.8</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Reverse osmosis</td>
</tr>
<tr>
<td>IT097_w</td>
<td>Dyeing - Shrink-proof finishing - Printing - Other</td>
<td>28</td>
<td>53.1</td>
<td>80</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
</tr>
<tr>
<td>PT111_w</td>
<td>Desizing - Dyeing - Fabric production - Wool Fulling - Functional finishing - Shrink-proof finishing - Dry cleaning - Thermal treatment</td>
<td>35</td>
<td>56.67</td>
<td>80</td>
<td>Equalisation, Neutralisation, Activated sludge process, Sedimentation, Sand filtration, Other</td>
</tr>
<tr>
<td>PT098_w</td>
<td>Wool Fulling - Functional finishing - Dyeing - Thermal treatment</td>
<td>27</td>
<td>58.30</td>
<td>91</td>
<td>Equalisation, Neutralisation, Sedimentation, Sand filtration, Activated sludge process, Other</td>
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<tr>
<td>BE007_w</td>
<td>Dyeing</td>
<td>NI</td>
<td>92.94</td>
<td>NI</td>
<td>Equalisation, Neutralisation, Sand filtration, Activated sludge process, Nitrification/denitrification</td>
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<tr>
<td>DE034_w</td>
<td>Washing synthetic fibre - Desizing - Bleaching - Dyeing</td>
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<td>97</td>
<td>Activated sludge process, Nitrification/denitrification</td>
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<tr>
<td>Task Description</td>
<td>FR</td>
<td>Duration</td>
<td>F20</td>
<td>FR20</td>
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<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
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<td></td>
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<tr>
<td>Screening, Activated sludge process</td>
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</tr>
</tbody>
</table>

NB:
NI = No information
Source: [196, TWG 2019]
Table 4.24: Environmental performance of combinations of waste water treatment techniques for total organic carbon (TOC) emissions to water

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Associated processes</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Combination of techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT092_w {1}</td>
<td>Dyeing - Other</td>
<td>10.4</td>
<td>10.4</td>
<td>10.4</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Reverse osmosis</td>
</tr>
<tr>
<td>IT097_w {1}</td>
<td>Dyeing - Shrink-proof finishing - Printing - Other</td>
<td>10.5</td>
<td>10.5</td>
<td>10.5</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
</tr>
<tr>
<td>BE010_w {1}</td>
<td>Bleaching - Dyeing - Bleaching - Scouring - Functional finishing</td>
<td>10</td>
<td>13.17</td>
<td>19</td>
<td>Equalisation, Activated sludge process, Nitrification/denitrification, Other</td>
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<tr>
<td>DE032_w {1}</td>
<td>Washing synthetic fibre - Desizing - Bleaching - Dyeing - Printing</td>
<td>12.5</td>
<td>16.82</td>
<td>22</td>
<td>Equalisation, Neutralisation, Grit separators, Coagulation and flocculation, Sedimentation, Sand filtration, Nitrification/denitrification, Activated sludge process</td>
</tr>
<tr>
<td>DE034_w {1}</td>
<td>Washing synthetic fibre - Desizing - Bleaching - Dyeing</td>
<td>9.6</td>
<td>16.53</td>
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<td>BE014_w {1}</td>
<td>Bleaching - Dyeing - Functional finishing</td>
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<td>BE007_w {1}</td>
<td>Dyeing</td>
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<td>DE025_w {1}</td>
<td>Washing synthetic fibre - Dyeing - Printing</td>
<td>22</td>
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<td>Emission point</td>
<td>Associated processes</td>
<td>Minimum concentration over 3 years (mg/l)</td>
<td>Average concentration over 3 years (mg/l)</td>
<td>Maximum concentration over 3 years (mg/l)</td>
<td>Combination of techniques</td>
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<td></td>
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<td>NI</td>
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<td>NI</td>
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<td>BE009_w</td>
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<td>4.11</td>
<td>7.7</td>
<td>Screening, Sedimentation, Equalisation, Activated sludge process, Sand filtration, Coagulation and flocculation, Flotation, Chemical oxidation (incl. Advanced oxidation), Sand filtration, Chemical reduction, Microfiltration, Reverse osmosis</td>
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<td>BE011_w</td>
<td>Dyeing</td>
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<td>4.85</td>
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<tr>
<td>IT092_w [1]</td>
<td>Dyeing - Other</td>
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<td>17.10</td>
<td>17.1</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Reverse osmosis</td>
</tr>
<tr>
<td>IT097_w [1]</td>
<td>Dyeing - Shrink-proof finishing - Printing - Other</td>
<td>6</td>
<td>12.25</td>
<td>18.5</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
</tr>
<tr>
<td>PT111_w [1]</td>
<td>Desizing - Dyeing - Fabric production - Wool Fulling - Functional finishing - Shrink-proof finishing - Dry cleaning - Thermal treatment</td>
<td>6</td>
<td>9.48</td>
<td>18.7</td>
<td>Equalisation, Neutralisation, Activated sludge process, Sedimentation, Sand filtration, Other</td>
</tr>
<tr>
<td>BE010_w [1]</td>
<td>Bleaching - Dyeing - Bleaching - Scouring - Functional finishing</td>
<td>3</td>
<td>8.24</td>
<td>19.9</td>
<td>Equalisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Other</td>
</tr>
</tbody>
</table>

NB: NI = No information
Source: [196, TWG 2019]
Table 4.26: Environmental performance of combinations of waste water treatment techniques for total phosphorus (TP) emissions to water

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Associated processes</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Combination of techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE007_w</td>
<td>Dyeing</td>
<td>0.15</td>
<td>0.19</td>
<td>0.35</td>
<td>Equalisation, Neutralisation, Sand filtration, Activated sludge process, Nitrification/denitrification</td>
</tr>
<tr>
<td>DE025_w</td>
<td>Washing synthetic fibre - Dyeing - Printing</td>
<td>0</td>
<td>0.13</td>
<td>0.47</td>
<td>Equalisation, Neutralisation, Coagulation and flocculation, Sedimentation, Activated sludge process</td>
</tr>
<tr>
<td>CZ020_w</td>
<td>Dyeing</td>
<td>0.08</td>
<td>0.21</td>
<td>0.65</td>
<td>Sedimentation, Nitrification/denitrification, Neutralisation, Coagulation and flocculation, Activated sludge process</td>
</tr>
<tr>
<td>BE010_w</td>
<td>Bleaching - Dyeing - Bleaching - Scouring - Functional finishing</td>
<td>0.2</td>
<td>0.57</td>
<td>0.91</td>
<td>EqualisationActivated sludge process, Nitrification/denitrification, Other</td>
</tr>
<tr>
<td>IT082_w</td>
<td>Dyeing - Singeing - Functional finishing - Thermal treatment - Wool Fulling</td>
<td>0.198</td>
<td>0.53</td>
<td>1</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Adsorption (e.g. powdered/granular activated carbon, lignite coke, etc.), Other</td>
</tr>
<tr>
<td>CZ019_w</td>
<td>Bleaching - Dyeing - Functional finishing - Desizing</td>
<td>NI</td>
<td>1.20</td>
<td>NI</td>
<td>Equalisation, Neutralisation, Anaerobic treatment, Nitrification/denitrification, Activated sludge process</td>
</tr>
<tr>
<td>DE032_w</td>
<td>Washing synthetic fibre - Desizing - Bleaching - Dyeing - Printing</td>
<td>0.35</td>
<td>0.81</td>
<td>1.4</td>
<td>Equalisation, Neutralisation, Grit separators, Coagulation and flocculation, Sedimentation, Sand filtration, Nitrification/denitrification, Activated sludge process</td>
</tr>
<tr>
<td>BE009_w</td>
<td>Printing - Coating and laminating</td>
<td>0</td>
<td>0.56</td>
<td>1.67</td>
<td>Screening, Sedimentation, Equalisation, Activated sludge process, Sand filtration, Coagulation and flocculation, Flotation, Chemical oxidation (incl. Advanced oxidation), Sand filtration, Chemical reduction, Microfiltration, Reverse osmosis</td>
</tr>
</tbody>
</table>
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| BE011_w  | Dyeing | 0.33 | 0.77 | 1.7 | Equalisation, Neutralisation, Coagulation and flocculation, Activated sludge process, Nitrification/denitrification, Sand filtration, Nanofiltration, Chemical oxidation (incl. Advanced oxidation) |
| BE014_w  | Bleaching - Dyeing - Functional finishing | 0.18 | 1.24 | 2.2 | Equalisation, Activated sludge process, Nitrification/denitrification |
| PT098_w  | Wool Fulling - Functional finishing - Dyeing - Thermal treatment | 0.15 | 1.05 | 2.4 | Equalisation, Neutralisation, Sedimentation, Sand filtration, Activated sludge process, Other |
| PT111_w  | Desizing - Dyeing - Fabric production - Wool Fulling - Functional finishing - Shrink-proof finishing - Dry cleaning - Thermal treatment | 0.33 | 1.20 | 2.4 | Equalisation, Neutralisation, Activated sludge process, Sedimentation, Sand filtration, Other |
| DE034_w  | Washing synthetic fibre - Desizing - Bleaching - Dyeing | 0.76 | 1.33 | 2.8 | Activated sludge process, Nitrification/denitrification |
| IT092_w  | Dyeing - Other | 0.3 | 1.24 | 2.9 | Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Reverse osmosis |
| IT097_w  | Dyeing - Shrink-proof finishing - Printing - Other | 0.1 | 1.99 | 3.32 | Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation |
| IT096_w  | Dyeing - Other | 2.3 | 4.67 | 7 | Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Other |
### Table 4.27: Environmental performance of individual or combinations of waste water treatment techniques for total suspended solids (TSS) emissions to water

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Associated processes</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Combination of techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT097_w [1]</td>
<td>Dyeing - Shrink-proof finishing - Printing - Other</td>
<td>5</td>
<td>8.00</td>
<td>11</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
</tr>
<tr>
<td>IT096_w [1]</td>
<td>Dyeing - Other</td>
<td>10</td>
<td>12.67</td>
<td>15</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Other</td>
</tr>
<tr>
<td>FR132_w [1]</td>
<td>No information</td>
<td>2</td>
<td>5.07</td>
<td>20</td>
<td>Sedimentation</td>
</tr>
<tr>
<td>FR132_w [2]</td>
<td>Bleaching - Dyeing</td>
<td>2</td>
<td>11.29</td>
<td>20</td>
<td>Screening, Activated sludge process</td>
</tr>
<tr>
<td>BE007_w [1]</td>
<td>Dyeing</td>
<td>NI</td>
<td>22.22</td>
<td>NI</td>
<td>Equalisation, Neutralisation, Sand filtration, Activated sludge process, Nitrification/denitrification</td>
</tr>
<tr>
<td>BE010_w</td>
<td>Bleaching - Dyeing - Bleaching - Scouring - Functional finishing</td>
<td>10</td>
<td>14.27</td>
<td>27</td>
<td>EqualisationActivated sludge process, Nitrification/denitrification, Other</td>
</tr>
<tr>
<td>CZ020_w</td>
<td>Dyeing</td>
<td>2</td>
<td>7.00</td>
<td>28</td>
<td>Sedimentation, Nitrification/denitrification, Neutralisation, Coagulation and flocculation, Activated sludge process</td>
</tr>
<tr>
<td>PT110_w</td>
<td>Dyeing</td>
<td>1</td>
<td>10.15</td>
<td>29</td>
<td>Equalisation, Grit separators, Screening, Coagulation and flocculation, Sedimentation, Activated sludge process, Other</td>
</tr>
<tr>
<td>PT111_w</td>
<td>Desizing - Dyeing - Fabric production - Wool Fulling - Functional finishing - Shrink-proof finishing - Dry cleaning - Thermal treatment</td>
<td>5</td>
<td>12.67</td>
<td>29</td>
<td>Equalisation, Neutralisation, Activated sludge process, Sedimentation, Sand filtration, Other</td>
</tr>
<tr>
<td>UK124_w</td>
<td>Dyeing - Functional finishing - Washing synthetic fibre</td>
<td>3</td>
<td>8.20</td>
<td>37.3</td>
<td>Neutralisation, Coagulation and flocculation, Flotation, Other</td>
</tr>
<tr>
<td>IT092_w</td>
<td>Dyeing - Other</td>
<td>2</td>
<td>10.05</td>
<td>39.2</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Reverse osmosis</td>
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<tr>
<td>PT098_w</td>
<td>Wool Fulling - Functional finishing - Dyeing - Thermal treatment</td>
<td>10</td>
<td>25.83</td>
<td>42</td>
<td>Equalisation, Neutralisation, Sedimentation, Sand filtration, Activated sludge process, Other</td>
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<tr>
<td>DE025_w</td>
<td>Washing synthetic fibre - Dyeing - Printing</td>
<td>0</td>
<td>5.85</td>
<td>45</td>
<td>Equalisation, Neutralisation, Coagulation and flocculation, Sedimentation, Activated sludge process</td>
</tr>
</tbody>
</table>

NB: NI = No information
Source: [196, TWG 2019]
4.1.7.5.2 Direct and indirect discharge

Tables below present the environmental performance (emissions to water) of the plants treating textile effluents with individual or combinations of waste water treatment techniques and discharging either directly to the receiving water body or to the sewage with downstream waste water treatment. The environmental performance for adsorbable organically bound halogens (AOX) is presented in Table 4.28, for hydrocarbon oil index (HOI) in Table 4.29, for antimony (Sb) in Table 4.30, for chromium (Cr) in Table 4.31, for copper (Cu) in Table 4.32, for nickel (Ni) in Table 4.33, for zinc (Zn) in Table 4.34 and for sulphides (S²⁻) in Table 4.35.
Table 4.28: Environmental performance of individual or combinations of waste water treatment techniques for adsorbable organically bound halogens (AOX) emissions to water

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Type of discharge</th>
<th>Associated processes</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Combination of techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE010_w {1}</td>
<td>DIR</td>
<td>Bleaching - Dyeing - Bleaching - Scouring - Functional finishing</td>
<td>0.08</td>
<td>0.10</td>
<td>0.12</td>
<td>Equalisation, Activated sludge process, Nitrification/denitrification, Other</td>
</tr>
<tr>
<td>DE032_w {1}</td>
<td>DIR</td>
<td>Washing synthetic fibre - Desizing - Bleaching - Dyeing - Printing</td>
<td>0.035</td>
<td>0.06</td>
<td>0.12</td>
<td>Equalisation, Neutralisation, Grit separators, Coagulation and flocculation, Sedimentation, Sand filtration, Nitrification/denitrification, Activated sludge process</td>
</tr>
<tr>
<td>IT064_w {1}</td>
<td>IND</td>
<td>Scouring - Wool Fulling - Functional finishing - Thermal treatment - Other</td>
<td>0.077</td>
<td>0.10</td>
<td>0.134</td>
<td>Other</td>
</tr>
<tr>
<td>IT079_w {1}</td>
<td>IND</td>
<td>Scouring - Wool Fulling - Functional finishing - Thermal treatment - Other</td>
<td>0.07</td>
<td>0.11</td>
<td>0.14</td>
<td>Other</td>
</tr>
<tr>
<td>BE014_w {1}</td>
<td>DIR</td>
<td>Bleaching - Dyeing - Functional finishing</td>
<td>0.033</td>
<td>0.06</td>
<td>0.158</td>
<td>Equalisation, Activated sludge process, Nitrification/denitrification</td>
</tr>
<tr>
<td>DE025_w {1}</td>
<td>DIR</td>
<td>Washing synthetic fibre - Dyeing - Printing</td>
<td>0</td>
<td>0.02</td>
<td>0.16</td>
<td>Equalisation, Neutralisation, Coagulation and flocculation, Sedimentation, Activated sludge process</td>
</tr>
<tr>
<td>IT068_w {1}</td>
<td>IND</td>
<td>Washing synthetic fibre - Desizing - Scouring - Bleaching - Dyeing - Functional finishing - Other</td>
<td>0.082</td>
<td>0.12</td>
<td>0.163</td>
<td>Other</td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>---------</td>
<td>---------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>-------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>SE118_w</td>
<td>IND</td>
<td>Washing synthetic fibre - Scouring - Bleaching - Dyeing - Singeing - Printing - Functional finishing - Shrink-proof finishing - Coating and laminating - Thermal treatment</td>
<td>0.05</td>
<td>0.09</td>
<td>0.17</td>
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<tr>
<td>BE009_w</td>
<td>DIR</td>
<td>Printing - Coating and laminating</td>
<td>0.085</td>
<td>0.12</td>
<td>0.175</td>
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</tr>
<tr>
<td>IT078_w</td>
<td>IND</td>
<td>Wool Fulling - Washing synthetic fibre - Dyeing</td>
<td>0.075</td>
<td>0.15</td>
<td>0.211</td>
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</tr>
<tr>
<td>BE008_w</td>
<td>IND</td>
<td>Printing - Dyeing</td>
<td>0.16</td>
<td>0.19</td>
<td>0.22</td>
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</tr>
<tr>
<td>IT074_w</td>
<td>IND</td>
<td>Washing synthetic fibre - Scouring - Functional finishing - Dry cleaning - Other</td>
<td>0.092</td>
<td>0.18</td>
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</tr>
<tr>
<td>IT097_w</td>
<td>DIR</td>
<td>Dyeing - Shrink-proof finishing - Printing - Other</td>
<td>0.28</td>
<td>0.32</td>
<td>0.35</td>
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</tr>
<tr>
<td>AT004_w</td>
<td>IND</td>
<td>Washing synthetic fibre</td>
<td>0</td>
<td>0.17</td>
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</tr>
<tr>
<td>BE011_w</td>
<td>DIR</td>
<td>Dyeing</td>
<td>0.08</td>
<td>0.17</td>
<td>0.38</td>
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</tr>
<tr>
<td>Code</td>
<td>Description</td>
<td>C1</td>
<td>C2</td>
<td>C3</td>
<td>Notes</td>
<td></td>
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<tr>
<td>----------</td>
<td>------------------------------------------------------------------------------</td>
<td>----</td>
<td>----</td>
<td>-------------</td>
<td>------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>DE022_w</td>
<td>Raw wool scouring - Washing synthetic fibre - Desizing - Scouring - Bleaching - Dyeing - Thermal treatment - Functional finishing - Coating and laminating</td>
<td>0.01</td>
<td>0.10</td>
<td>0.391</td>
<td>Neutralisation, Oil separation, Evaporation</td>
<td></td>
</tr>
<tr>
<td>FR131_w</td>
<td>Washing synthetic fibre - Bleaching - Dyeing - Printing - Functional finishing - Coating and laminating - Thermal treatment</td>
<td>0.019</td>
<td>0.13</td>
<td>0.41</td>
<td>Screening, Sedimentation, Activated sludge process, Sedimentation, Other</td>
<td></td>
</tr>
<tr>
<td>DE047_w</td>
<td>Desizing - Mercerising - Bleaching - Dyeing - Functional finishing</td>
<td>0</td>
<td>0.19</td>
<td>0.451</td>
<td>Neutralisation</td>
<td></td>
</tr>
<tr>
<td>DE051_w</td>
<td>Washing synthetic fibre - Scouring - Bleaching - Dyeing - Functional finishing</td>
<td>0.04</td>
<td>0.14</td>
<td>0.47</td>
<td>Neutralisation, Coagulation and flocculation, Equalisation</td>
<td></td>
</tr>
<tr>
<td>IT065_w</td>
<td>Desizing - Mercerising - Bleaching - Dyeing - Singeing - Singeing - Functional finishing</td>
<td>0.19</td>
<td>0.34</td>
<td>0.49</td>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Code</th>
<th>Type</th>
<th>Processes</th>
<th>DIR</th>
<th>IND</th>
<th>Other</th>
</tr>
</thead>
<tbody>
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<td>IT089_w</td>
<td>IND</td>
<td>Scouring - Dyeing - Thermal</td>
<td>0.045</td>
<td>0.14</td>
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</tr>
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<td></td>
<td></td>
<td>treatment - Other - Bleaching</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>DE049_w</td>
<td>IND</td>
<td>Desizing - Bleaching - Bleaching</td>
<td>0.05</td>
<td>0.16</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Dyeing - Singeing - Printing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Coating and laminating - Scouring - Functional finishing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE024_w</td>
<td>IND</td>
<td>Desizing - Dyeing - Scouring -</td>
<td>0.1</td>
<td>0.32</td>
<td>0.5</td>
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<tr>
<td></td>
<td></td>
<td>Singeing - Singeing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AT002_w</td>
<td>IND</td>
<td>Bleaching - Dyeing</td>
<td>0</td>
<td>0.25</td>
<td>0.52</td>
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<tr>
<td>CZ016_w</td>
<td>IND</td>
<td>Shrink-proof finishing</td>
<td>0.026</td>
<td>0.16</td>
<td>0.53</td>
</tr>
</tbody>
</table>

**NB:**
- DIR = direct discharge
- IND = indirect discharge
- Source: [196, TWG 2019]
Table 4.29: Environmental performance of individual or combinations of waste water treatment techniques for hydrocarbon oil index (HOI) emissions to water

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Type of discharge</th>
<th>Associated processes</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Combination of techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE007_w {1}</td>
<td>DIR</td>
<td>Dyeing</td>
<td>0.82</td>
<td>0.88</td>
<td>0.93</td>
<td>Equalisation, Neutralisation, Sand filtration, Activated sludge process, Nitrification/denitrification</td>
</tr>
<tr>
<td>PT115_w {1}</td>
<td>IND</td>
<td>Dyeing - Functional finishing</td>
<td>0.04</td>
<td>1.41</td>
<td>2.48</td>
<td>Equalisation, Neutralisation, Screening</td>
</tr>
<tr>
<td>PT108_w {1}</td>
<td>IND</td>
<td>Fabric production - Fabric production</td>
<td>0.3</td>
<td>2.58</td>
<td>4</td>
<td>Neutralisation, Sand filtration, Sand filtration</td>
</tr>
<tr>
<td>IT063_w {1}</td>
<td>IND</td>
<td>Dyeing - Fabric production - Dry cleaning - Printing - Printing - Functional finishing</td>
<td>0.5</td>
<td>1.69</td>
<td>5.7</td>
<td>Equalisation</td>
</tr>
<tr>
<td>PT099_w {1}</td>
<td>IND</td>
<td>Dyeing - Printing - Functional finishing</td>
<td>1</td>
<td>1.64</td>
<td>5.7</td>
<td>Screening, Oil separation, Other</td>
</tr>
<tr>
<td>IT059_w {1}</td>
<td>IND</td>
<td>Scouring - Mercerising - Bleaching - Dyeing - Singeing - Dry cleaning</td>
<td>3.2</td>
<td>4.37</td>
<td>6</td>
<td>Other</td>
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<tr>
<td>PT104_w {1}</td>
<td>IND</td>
<td>Dyeing - Bleaching</td>
<td>0.23</td>
<td>2.51</td>
<td>7</td>
<td>Ultrafiltration, Other,</td>
</tr>
<tr>
<td>PT113_w {1}</td>
<td>IND</td>
<td>Dyeing - Washing synthetic fibre - Bleaching - Functional finishing</td>
<td>2</td>
<td>3.67</td>
<td>7</td>
<td>Screening, Other,</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>IT065_w {1}</th>
<th>IND</th>
<th>Desizing - Mercerising - Bleaching - Dyeing - Singeing - Singeing functional finishing</th>
<th>2.5</th>
<th>5.53</th>
<th>9.4</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT002_w {1}</td>
<td>IND</td>
<td>Bleaching - Dyeing</td>
<td>0</td>
<td>1.56</td>
<td>9.8</td>
<td>Screening, Neutralisation</td>
</tr>
<tr>
<td>AT005_w {1}</td>
<td>IND</td>
<td>Dyeing</td>
<td>1</td>
<td>3.13</td>
<td>10</td>
<td>Neutralisation</td>
</tr>
<tr>
<td>PT114_w {1}</td>
<td>IND</td>
<td>Mercerising - Dyeing - Washing synthetic fibre - Desizing - Scouring - Bleaching - Thermal treatment - Dry cleaning</td>
<td>5</td>
<td>6.67</td>
<td>10</td>
<td>Equalisation, Neutralisation, Screening, Coagulation and flocculation, Sedimentation, Sand filtration, Adsorption (e.g. powdered/granular activated carbon, lignite coke, etc.)</td>
</tr>
</tbody>
</table>

**NB:**
- DIR = direct discharge
- IND = indirect discharge

*Source: [196, TWG 2019]*
Table 4.30: Environmental performance of combinations of waste water treatment techniques for antimony (Sb) emissions to water

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Type of discharge</th>
<th>Associated processes</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Combination of techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE118_w {1} (£)</td>
<td>IND</td>
<td>Washing synthetic fibre - Scouring - Bleaching - Dyeing - Singeing - Printing - Functional finishing - Shrink-proof finishing - Coating and laminating - Thermal treatment</td>
<td>0.0497</td>
<td>0.07</td>
<td>0.11</td>
<td>Sedimentation, Equalisation, Neutralisation</td>
</tr>
<tr>
<td>IT084_w {1} (£)</td>
<td>IND</td>
<td>Bleaching - Dyeing - Thermal treatment</td>
<td>0.001</td>
<td>0.03</td>
<td>0.12</td>
<td>Equalisation, Neutralisation, Grit separators, Screening, Coagulation and flocculation, Sedimentation</td>
</tr>
<tr>
<td>BE014_w {1}</td>
<td>DIR</td>
<td>Bleaching - Dyeing - Functional finishing</td>
<td>0.033</td>
<td>0.06</td>
<td>0.158</td>
<td>Equalisation, Activated sludge process, Nitrification/denitrification</td>
</tr>
<tr>
<td>SE119_w {1} (£)</td>
<td>IND</td>
<td>Washing synthetic fibre - Desizing - Functional finishing - Dyeing</td>
<td>0.126</td>
<td>0.19</td>
<td>0.35</td>
<td>Equalisation, Oil separation, Neutralisation</td>
</tr>
<tr>
<td>DE051_w {1} (£)</td>
<td>IND</td>
<td>Washing synthetic fibre - Scouring - Bleaching - Dyeing - Functional finishing</td>
<td>0.03</td>
<td>0.15</td>
<td>0.44</td>
<td>Neutralisation, Coagulation and flocculation, Equalisation</td>
</tr>
</tbody>
</table>
## Chapter 4

<table>
<thead>
<tr>
<th>DE022_w {1} {2}</th>
<th>IND</th>
<th>Raw wool scouring - Washing synthetic fibre - Desizing - Scouring - Bleaching - Dyeing - Thermal treatment - Functional finishing - Coating and laminating</th>
<th>0.16</th>
<th>0.36</th>
<th>0.7</th>
<th>Neutralisation, Oil separation, Evaporation</th>
</tr>
</thead>
</table>

NB:
- DIR = direct discharge
- IND = indirect discharge
- {1} pretreatment and/or dyeing of polyester
- {2} finishing with flame retardant using antimony trioxide

Source: [196, TWG 2019]
### Table 4.31: Environmental performance of individual or combinations of waste water treatment techniques for chromium (Cr) emissions to water

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Type of discharge</th>
<th>Associated processes</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Combination of techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE042_w {1}</td>
<td>IND</td>
<td>Washing synthetic fibre - Desizing - Bleaching - Dyeing - Functional finishing</td>
<td>0.005</td>
<td>0.01</td>
<td>0.01</td>
<td>Neutralisation, Equalisation</td>
</tr>
<tr>
<td>DE039_w {1}</td>
<td>IND</td>
<td>Mercerising - Dyeing - Washing synthetic fibre - Bleaching - Desizing</td>
<td>0.008</td>
<td>0.01</td>
<td>0.013</td>
<td>Equalisation, Neutralisation</td>
</tr>
<tr>
<td>FR134_w {1}</td>
<td>DIR</td>
<td>Washing synthetic fibre - Desizing - Mercerising - Bleaching - Dyeing - Singeing - Functional finishing</td>
<td>0.0025</td>
<td>0.01</td>
<td>0.013</td>
<td>Equalisation, Neutralisation, Grit separators, Activated sludge process, Anaerobic treatment</td>
</tr>
<tr>
<td>DE024_w {1}</td>
<td>IND</td>
<td>Desizing - Dyeing - Scouring - Singeing</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>Equalisation</td>
</tr>
<tr>
<td>FR136_w {1}</td>
<td>IND</td>
<td>Desizing - Scouring - Bleaching - Mercerising - Dyeing - Singeing - Fabric production - Functional finishing</td>
<td>0.006</td>
<td>0.01</td>
<td>0.021</td>
<td>Grit separators, Neutralisation</td>
</tr>
<tr>
<td>IT059_w {1} (2) (3)</td>
<td>IND</td>
<td>Scouring - Mercerising - Bleaching - Dyeing - Singeing - Dry cleaning</td>
<td>0.00127</td>
<td>0.01</td>
<td>0.021</td>
<td>Other</td>
</tr>
<tr>
<td>Code</td>
<td>Country</td>
<td>Activity Description</td>
<td>Value1</td>
<td>Value2</td>
<td>Value3</td>
<td>Category</td>
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<tr>
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<td>--------</td>
<td>--------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>IT074_w</td>
<td>IND</td>
<td>Washing synthetic fibre - Scouring</td>
<td>0.009</td>
<td>0.02</td>
<td>0.028</td>
<td>Equalisation, Flotation, Coagulation and flocculation, Activated sludge process, Nitrification/denitrification, Sedimentation, Membrane bioreactor</td>
</tr>
<tr>
<td>IT076_w</td>
<td>IND</td>
<td>Raw wool scouring</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>Equalisation, Neutralisation, Screening</td>
</tr>
<tr>
<td>DE030_w</td>
<td>IND</td>
<td>Washing synthetic fibre - Desizing - Mercerising - Bleaching - Singeing - Dyeing - Functional finishing - Thermal treatment</td>
<td>0.005</td>
<td>0.01</td>
<td>0.031</td>
<td>Equalisation, Neutralisation, Screening</td>
</tr>
<tr>
<td>FR135_w</td>
<td>IND</td>
<td>Washing synthetic fibre</td>
<td>0</td>
<td>0.00</td>
<td>0.031</td>
<td>Grit separators</td>
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<tr>
<td>PT109_w</td>
<td>IND</td>
<td>Mercerising - Desizing - Scouring - Bleaching - Dyeing - Shrink-proof finishing - Singeing - Functional finishing - Thermal treatment</td>
<td>0.0335</td>
<td>0.03</td>
<td>0.0335</td>
<td>Oil separation, Neutralisation</td>
</tr>
<tr>
<td>IT065_w</td>
<td>IND</td>
<td>Desizing - Mercerising - Bleaching - Dyeing - Singeing - Singeing - Functional finishing</td>
<td>0.012</td>
<td>0.02</td>
<td>0.04</td>
<td>Other</td>
</tr>
<tr>
<td>CZ015_w</td>
<td>IND</td>
<td>Dyeing - Functional finishing</td>
<td>0.007</td>
<td>0.04</td>
<td>0.05</td>
<td>Grit separators, Equalisation, Sedimentation</td>
</tr>
<tr>
<td>Code</td>
<td>Type</td>
<td>Process</td>
<td>Value 1</td>
<td>Value 2</td>
<td>Value 3</td>
<td>Additional Treatments</td>
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<td>--------------------------------------------------------------------------------------</td>
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<tr>
<td>DE051_w</td>
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<td>Washing synthetic fibre - Scouring - Bleaching - Dyeing - Functional finishing</td>
<td>0.01</td>
<td>0.01</td>
<td>0.05</td>
<td>Neutralisation, Coagulation and flocculation, Equalisation</td>
</tr>
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<td>FR132_w</td>
<td>DIR</td>
<td>Bleaching - Dyeing</td>
<td>0.0025</td>
<td>0.01</td>
<td>0.05</td>
<td>Screening, Activated sludge process</td>
</tr>
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<td>SE120_w</td>
<td>IND</td>
<td>Washing synthetic fibre - Desizing - Bleaching</td>
<td>0.0071</td>
<td>0.03</td>
<td>0.051</td>
<td>Neutralisation, Oil separation, Sedimentation, Equalisation</td>
</tr>
<tr>
<td>IT082_w</td>
<td>DIR</td>
<td>Dyeing - Singeing - Functional finishing - Thermal treatment - Wool Fulling</td>
<td>0</td>
<td>0.03</td>
<td>0.059</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Adsorption (e.g. powdered/granular activated carbon, lignite coke, etc.), Other</td>
</tr>
<tr>
<td>AT006_w</td>
<td>IND</td>
<td>Bleaching - Dyeing</td>
<td>0.019</td>
<td>0.04</td>
<td>0.062</td>
<td>Flotation</td>
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<tr>
<td>IT069_w</td>
<td>IND</td>
<td>Scouring - Bleaching - Mercerising</td>
<td>0.018</td>
<td>0.03</td>
<td>0.065</td>
<td>Other</td>
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<tr>
<td>IT097_w</td>
<td>DIR</td>
<td>Dyeing - Shrink-proof finishing - Printing - Other</td>
<td>0.005</td>
<td>0.04</td>
<td>0.07</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
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<tr>
<td>BE009_w</td>
<td>DIR</td>
<td>Printing - Coating and laminating</td>
<td>0.039</td>
<td>0.05</td>
<td>0.073</td>
<td>Screening, Sedimentation, Equalisation, Activated sludge process, Sand filtration, Coagulation and flocculation, Flotation, Chemical oxidation (incl. Advanced oxidation), Sand filtration, Chemical reduction, Microfiltration, Reverse osmosis</td>
</tr>
<tr>
<td>IT064_w</td>
<td>IND</td>
<td>Scouring</td>
<td>0.007</td>
<td>0.04</td>
<td>0.078</td>
<td>Other</td>
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<td>IT074_w</td>
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<td>Washing synthetic fibre - Scouring - Functional finishing - Dry cleaning - Other</td>
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<td>Country Code</td>
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<td>Waste Stream</td>
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<td>TDS 2</td>
<td>TDS 3</td>
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<tr>
<td>UK127_w {1}</td>
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<td>Mercerising - Bleaching - Dyeing - Scouring - Singeing - Printing</td>
<td>0.0914</td>
<td>0.03</td>
<td>0.0859</td>
<td>Neutralisation</td>
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<td>AT003_w {1}</td>
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<td>Mercerising - Dyeing - Desizing - Bleaching</td>
<td>0.01</td>
<td>0.03</td>
<td>0.09</td>
<td>Neutralisation</td>
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<tr>
<td>DE049_w {1}</td>
<td>IND</td>
<td>Desizing - Bleaching - Bleaching - Dyeing - Singeing - Printing - Coating and laminating - Scouring - Functional finishing</td>
<td>0.005</td>
<td>0.03</td>
<td>0.095</td>
<td>Equalisation, Neutralisation</td>
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<tr>
<td>IT092_w {1}</td>
<td>DIR</td>
<td>Dyeing - Other</td>
<td>0.05</td>
<td>0.08</td>
<td>0.1</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Reverse osmosis</td>
</tr>
<tr>
<td>BE008_w {2}</td>
<td>IND</td>
<td>Dyeing - Printing</td>
<td>0.04</td>
<td>0.06</td>
<td>0.11</td>
<td>Equalisation, Grit separators, Other</td>
</tr>
<tr>
<td>IT068_w {1}</td>
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<td>Washing synthetic fibre - Desizing - Scouring - Bleaching - Dyeing - Functional finishing - Other</td>
<td>0.011</td>
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<td>0.116</td>
<td>Other</td>
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<tr>
<td>IT084_w {1}</td>
<td>IND</td>
<td>Bleaching - Dyeing - Thermal treatment</td>
<td>0.001</td>
<td>0.02</td>
<td>0.13</td>
<td>Equalisation, Neutralisation, Grit separators, Screening, Coagulation and flocculation, Sedimentation</td>
</tr>
<tr>
<td>AT005_w {1}</td>
<td>IND</td>
<td>Dyeing</td>
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<td>0.04</td>
<td>0.14</td>
<td>Neutralisation</td>
</tr>
<tr>
<td>AT002_w {1}</td>
<td>IND</td>
<td>Bleaching - Dyeing</td>
<td>0.019</td>
<td>0.07</td>
<td>0.15</td>
<td>Screening, Neutralisation</td>
</tr>
<tr>
<td>Team</td>
<td>Code</td>
<td>Order</td>
<td>Process Description</td>
<td>Weight</td>
<td>Volume</td>
<td>Area</td>
</tr>
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<td>---------------------</td>
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<tr>
<td>DE022_w</td>
<td>{1} ({2})</td>
<td>IND</td>
<td>Raw wool scouring - Washing synthetic fibre - Desizing - Scouring - Bleaching - Dyeing - Thermal treatment - Functional finishing - Coating and laminating</td>
<td>0.01</td>
<td>0.02</td>
<td>0.15</td>
</tr>
<tr>
<td>PT098_w</td>
<td>{1} ({2})</td>
<td>DIR</td>
<td>Wool Fulling - Functional finishing - Dyeing - Thermal treatment</td>
<td>0.028</td>
<td>0.08</td>
<td>0.15</td>
</tr>
<tr>
<td>PT115_w</td>
<td>{1}</td>
<td>IND</td>
<td>Dyeing - Functional finishing</td>
<td>0.0239</td>
<td>0.08</td>
<td>0.15</td>
</tr>
<tr>
<td>BE014_w</td>
<td>{1} ({2})</td>
<td>DIR</td>
<td>Bleaching - Dyeing - Functional finishing</td>
<td>0.017</td>
<td>0.06</td>
<td>0.152</td>
</tr>
<tr>
<td>BE009_w</td>
<td>{1}</td>
<td>DIR</td>
<td>Printing - Coating and laminating</td>
<td>0.05</td>
<td>0.08</td>
<td>0.158</td>
</tr>
<tr>
<td>IT082_w</td>
<td>{2} ({3})</td>
<td>IND</td>
<td>Dyeing - Singeing - Functional finishing - Thermal treatment - Wool Fulling</td>
<td>0.019</td>
<td>0.09</td>
<td>0.17</td>
</tr>
<tr>
<td>IT078_w</td>
<td>{1} ({2})</td>
<td>IND</td>
<td>Wool Fulling - Washing synthetic fibre - Dyeing -</td>
<td>0.046</td>
<td>0.12</td>
<td>0.18</td>
</tr>
<tr>
<td>BE008_w</td>
<td>{1}</td>
<td>IND</td>
<td>Printing - Dyeing</td>
<td>0.061</td>
<td>0.10</td>
<td>0.19</td>
</tr>
<tr>
<td>IT061_w</td>
<td>{1}</td>
<td>IND</td>
<td>Scouring - Wool Carbonising</td>
<td>0.015</td>
<td>0.10</td>
<td>0.199</td>
</tr>
</tbody>
</table>
## Chapter 4

<table>
<thead>
<tr>
<th>PT110_w {2}</th>
<th>IND</th>
<th>Dyeing</th>
<th>0.01</th>
<th>0.17</th>
<th>0.2</th>
<th>Equalisation, Grit separators, Screening</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT113_w {1}</td>
<td>IND</td>
<td>Dyeing - Washing synthetic fibre - Bleaching - Functional finishing</td>
<td>0.2</td>
<td>0.20</td>
<td>0.2</td>
<td>Screening, Other,</td>
</tr>
<tr>
<td>BE007_w {1} (1)</td>
<td>DIR</td>
<td>Dyeing</td>
<td>0.085</td>
<td>0.12</td>
<td>0.21</td>
<td>Equalisation, Neutralisation, Sand filtration, Activated sludge process, Nitrification/denitrification</td>
</tr>
<tr>
<td>IT087_w {1} (3)</td>
<td>IND</td>
<td>Dyeing - Shrink-proof finishing - Shrink-proof finishing - Other</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>Equalisation</td>
</tr>
<tr>
<td>IT079_w {1}</td>
<td>IND</td>
<td>Scouring - Wool Fulling - Functional finishing - Thermal treatment - Other</td>
<td>0.07</td>
<td>0.13</td>
<td>0.26</td>
<td>Other</td>
</tr>
<tr>
<td>IT071_w {2} (1) (4)</td>
<td>IND</td>
<td>Dyeing - Other - Functional finishing</td>
<td>0.024</td>
<td>0.18</td>
<td>0.27</td>
<td>Other</td>
</tr>
<tr>
<td>CZ017_w {1}</td>
<td>IND</td>
<td>Spinning - Fabric production - Singeing - Functional finishing - Shrink-proof finishing - Thermal treatment - Other</td>
<td>0.126</td>
<td>0.22</td>
<td>0.303</td>
<td>Equalisation, Other,</td>
</tr>
<tr>
<td>IT067_w {1} (1) (3)</td>
<td>DIR</td>
<td>Dyeing - Printing - Other - Shrink-proof finishing</td>
<td>0.03</td>
<td>0.08</td>
<td>0.33</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
</tr>
</tbody>
</table>

**NB:**
- DIR = direct discharge
- IND = indirect discharge
- Dyeing with chromium-containing dyes:
  - (1) chromium dyes
  - (2) metal complex 1:1 dyes (some may contain chromium)
  - (3) metal complex 1:2 dyes (some may contain chromium)

**Source:** [196, TWG 2019]
Table 4.32: Environmental performance of individual or combinations of waste water treatment techniques for copper (Cu) emissions to water

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Type of discharge</th>
<th>Associated processes</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Combination of techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT098_w {1}</td>
<td>DIR</td>
<td>Wool Fulling - Functional finishing - Dyeing - Thermal treatment</td>
<td>0.0075</td>
<td>0.02</td>
<td>0.027</td>
<td>Equalisation, Neutralisation, Sedimentation, Sand filtration, Activated sludge process, Other</td>
</tr>
<tr>
<td>DE032_w {1}</td>
<td>DIR</td>
<td>Washing synthetic fibre - Desizing - Bleaching - Dyeing - Printing</td>
<td>0.003</td>
<td>0.01</td>
<td>0.028</td>
<td>Equalisation, Neutralisation, Grit separators, Coagulation and flocculation, Sedimentation, Sand filtration, Nitrification/denitrification, Activated sludge process</td>
</tr>
<tr>
<td>UK124_w {1}</td>
<td>DIR</td>
<td>Dyeing - Functional finishing - Washing synthetic fibre</td>
<td>0.001</td>
<td>0.02</td>
<td>0.0288</td>
<td>Neutralisation, Coagulation and flocculation, Flotation, Other</td>
</tr>
<tr>
<td>IT074_w {2}</td>
<td>IND</td>
<td>Washing synthetic fibre - Scouring</td>
<td>0.02</td>
<td>0.03</td>
<td>0.029</td>
<td>Other</td>
</tr>
<tr>
<td>IT076_w {1}</td>
<td>IND</td>
<td>Raw wool scouring</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>Equalisation, Flotation, Coagulation and flocculation, Activated sludge process, Nitrification/denitrification, Sedimentation, Membrane bioreactor</td>
</tr>
<tr>
<td>IT069_w {1}</td>
<td>IND</td>
<td>Scouring - Bleaching - Mercerising</td>
<td>0.023</td>
<td>0.03</td>
<td>0.031</td>
<td>Other</td>
</tr>
<tr>
<td>BE008_w {2}</td>
<td>IND</td>
<td>Dyeing - Printing</td>
<td>0.007</td>
<td>0.01</td>
<td>0.034</td>
<td>Equalisation, Grit separators, Other</td>
</tr>
<tr>
<td>IT082_w {2}</td>
<td>IND</td>
<td>Dyeing - Singeing - Functional finishing - Thermal treatment - Wool Fulling</td>
<td>0.025</td>
<td>0.03</td>
<td>0.038</td>
<td>Equalisation</td>
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<td>Code</td>
<td>Type</td>
<td>Processes</td>
<td>Unit 1</td>
<td>Unit 2</td>
<td>Unit 3</td>
<td>Other</td>
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<tr>
<td>IT079_w 1</td>
<td>IND</td>
<td>Scouring - Wool Fulling - Functional finishing - Thermal treatment - Other</td>
<td>0.01</td>
<td>0.02</td>
<td>0.04</td>
<td>Other</td>
</tr>
<tr>
<td>PT109_w 1</td>
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<td>0.0444</td>
<td>Oil separation, Neutralisation</td>
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<td>Bleaching - Dyeing - Thermal treatment</td>
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<td>0.01</td>
<td>0.045</td>
<td>Equalisation, Neutralisation, Grit separators, Screening, Coagulation and flocculation, Sedimentation</td>
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<td>AT005_w 1</td>
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<td>0.02</td>
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<td>0.03</td>
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<td>IT061_w 1</td>
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<td>Scouring - Wool Carbonising</td>
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<tr>
<td>BE009_w 1</td>
<td>DIR</td>
<td>Printing - Coating and laminating</td>
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<td>0.07</td>
<td>0.019</td>
<td>Screening, Sedimentation, Equalisation, Activated sludge process, Sand filtration, Coagulation and flocculation, Flotation, Chemical oxidation (incl. Advanced oxidation), Sand filtration, Chemical reduction, Microfiltration, Reverse osmosis</td>
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<td>IND</td>
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<td>0.078</td>
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<td>Functional finishing - Coating and laminating - Thermal treatment</td>
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<td>0.03</td>
<td>0.081</td>
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<td>0.04</td>
<td>0.084</td>
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<td>0.0872</td>
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<td>SE118_w</td>
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<td>Sedimentation, Equalisation, Neutralisation</td>
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<td>IT067_w {1}</td>
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<td>Dyeing - Printing - Other - Shrink-proof finishing</td>
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<td>0.04</td>
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<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
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<td>0.108</td>
<td>Grit separators, Neutralisation</td>
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<td>Wool Fulling - Washing synthetic fibre - Dyeing</td>
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<td>IND</td>
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<td>Equalisation, Neutralisation</td>
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<td>0.01</td>
<td>0.04</td>
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<td>Neutralisation, Oil separation, Evaporation</td>
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<td>FR132_w {2}</td>
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<td>Screening, Activated sludge process</td>
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<td>Equalisation, Grit separators, Screening</td>
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<td>SE119_w {1}</td>
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<td>0.10</td>
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<td>Type</td>
<td>Activity Details</td>
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<td>Value 2</td>
<td>Value 3</td>
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<td>0.04</td>
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<td>Equalisation, Neutralisation, Activated sludge process,</td>
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<td></td>
<td>Nitrification/denitrification, Sedimentation</td>
</tr>
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<td>0.0085</td>
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<td>Sand filtration, Other</td>
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<td>FR134_w {1}</td>
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<td>0.047</td>
<td>0.12</td>
<td>0.32</td>
<td>Equalisation, Neutralisation, Grit separators, Activated sludge process,</td>
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<td>Anaerobic treatment</td>
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<tr>
<td>PT108_w {1}</td>
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<td>Fabric production - Fabric production</td>
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<td>0.32</td>
<td>Neutralisation, Sand filtration, Sand filtration</td>
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<td>AT002_w {1}</td>
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<td>0.055</td>
<td>0.15</td>
<td>0.37</td>
<td>Screening, Neutralisation</td>
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<td>Washing synthetic fibre - Scouring - Bleaching - Dyeing - Functional finishing</td>
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<td>0.09</td>
<td>0.39</td>
<td>Neutralisation, Coagulation and flocculation, Equalisation</td>
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<td>IND</td>
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<td>0.12</td>
<td>0.27</td>
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</tr>
</tbody>
</table>

NB: DIR = direct discharge
IND = indirect discharge
Source: [196, TWG 2019]
## Table 4.33: Environmental performance of individual or combinations of waste water treatment techniques for nickel (Ni) emissions to water

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Type of discharge</th>
<th>Associated processes</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Combination of techniques</th>
</tr>
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<tbody>
<tr>
<td>AT005_w {1}</td>
<td>IND</td>
<td>Dyeing</td>
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<td>0.01</td>
<td>0.01</td>
<td>Neutralisation</td>
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<td>Neutralisation, Equalisation</td>
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<td>Equalisation, Neutralisation, Coagulation and flocculation, Sedimentation, Activated sludge process</td>
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<tr>
<td>SE119_w {1}</td>
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<td>Equalisation, Oil separation, Neutralisation</td>
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<td>0.01</td>
<td>0.011</td>
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<td>Equalisation, Neutralisation, Coagulation and flocculation, Activated sludge process, Nitrification/denitrification, Sand filtration, Nanofiltration, Chemical oxidation (incl. Advanced oxidation)</td>
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<tr>
<td>Code</td>
<td>Type</td>
<td>Description</td>
<td>E</td>
<td>O</td>
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<td>Neutralisation, Coagulation and flocculation, Equalisation</td>
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<td>Type</td>
<td>Process Description</td>
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<td>BOD</td>
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<td>Equalisation, Neutralisation, Screening</td>
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<td>0.002</td>
<td>0.03</td>
<td>0.19</td>
<td>Equalisation, Neutralisation, Grit separators, Activated sludge process, Anaerobic treatment</td>
</tr>
<tr>
<td>PT102_w</td>
<td>IND</td>
<td>Scouring - Dyeing - Bleaching</td>
<td>0.002</td>
<td>0.17</td>
<td>0.2</td>
<td>Other</td>
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<td>PT111_w</td>
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<td>0.34</td>
<td>0.5</td>
<td>Equalisation, Neutralisation, Activated sludge process, Sedimentation, Sand filtration, Other</td>
</tr>
</tbody>
</table>

NB:  
DIR = direct discharge  
IND = indirect discharge  
Source: [ 196, TWG 2019 ]
Table 4.34: Environmental performance of individual or combinations of waste water treatment techniques for zinc (Zn) emissions to water

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Type of discharge</th>
<th>Associated processes</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Combination of techniques</th>
</tr>
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<tbody>
<tr>
<td>BE011_w [1]</td>
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<td>Dyeing</td>
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<td>0.03</td>
<td>0.038</td>
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<td>0.03</td>
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<td>Neutralisation, Oil separation, Evaporation</td>
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<td>IND</td>
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<td>IND</td>
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<td>Other</td>
</tr>
<tr>
<td>BE014_w</td>
<td>DIR</td>
<td>Bleaching - Dyeing - Functional finishing</td>
<td>0.03</td>
<td>0.10</td>
<td>0.295</td>
<td>Equalisation, Activated sludge process, Nitrification/denitrification</td>
</tr>
<tr>
<td>IT094_w</td>
<td>IND</td>
<td>No information</td>
<td>0.001</td>
<td>0.11</td>
<td>0.3</td>
<td>Other</td>
</tr>
<tr>
<td>IT092_w</td>
<td>DIR</td>
<td>Dyeing - Other</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation, Reverse osmosis</td>
</tr>
<tr>
<td>PT113_w</td>
<td>IND</td>
<td>Dyeing - Washing synthetic fibre - Bleaching - Functional finishing</td>
<td>0.07</td>
<td>0.18</td>
<td>0.32</td>
<td>Screening, Other</td>
</tr>
<tr>
<td>IT078_w {1}</td>
<td>IND</td>
<td>Wool Fulling - Washing synthetic fibre - Dyeing</td>
<td>0.068</td>
<td>0.18</td>
<td>0.34</td>
<td>Other</td>
</tr>
<tr>
<td>AT002_w {1}</td>
<td>IND</td>
<td>Bleaching - Dyeing</td>
<td>0.055</td>
<td>0.12</td>
<td>0.39</td>
<td>Screening, Neutralisation</td>
</tr>
<tr>
<td>DE051_w {1}</td>
<td>IND</td>
<td>Washing synthetic fibre - Scouring - Bleaching - Dyeing - Functional finishing</td>
<td>0.06</td>
<td>0.21</td>
<td>0.39</td>
<td>Neutralisation, Coagulation and flocculation, Equalisation</td>
</tr>
<tr>
<td>IT067_w {1}</td>
<td>DIR</td>
<td>Dyeing - Printing - Other - Shrink-proof finishing</td>
<td>0.18</td>
<td>0.27</td>
<td>0.4</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
</tr>
<tr>
<td>IT071_w {2}</td>
<td>IND</td>
<td>Dyeing - Other - Functional finishing</td>
<td>0.27</td>
<td>0.38</td>
<td>0.5</td>
<td>Other</td>
</tr>
<tr>
<td>IT083_w {1}</td>
<td>IND</td>
<td>Scouring - Dyeing - Functional finishing</td>
<td>0.28</td>
<td>0.40</td>
<td>0.5</td>
<td>Other</td>
</tr>
<tr>
<td>IT097_w {1}</td>
<td>DIR</td>
<td>Dyeing - Shrink-proof finishing - Printing - Other</td>
<td>0.005</td>
<td>0.13</td>
<td>0.5</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
</tr>
</tbody>
</table>

NB:
DIR = direct discharge
IND = indirect discharge
Source: [196, TWG 2019]
Table 4.35  Environmental performance of combinations of waste water treatment techniques for sulphides (S2-) emissions to water

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Type of discharge</th>
<th>Associated processes</th>
<th>Minimum concentration over 3 years (mg/l)</th>
<th>Average concentration over 3 years (mg/l)</th>
<th>Maximum concentration over 3 years (mg/l)</th>
<th>Combination of techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE022_w {1} (1)</td>
<td>IND</td>
<td>Raw wool scouring - Washing synthetic fibre - Desizing - Scouring - Bleaching - Dyeing - Thermal treatment - Functional finishing - Coating and laminating</td>
<td>0.006</td>
<td>0.03</td>
<td>0.34</td>
<td>Neutralisation, Oil separation, Evaporation</td>
</tr>
<tr>
<td>DE030_w {1} (1)</td>
<td>IND</td>
<td>Washing synthetic fibre - Desizing - Mercerising - Bleaching - Singeing - Dyeing - Functional finishing - Thermal treatment</td>
<td>0.04</td>
<td>0.18</td>
<td>0.58</td>
<td>Equalisation, Neutralisation, Screening</td>
</tr>
<tr>
<td>PT108_w {1} (2)</td>
<td>IND</td>
<td>Fabric production - Fabric production</td>
<td>0.05</td>
<td>0.36</td>
<td>0.97</td>
<td>Neutralisation, Sand filtration, Sand filtration</td>
</tr>
<tr>
<td>IT097_w {1}</td>
<td>DIR</td>
<td>Dyeing - Shrink-proof finishing - Printing - Other</td>
<td>1</td>
<td>1.00</td>
<td>1</td>
<td>Equalisation, Neutralisation, Activated sludge process, Nitrification/denitrification, Sedimentation</td>
</tr>
</tbody>
</table>

NB:  
DIR = direct discharge  
IND = indirect discharge  
(1) dyeing with sulphur dyes  
(2) dyeing with sow-sulphide dyes  
Source: [196, TWG 2019]
4.1.8 Prevention and reduction of emissions to air

4.1.8.1 Overview

This section contains techniques used in the textiles sector to prevent, reduce or control the emissions to air.

This section only covers those techniques most relevant to the textiles sector. These techniques have already been described and analysed in the CWW BREF [24, COM 2016]. For this reason, it is not intended in this section to provide a complete analysis of each of the different techniques. Instead, only a short description of the techniques is given as well as examples of plants from the data collection where these techniques are applied.

4.1.8.2 Wet scrubbing

Description

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.

The major waste gas treatment applications of scrubbing processes are as follows:

- The removal of gaseous pollutants, such as hydrogen halides, SO₂, ammonia, hydrogen sulphide (H₂S) or volatile organic solvents.
- The removal of dust with certain types of scrubbers. Wet dust scrubbing entails separating the dust by intensively mixing the incoming gas with water, usually combined with the removal of the coarse particles through the use of centrifugal force. In order to achieve this, the gas is inserted tangentially (at an angle from the side). This technique allows the abatement of dust emissions and bioaerosols as well as inorganic chemicals (such as SO₂, NH₃, NH₄Cl), VOCs and heavy metals that may be attached to the dust.

Depending on the pollutants to be removed, several aqueous scrubbing liquids are used including the following:

- **Water**, to remove solvents and gases such as hydrogen halides or ammonia, with the main aim being to recover and reuse these contaminants.
- **Alkaline solutions** (e.g. caustic soda (i.e. sodium hydroxide) and sodium carbonate), to remove acid components such as hydrogen halides, sulphur dioxide, hydrogen sulphide (H₂S), phenols, chlorine; also used for second-stage scrubbing to remove residual hydrogen halides after first-stage aqueous absorption; and for biogas desulphurisation.
- **Alkaline oxidation solutions**, i.e. alkaline solutions with oxidants such as sodium hypochlorite (NaClO), chlorine dioxide (ClO₂), ozone (O₃) or hydrogen peroxide (H₂O₂).
- **Oxidation solutions**, to recover NOₓ from concentrated waste gases.
- **Sodium hydrogen sulphite solutions**, to remove odour (e.g. aldehydes).
- **Na₂S₄ solutions**, to remove mercury from waste gas.
• **Acidic solutions**, to remove alkaline components, e.g. ammonia, amines and esters. The dosing of the acid is done by means of pH regulation.

• **Monoethanolamine and diethanolamine solutions**, suitable for the absorption and recovery of hydrogen sulphide.

• **Organic solvents with low volatility**, e.g. chilled nonane for the recovery of light VOCs such as butanes and pentanes.

**Example plants**
Table 4.36 shows the list of plants from the data collection equipped with wet scrubbers (either water or acid scrubbers).

<table>
<thead>
<tr>
<th>Plants equipped with a wet scrubbing system as an abatement technique</th>
<th>Type of scrubbing</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT003, BE013, CZ016, DE022, DE023, DE030, DE032, DE041, DE049, DE050, IT059, IT061, IT063, IT064, IT065, IT067, IT070, IT071, IT072, IT074, IT077, IT078, IT079, IT082, IT087, IT094, IT097, PT109, PT111, UK127. IT060, UK127.</td>
<td>Water scrubbing</td>
</tr>
<tr>
<td></td>
<td>Acid scrubbing</td>
</tr>
</tbody>
</table>

**Reference literature**
[24, COM 2016]

### 4.1.8.3 Electrostatic precipitator (ESP)

**Description**
An electrostatic precipitator (ESP) is a particulate collection device that removes particles from a gas flow using the force of an induced electrostatic charge. The entrained particles are given an electrical charge when they pass through a corona where gaseous ions flow. Electrodes in the centre of the flow lane are maintained at a high voltage and generate the electrical field that forces the particles to the collector walls.

In dry ESPs, the collectors are knocked or rapped by various mechanical means to dislodge the particles, which slide downwards into a hopper.

In wet ESPs, the collectors are either intermittently or continuously washed by a spray of water, and the collection hoppers are replaced with a drainage system.

**Example plants**
Table 4.37 shows the list of plants from the data collection equipped with ESPs (either dry or wet ESPs).

<table>
<thead>
<tr>
<th>Plants equipped with an ESP as an abatement technique</th>
<th>Type of ESPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE022, IT063, IT084, UK124, UK127.</td>
<td>Dry ESP</td>
</tr>
<tr>
<td>AT001, DE023, DE050.</td>
<td>Wet ESP</td>
</tr>
</tbody>
</table>

**Reference literature**
[24, COM 2016]
4.1.8.4 Condensation

Description
Condensation is a technique that eliminates vapours of organic and inorganic compounds from a waste gas stream by reducing its temperature below its dew point.

There are different methods of condensation, depending on the operating temperature range and including:

- coolant condensation, for a condensation temperature down to about 25 °C;
- refrigerant condensation, for a condensation temperature down to about 2 °C;
- brine condensation, for a condensation temperature down to about -10 °C;
- ammonia brine condensation, for a condensation temperature down to about -40 °C (one-stage) or -60 °C (two-stage);
- cryogenic condensation, for a condensation temperature down to about -120 °C, in practice often operated between -40 °C and -80 °C in the condensation device;
- closed-cycle inert gas condensation.

Example plants
Plants from the data collection: DE049, IT077, IT083, SE118, SE119, UK124 and UK127.

Reference literature
[ 24, COM 2016 ]

4.1.8.5 Thermal oxidation

Description
Thermal oxidation (also often referred to as ‘incineration’, ‘thermal incineration’ or ‘oxidative combustion’) is the oxidation of combustible gases and odorants in a waste gas stream by heating a mixture of contaminants with air or oxygen above its ignition point in a combustion chamber and maintaining it at a high temperature for sufficient time to complete combustion to carbon dioxide and water.

Thermal oxidisers are used to reduce emissions from almost all VOC sources. They can handle minor fluctuations in flow, but large fluctuations require the use of other techniques such as flares and flash tanks. Their fuel consumption can be high when low-loaded waste gases are fed so thermal units are best suited for smaller process applications with moderate to high VOC loadings.

Several types of thermal oxidisers are operated:

- the straight thermal oxidiser;
- the regenerative thermal oxidiser;
- the recuperative thermal oxidiser;
- gas engines or steam boilers.

Example plants
Table 4.38 below shows the plants from the data collection equipped with thermal oxidation systems.
### Table 4.38: Plants from the data collection equipped with thermal oxidation

<table>
<thead>
<tr>
<th>Plants equipped with a thermal oxidation system as an abatement technique</th>
<th>Type of thermal oxidiser</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE024</td>
<td>Thermal oxidiser</td>
</tr>
<tr>
<td>DE032, DE042</td>
<td>Regenerative thermal oxidiser</td>
</tr>
</tbody>
</table>

**Reference literature**
[24, COM 2016]

### 4.1.8.6 Catalytic oxidation

**Description**
Catalytic oxidisers operate in a very similar way to thermal oxidisers (see Section 4.1.8.5), with the main difference being that the gas, after passing through the flame area, passes through a catalyst bed. The catalyst has the effect of increasing the oxidation reaction rate, enabling conversion at lower reaction temperatures than in thermal oxidation units. Catalysts, therefore, also allow smaller oxidisers to be used.

**Example plants**
Plant DE047.

**Reference literature**
[24, COM 2016]

### 4.1.8.7 Cyclone

**Description**
Equipment for the removal of dust from a waste gas stream based on imparting centrifugal forces, usually within a conical chamber.

**Example plants**
Plants from the data collection: IT064, IT069, IT078 and PT115.

**Reference literature**
[24, COM 2016]

### 4.1.8.8 Absolute filter

**Description**
In absolute filters (e.g. HEPA (high-efficiency particle air filter), ULPA (ultra-low penetration air filter)), the filter medium is paper or matted glass fibre with a high packing density. The waste gas stream is passed through the filter medium, where dust is collected. The dust cake that forms on the filter medium can increase the collection efficiency. The filter medium is pleated to provide a smaller A/C ratio (volume flow rate to surface area).

The most common designs are a box filter cell and a cylindrical filter cell. In a box filter cell, the pleated medium is placed in a rigid, square frame constructed of wood or metal. The air flows from the front to the back of the filter. In a cylindrical filter cell, a metal cap seals the medium at one end. The air flows from the outside to the inside of the filter.

**Example plants**
Plants from the data collection: IT072 and IT083.
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Reference literature
[ 24, COM 2016 ]

4.1.8.9 Fabric filter

Description
The creation of a barrier separates the dust from the waste gases. Solid particles are trapped by a woven fabric while the gas flow can pass through it.

Example plants
Plants from the data collection: IT061 and IT094.

Reference literature
[ 24, COM 2016 ]

4.1.8.10 Mist filter

Description
The most common mist filters (mist eliminators, demisters) are mesh pad filters. Mesh pad filters usually consist of woven or knitted metallic or synthetic material monofilament in either a random or specific configuration and are used for deep-bed filtration, which takes place over the entire depth of the filter. Solid dust particles remain in the filter until it is saturated and thus has to be cleaned by flushing. When the mist filter is used to collect droplets and/or aerosols, it is usually self-cleaning, drained by the liquid. It works by mechanical impingement and is velocity-dependent. Baffle angle separators are also commonly used as mist filters.

Demisters often form an integrated part of other techniques, for example gas scrubbers.

Example plants
Plant UK127.

Reference literature
[ 24, COM 2016 ]

4.1.8.11 Adsorption

Description
Adsorption is a heterogeneous reaction in which gas molecules are retained on a solid or liquid surface (the adsorbent is also referred to as a molecular sieve) that prefers specific compounds to others and thus removes them from effluent streams. When the surface has adsorbed as much as it can, the adsorbent is replaced or the adsorbed content is desorbed as part of the regeneration of the adsorbent. When desorbed, the contaminants are usually at a higher concentration and can either be recovered or disposed of.

Typical adsorbents include:

- granular activated carbon (GAC), the most common adsorbent with a wide efficiency range and not restricted to polar or non-polar compounds; GAC can be impregnated, e.g. with oxidants such as potassium permanganate or with sulphur compounds (improving the retention of heavy metals);
- zeolites, with properties depending on their manufacture, working either as mere molecular sieves, selective ion exchangers or hydrophobic VOC adsorbers;
- macroporous polymer particles, which are used as granules or beads, without being highly selective with respect to VOCs;

Reference literature
[ 24, COM 2016 ]
- silica gel;
- sodium-aluminium silicates.

The application of adsorption encompasses:

- the recovery of VOCs (raw material, product, solvent, etc.) for reuse or recirculation; it may be used as a stand-alone system, as a concentration step to improve the viability of further recovery operations such as membrane separation or to treat the tail gas emissions from an abatement system;
- the abatement of pollutants that cannot be recirculated or otherwise used, possibly with GAC as an adsorbent which is then not regenerated but incinerated;
- its use as a guard filter after final treatment facilities.

Example plants
Plants from the data collection: BE013, CZ015 and IT074.

Reference literature
[24, COM 2016]

4.1.8.12 Ionisation

Description
In ionisation (also referred to as the direct cold plasma technique), the air or the incoming gas flow is led through a reaction chamber where it is submitted to a very strong electrical field (20-30 kV) generated by electrodes, causing ions, free electrons, radicals and other highly reactive particles to be formed. However, no notable rise in temperature takes place. The highly reactive compounds cause the decomposition and (partial) oxidation of the pollutants present in the incoming gas. The most active particles in this process are the N, O and OH radicals. They are formed of nitrogen (N\textsubscript{2}), oxygen (O\textsubscript{2}) and water (H\textsubscript{2}O). If the gas flow is sent directly into the plasma reactor, it acts as an electrostatic precipitator (see Section 4.1.8.3) with a dust removal efficiency of > 90%.

With direct treatment, the removal of organic chemicals is possible. In the case of injection of an ionised air stream, a modification of the odour molecules occurs and, to a lesser extent, a removal of the organic load.

The decomposition of VOCs can generate emissions of CO\textsubscript{2}, H\textsubscript{2}O\textsubscript{2}, CO, NO\textsubscript{X}, etc. which can be treated using a catalyst system.

Example plants
Plant from the data collection: IT083.

Reference literature
[24, COM 2016]

4.1.8.13 Biological waste gas treatment after flame lamination
[36, ÖKOPOL 2011]

Description
Combination of biotrickling and a biofilter for abatement of cyanide (HCN) from the waste gas of flame lamination.

Technical description
The abatement system consists of a washer and a filter module, both filled with plastic material for growth of organics. Additionally, the plants have a waste gas fan and a circulation pump. The circuit has an automatic conditioning system to keep the temperature and the pH constant.
The plant is vaccinated with a specific bacteria culture, able to degrade HCN into non-toxic metabolites. The plant works as a two-step trickle reactor. In the first step, HCN contained in the waste gas is dissolved in water by intensive gas-water contact (countercurrent gas wash). Afterwards, washing water loaded with HCN is conducted to the second step (filter), where the biological elimination takes place. In the second step, the remaining HCN is dissolved, at the same time as the biological elimination.

After the filter module, the cleaned waste gas is channelled to the stack and released into the atmosphere. [36, ÖKOPOL 2011]

See [24, COM 2016] for more details on biotrickling and biofiltration.

**Achieved environmental benefit**
Reduction of cyanide and dust emissions to air.

**Environmental performance and operational data**
Two example plants achieve a HCN reduction of 30-60%. Both plants generally achieve HCN concentrations < 3 mg/Nm³. [36, ÖKOPOL 2011]

Furthermore, improved working conditions for the employees at the flame lamination machine are achieved.

**Data of example plant A:**
- Treated waste gas volume: 15 500 m³/h.
- Filling material volume of the washer: approximately 8 m³.
- Filling material volume of the filter: approximately 12 m³.
- Water reservoir: 6.6 m³.
- Circuit pump: 4 kW.
- Automatic pH and temperature control.
- Beds of the washer and the filter are filled with loose heaped-up polypropylene pall rings.
- Twice a year maintenance is carried out, including disposal of the circuit water and the biomass sludge.
  [36, ÖKOPOL 2011]

**Cross-media effects**
Waste water is generated by operating the waste gas treatment system and is disposed of as hazardous waste. In example plant A, the waste water amount is approximately 10 m³/year. [36, ÖKOPOL 2011]

The operation of the waste gas treatment system also leads to additional energy consumption: in plant A, additional energy consumption is 52 550 kWh/year. This consumption does not include the electricity consumption of the fan (54 912 kWh/year), as for workers’ protection several small fans were needed before installing the waste gas abatement system, comprising similar electricity consumption. [36, ÖKOPOL 2011]

**Technical considerations relevant to applicability**
The biological waste gas cleaning system is applicable to new and existing plants. In existing plants, the applicability may be restricted by space availability.

**Economics**
Investment and operation costs depend on the treated waste gas volume. In example plant A, specific treatment costs with about 5 000 operation hours per year were approximately EUR 0.94 per 1 000 m³ (or EUR 0.77 per 1 000 m³ when deducting the electricity costs which were also needed for ventilation before installing the waste gas abatement system).

More details about example plant A are given below: [36, ÖKOPOL 2011]
Investment costs: approximately EUR 130 000 (complete waste gas treatment system without construction costs and connecting ducts).

Annual costs: EUR 29 700 for a volume of waste gas treated of approximately 38 700 000 m³/a (EUR 36 400 when including the electricity costs for the fan). This includes:
- Capital costs: EUR 13 000 (over 10 years).
- Maintenance costs: EUR 7 000.
- Operating material:
  - buffer and nutrition media: EUR 2 200.
  - water/waste water costs: EUR 1 200.
  - electricity costs: EUR 6 300 without fan or EUR 13 000 with fan.

Driving force for implementation
Environmental legislation.

Example plants
- C.H. Müller GmbH, DE-08486 Netzschkau (Plant A);
- Vowalon GmbH, DE-08233 Treuen.

Reference literature
[36, ÖKOPOL 2011]

4.1.8.14 [Air emission abatement techniques] Reduction of emissions to air of ammonia, dust and VOCs

Description
One or a combination of techniques (see Sections 4.1.8.2 to 4.1.8.12) to abate emissions to air from dryers, curers and stenters.

Technical description
The following off-gas abatement techniques can be used in textile finishing:
- oxidation techniques (thermal incineration, catalytic incineration)
- condensation techniques (e.g. heat exchangers)
- absorption techniques (e.g. wet scrubbers)
- particulates separation techniques (e.g. electrostatic precipitators, cyclones, fabric filters)
- adsorption techniques (e.g. activated carbon adsorption).

The description and the performance of these techniques are treated in detail in another BREF ([196, EIPPCB, 2001]). Depending on the type of air stream and pollutants to be treated, they can either be used as single treatments or be applied in combination. Typical applied systems are:
- wet scrubbers
- combination of wet scrubber and electrostatic precipitation
- combination of heat exchanger, aqueous scrubber and electrostatic precipitation
- heat exchangers (primarily used for energy saving, but partial condensation of certain pollutants is also achieved)
- adsorption on activated carbon.

One or a combination of the following techniques may be used to reduce emissions to air of VOCs, including formaldehyde:
- wet scrubbing (see Section 4.1.8.20);
- condensation (see Section 4.1.8.4);
- thermal oxidation (see Section 4.1.8.5);
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- catalytic oxidation (see Section 4.1.8.6);
- ionisation (see Section 4.1.8.12).

Wet scrubbing, as well as ESP (see Section 4.1.8.3) or cyclone (see Section 4.1.8.7) may be used alone or in combination to reduce dust emissions to air.

Wet scrubbing may be used to reduce NH₃ emissions to air.

Biowashers and biofilters (e.g. trickle bed reactors with filling material) are not used after drying because the waste gas load may vary significantly and may contain bactericide substances (e.g. formaldehyde). Biowashers and biofilters are more appropriate for treatment of emissions from flame lamination (see Section 4.1.8.13).[36, ÖKOPOL 2011]

Main-Achieved environmental benefits
Reduction of volatile organic carbon compounds (VOCs), particulates and special toxic including hazardous substances such as formaldehyde or methanol, and dust in the off-gas as well as minimisation of odour nuisances.

Environmental performance and operational data
To achieve high operational reliability, adjustment of the appropriate operating conditions and proper maintenance (in some cases a weekly inspection and cleaning of the devices) of the equipment are crucial [179, UBA, 2001].

Oxidation techniques
The disadvantage of thermal incineration oxidation is the high energy consumption for heating the off-gas to at least 750 °C. After incineration oxidation, the temperature of the cleaned off-gas is around 200 °C to 450 °C and heat could be recovered for the process with a heat exchanger. The textile industry does not have a demand for thermal energy in this sort of amount so most of it would be wasted.

Another problem arises from the gas-air mixture typical of exhaust air from textile finishing. In the textile industry, most of the emissions to be treated are characterised by high off-gas flows, but relatively low loads. Moreover, the characteristics of the off-gases are often subject to fluctuation, leading to inefficient thermal incineration oxidation.

Usually, thermal oxidation of waste gas from stenters is not considered proportionate due to the low VOC content of the raw waste gas (less than 500 mg/Nm³) and the high energy consumption required for thermal oxidation.

In catalytic incineration, phosphorus compounds, halogens, silicones and heavy metals can poison the catalyst. These compounds are quite relatively common in the textile industry, so special care has to be taken when using catalytic oxidation in this sector.

Catalytic oxidation with full heat recovery is applied in some mills for treating off-gases arising from singeing operations (see Section 2.6.1.1). The hot gas at the outlet of the catalytic afterburner oxidiser is drawn through air-to-water heat exchangers and the hot water generated by the cooling process is used in the pretreatment process or in the heating system. The gas (with its remaining thermal content) is further used in the drying step taking place after the pretreatment process [281, Belgium, 2002] [36, ÖKOPOL 2011].

If softeners are contained in the waste gas, this can lead to coatings in the inlet of the heat exchanger of a regenerative thermal oxidiser and subsequent blocking of the system. Such coatings can be incinerated with a burnout system. If silicium-organic compounds are contained in the waste gas, the system is equipped with sufficiently large openings for maintenance as
silicia oxide compounds may cover the honeycombs of the renegenative system. Such coatings may be removed with compressed air. [36, ÖKOPOL 2011]

Absorption techniques
In the case of formaldehyde, the scrubber can be operated with addition of hydrogen peroxide in alkaline conditions. The scrubbing liquor is usually circulated and thus warms up quickly.

In the case of methanol, the removal efficiency depends on the concentration of methanol in the raw waste gas, the quantity of water used for scrubbing and the temperature of the circulating scrubber liquor. A possible scrubber setup is shown in Figure 4.28. [212, HAZBREF 2019]

Figure 4.28: Example of a scrubbing system for the abatement of water-soluble and partly insoluble compounds

Volatile substances (e.g. formaldehyde, methanol) may evaporate from the scrubbing liquor. [36, ÖKOPOL 2011]

Electrostatic precipitation
Electrostatic precipitation in combination with heat exchangers or scrubbers is successfully applied in the treatment of fumes emitted from the stenters where the fabric is submitted to thermofixation.
The combination of electrostatic precipitation with heat exchangers (dry electrofiltration) is particularly advantageous when this operation is carried out as a first treatment step before washing. The oils and preparation agents present on the grey fabric evaporate and give rise to a dense smoke also associated with odour emissions. This off-gas can be treated in four steps:

1) mechanical filtration;
2) cooling and condensation (the suspended condensable compounds are separated in the form of oily droplets and thermal energy is recovered);
3) ionisation/electrofiltration;
4) collection of the condensates and separation of the oily phase from the aqueous phase in a static decanter.

One of the advantages of this dry electrofiltration system is that the oily condensates (mineral oils, silicone oils, etc.) are collected separately and thus recovered instead of being transferred to the water effluent (e.g. via a scrubber). Energy recovery is another advantage of this technique. Recovered energy (35-40 % of the supplied amount) can be used to preheat the fresh air supplied to the stenter or to heat up process water.

Combination of techniques [212, HAZBREF 2019]

The design of an end-of-pipe treatment system depends on the type and concentration of pollutants. In the case of oily compounds and particles as well as some easily water-soluble compounds, a combination of a two-stage heat exchanger, followed by a fine mist scrubber and an electrostatic precipitator could for instance reduce the aforementioned components by 90 %. The scrubber can often further reduce the waste gas temperature which also improves the efficiency of the electrostatic precipitator. The combination of techniques described above is shown in Figure 4.29.

Source: [212, HAZBREF 2019]

**Figure 4.29:** Example of end-of-pipe treatment system for the abatement of oily and water-soluble compounds

Provided that the waste gas temperature is not higher than 50 °C after heat exchange, the specific water consumption is in the order of 0.2-0.4 l/Nm³ for a methanol removal efficiency of 50-60 % and can be as high as 2 l/Nm³ for a removal efficiency of about 90 %. However, by cooling the circulating scrubbing liquor, the specific water consumption for high removal efficiencies can be significantly reduced.
It is important to regularly clean the heat exchanger and the electrostatic precipitator. The required frequency depends on the type of compounds and their concentration in the raw waste gas. For example, in case of raw fixation of synthetic knitwear, heat exchangers and electrostatic precipitators are cleaned very often, i.e. weekly.

The environmental performance of the abatement techniques for TVOC, formaldehyde, dust and ammonia are shown in Table 4.39, Table 4.40, Table 4.41 and Table 4.42 respectively.
### Table 4.39: Environmental performance of abatement techniques for TVOC emissions to air

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Process(es) associated to the emissions</th>
<th>Abatement techniques</th>
<th>Minimum concentration (mg/Nm³)</th>
<th>Average concentration (mg/Nm³)</th>
<th>Maximum concentration (mg/Nm³)</th>
<th>Maximum load (g/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT082_[3]</td>
<td>Functional finishing - Thermal treatment</td>
<td>Water scrubber system</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>73</td>
</tr>
<tr>
<td>IT082_[4]</td>
<td>Functional finishing - Thermal treatment</td>
<td>Water scrubber system</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>96</td>
</tr>
<tr>
<td>DE032_[1]</td>
<td>Functional finishing - Coating and laminating - Thermal treatment</td>
<td>Regenerative thermal oxidation</td>
<td>2.7</td>
<td>3</td>
<td>3.2</td>
<td>39</td>
</tr>
<tr>
<td>DE024_[8]</td>
<td>Coating and laminating</td>
<td>Thermal oxidation</td>
<td>3.2</td>
<td>3.2</td>
<td>3.2</td>
<td>39</td>
</tr>
<tr>
<td>IT077_[8]</td>
<td>NI</td>
<td>Condensation</td>
<td>1.2</td>
<td>2.47</td>
<td>4.1</td>
<td>NI</td>
</tr>
<tr>
<td>AT003_[2]</td>
<td>Functional finishing</td>
<td>Water scrubber system</td>
<td>3.2</td>
<td>4.23</td>
<td>5.4</td>
<td>NI</td>
</tr>
<tr>
<td>IT082_[2]</td>
<td>Functional finishing - Thermal treatment</td>
<td>Water scrubber system</td>
<td>5.8</td>
<td>5.8</td>
<td>5.8</td>
<td>155</td>
</tr>
<tr>
<td>IT094_[3]</td>
<td>Thermal treatment</td>
<td>Water scrubber system</td>
<td>5.96</td>
<td>5.96</td>
<td>5.96</td>
<td>45</td>
</tr>
<tr>
<td>IT082_[10]</td>
<td>Functional finishing - Thermal treatment</td>
<td>Water scrubber system</td>
<td>6.1</td>
<td>6.1</td>
<td>6.1</td>
<td>105</td>
</tr>
<tr>
<td>IT065_[8]</td>
<td>Singeing</td>
<td>Water scrubber system</td>
<td>4.12</td>
<td>5.22</td>
<td>8.18</td>
<td>83</td>
</tr>
<tr>
<td>IT064_[3]</td>
<td>NI</td>
<td>Water scrubber system</td>
<td>2.5</td>
<td>6.07</td>
<td>12.9</td>
<td>213</td>
</tr>
<tr>
<td>PT109_2[3]</td>
<td>Functional finishing - Shrink-proof finishing - Thermal treatment</td>
<td>Water scrubber system</td>
<td>8.9</td>
<td>8.9</td>
<td>8.9</td>
<td>60</td>
</tr>
<tr>
<td>IT083_[14]</td>
<td>Functional finishing</td>
<td>Condensation, ionisation</td>
<td>8.4</td>
<td>9.23</td>
<td>9.8</td>
<td>278</td>
</tr>
<tr>
<td>DE049_[3]</td>
<td>Functional finishing - Coating and laminating</td>
<td>Water scrubber system</td>
<td>10.2</td>
<td>10.5</td>
<td>10.8</td>
<td>352</td>
</tr>
<tr>
<td>IT063_[3]</td>
<td>Printing</td>
<td>Water scrubber system</td>
<td>5.4</td>
<td>7.53</td>
<td>11.6</td>
<td>75</td>
</tr>
<tr>
<td>DE049_[5]</td>
<td>Printing</td>
<td>Water scrubber system</td>
<td>8.6</td>
<td>9.87</td>
<td>12.3</td>
<td>62</td>
</tr>
<tr>
<td>IT078_[3]</td>
<td>NI</td>
<td>Water scrubber system</td>
<td>1.2</td>
<td>4.92</td>
<td>12.4</td>
<td>NI</td>
</tr>
<tr>
<td>IT064_[3]</td>
<td>NI</td>
<td>Water scrubber system</td>
<td>2.5</td>
<td>6.07</td>
<td>12.9</td>
<td>213</td>
</tr>
<tr>
<td>IT077_[9]</td>
<td>Thermal treatment</td>
<td>Water scrubber system</td>
<td>6.3</td>
<td>8.62</td>
<td>13</td>
<td>NI</td>
</tr>
<tr>
<td>Emission point</td>
<td>Process(es) associated to the emissions</td>
<td>Abatement techniques</td>
<td>Minimum concentration (mg/Nm³)</td>
<td>Average concentration (mg/Nm³)</td>
<td>Maximum concentration (mg/Nm³)</td>
<td>Maximum load (g/h)</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>-------------------------------</td>
<td>-------------------------------</td>
<td>-------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>UK127_[6]</td>
<td>Thermal treatment</td>
<td>Water scrubber system, ionisation</td>
<td>0.15</td>
<td>0.55</td>
<td>1.2</td>
<td>8</td>
</tr>
<tr>
<td>DE024_[8]</td>
<td>Coating and laminating</td>
<td>Thermal oxidation</td>
<td>1</td>
<td>1.23</td>
<td>1.4</td>
<td>17</td>
</tr>
<tr>
<td>UK127_[1]</td>
<td>Dyeing</td>
<td>Condensation, dry electrostatic precipitation (ESP), ionisation, acid scrubber system</td>
<td>0.23</td>
<td>1.32</td>
<td>2.9</td>
<td>39</td>
</tr>
<tr>
<td>DE049_[3]</td>
<td>Functional finishing - Coating and laminating</td>
<td>Water scrubber system</td>
<td>2.5</td>
<td>2.67</td>
<td>2.9</td>
<td>95</td>
</tr>
<tr>
<td>DE050_[1]</td>
<td>Functional finishing - Thermal treatment</td>
<td>Wet electrostatic precipitation, water scrubber system</td>
<td>2.88</td>
<td>3.04</td>
<td>3.28</td>
<td>102</td>
</tr>
<tr>
<td>UK127_[2]</td>
<td>Dyeing</td>
<td>Condensation, water scrubber system, mist filter, dry electrostatic precipitation (ESP)</td>
<td>0.38</td>
<td>1.83</td>
<td>5</td>
<td>67</td>
</tr>
</tbody>
</table>

Source: [196, TWG 2019]

NB:
NI = No information
Table 4.41: Environmental performance of abatement techniques for dust emissions to air

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Process(es) associated to the emissions</th>
<th>Abatement techniques</th>
<th>Minimum concentration (mg/Nm³)</th>
<th>Average concentration (mg/Nm³)</th>
<th>Maximum concentration (mg/Nm³)</th>
<th>Maximum load (g/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT097_{4}</td>
<td>Shrink-proof finishing</td>
<td>Water scrubber system</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>IT060_{9}</td>
<td>Singeing</td>
<td>Acid scrubber system</td>
<td>0.16</td>
<td>0.17</td>
<td>0.18</td>
<td>4</td>
</tr>
<tr>
<td>IT083_{15}</td>
<td>Dyeing</td>
<td>Absolute filter system</td>
<td>0.22</td>
<td>0.29</td>
<td>0.38</td>
<td>1</td>
</tr>
<tr>
<td>IT096_{11}</td>
<td>Other</td>
<td>Water scrubber system</td>
<td>0.49</td>
<td>0.49</td>
<td>0.49</td>
<td>1</td>
</tr>
<tr>
<td>IT072_{3}</td>
<td>Dyeing</td>
<td>Water scrubber system</td>
<td>0.26</td>
<td>0.39</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>IT082_{3}</td>
<td>Functional finishing - Thermal treatment</td>
<td>Water scrubber system</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>13</td>
</tr>
<tr>
<td>IT082_{4}</td>
<td>Functional finishing - Thermal treatment</td>
<td>Water scrubber system</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>23</td>
</tr>
<tr>
<td>IT082_{15}</td>
<td>Singeing</td>
<td>Water scrubber system</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>PT111_{3}</td>
<td>Functional finishing - Thermal treatment</td>
<td>Water scrubber system, other</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>IT078_{4}</td>
<td>Singeing</td>
<td>Cyclonic separation</td>
<td>0.37</td>
<td>0.79</td>
<td>1.5</td>
<td>NI</td>
</tr>
<tr>
<td>DE032_{2}</td>
<td>Singeing</td>
<td>Water scrubber system</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>12</td>
</tr>
<tr>
<td>IT082_{2}</td>
<td>Functional finishing - Thermal treatment</td>
<td>Water scrubber system</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>48</td>
</tr>
<tr>
<td>PT109_{2}</td>
<td>Functional finishing - Shrink-proof finishing - Thermal treatment</td>
<td>Water scrubber system</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>17</td>
</tr>
<tr>
<td>IT061_{4}</td>
<td>Wool Carbonising</td>
<td>Bag filter system</td>
<td>0.4</td>
<td>1.13</td>
<td>2.5</td>
<td>58</td>
</tr>
<tr>
<td>DE041_{1}</td>
<td>Singeing</td>
<td>Water scrubber system</td>
<td>3.1</td>
<td>3.1</td>
<td>3.1</td>
<td>18</td>
</tr>
<tr>
<td>PT115_{4}</td>
<td>Thermal treatment - Functional finishing</td>
<td>Cyclonic separation</td>
<td>2</td>
<td>2.6</td>
<td>3.2</td>
<td>17</td>
</tr>
<tr>
<td>IT069_{11}</td>
<td>Singeing</td>
<td>Cyclonic separation</td>
<td>0.1</td>
<td>1.15</td>
<td>3.9</td>
<td>13</td>
</tr>
<tr>
<td>IT063_{11}</td>
<td>Thermal treatment - Functional finishing</td>
<td>Dry electrostatic precipitation (ESP)</td>
<td>0.8</td>
<td>2.2</td>
<td>3.9</td>
<td>NI</td>
</tr>
<tr>
<td>IT082_{10}</td>
<td>Functional finishing - Thermal treatment</td>
<td>Water scrubber system</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>69</td>
</tr>
<tr>
<td>IT059_{2}</td>
<td>Singeing</td>
<td>Water scrubber system</td>
<td>0.4</td>
<td>1.7</td>
<td>4.3</td>
<td>31</td>
</tr>
</tbody>
</table>
Table 4.42: Environmental performance of abatement techniques for NH3 emissions to air

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Process(es) associated to the emissions</th>
<th>Abatement techniques</th>
<th>Minimum concentration (mg/Nm³)</th>
<th>Average concentration (mg/Nm³)</th>
<th>Maximum concentration (mg/Nm³)</th>
<th>Maximum load (g/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE049_{3}</td>
<td>Functional finishing - Coating and laminating</td>
<td>Water scrubber system</td>
<td>2.2</td>
<td>2.67</td>
<td>3.1</td>
<td>101</td>
</tr>
<tr>
<td>ITO94_{1}</td>
<td>Thermal treatment</td>
<td>Water scrubber system</td>
<td>1.2</td>
<td>3.42</td>
<td>6.85</td>
<td>169</td>
</tr>
<tr>
<td>ITO63_{3}</td>
<td>Printing</td>
<td>Water scrubber system</td>
<td>2.2</td>
<td>6.85</td>
<td>9.7</td>
<td>63</td>
</tr>
</tbody>
</table>
Cross-media effects
The high energy demand and corresponding high amounts of CO\textsubscript{2} resulting from thermal and catalytic incineration need to be addressed (greenhouse effect). However, this disadvantage can be considered to be outweighed by the benefit in terms of organic compounds removed [179, UBA, 2001].

In wet scrubbers, the pollutants are shifted from off-gas to the waste water. Efficient waste water treatment (e.g. oil/water separators, biological waste water treatment) is required. See Sections 4.1.8.2 to 4.1.8.13 and [24, COM 2016] for the cross-media effects of the individual abatement techniques.

Concerning wet scrubbing, most compounds dissolved in the scrubbing liquor can be decomposed biologically. However, substances may be introduced into the waste water that have toxic potential for bacteria (e.g. from biocide finishing), such as formaldehyde, triclosan, isothiazolinone or mercaptobenzimidazole. In the case of PA 6, the nitrogen load into the waste water is increased by caprolactam adsorption. [36, ÖKOPOL 2011]

Technical considerations relevant to applicability
See Sections 4.1.8.2 to 4.1.8.13 and [24, COM 2016] for the applicability of the individual abatement techniques.

Off-gas cleaning can be installed in both new and existing installations. However if existing machinery has to be rebuilt, applicability can be limited by economic, technical and logistical factors.

In each case, for the installation of an off-gas cleaning system, a tailor-made solution using the above-mentioned techniques has to be developed. In general, however, the following considerations about the applicability of the different abatement techniques have to be borne in mind.

Condensation techniques
Pollutants with a high volatility and, in most cases, odour-intensive substances are removed.

Absorption techniques
The efficiency of wet scrubbers in textile finishing depends strongly on process-specific parameters. Normally the efficiency is in the range of 40 to 60 %. Applicability for water-insoluble pollutants is limited.

Electrostatic precipitation
Electrostatic precipitators can precipitate dusts and aerosols with a size of 0.01 to 20 μm. Maximum efficiency will be reached at around 0.1 μm – 1.5 μm. Manufacturers therefore recommend installing a mechanical filter before the electrostatic filter, which precipitates most of the particles with size > 20 μm.

The efficiency of electrostatic precipitators for particle-sized solid and liquid pollutants is in the range of 90 % to 95 %. Gaseous pollutants and odorous substances cannot be precipitated. For best overall efficiency, it is therefore important that almost all condensable substances, emitted as aerosols, are removed before reaching the electrostatic precipitator. This can be achieved by heat exchangers or scrubbers.

Economics
See Sections 4.1.8.2 to 4.1.8.13 and [24, COM 2016] for the economics of the individual abatement techniques.
Chapter 4

The investment costs for a heat exchanger, fine mist scrubber and electrostatic precipitator for a stenter (based on a waste gas flow in the range of 7,000-10,000 Nm$^3$/h) are in the order of EUR 200,000. [212, HAZBREF 2019]

Installation and running costs have to be considered. In particular, costs of equipment maintenance and energy should be considered. Detailed information about costs is reported in another BREF ([196, EIPPCB, 2001]). Among the above-mentioned techniques, oxidation techniques have by far the highest investment and operating costs. Specific information about dry electrofiltration (combination of heat exchangers and electrostatic precipitation) has been submitted for the present document. A capital investment of EUR 70,000 is reported for a 10,000 m$^3$/h unit with a pay-back time of less than 3 years [44, Comm., 2000].

Driving force for implementation

Environmental legislation.

Need to comply with standards set by environmental legislation for air pollution and improving environmental performance in terms of odour nuisances.

Reference—Example plants

See Sections 4.1.8.2 to 4.1.8.13 for example plants.

Many plants. Systems based on heat exchangers, aqueous scrubbers and electrostatic precipitators dominate [179, UBA, 2001].

Reference literature

[179, UBA, 2001], [281, Belgium, 2002], [44, Comm., 2000], [36, ÖKOPOL 2011] [212, HAZBREF 2019] [196, TWG 2019]

4.1.9 Waste management

4.1.9.1 Waste management plan

Description

The waste management plan is part of the EMS (see Section 4.1.1.1) and is a set of measures to minimise the generation of waste, to optimise the reuse, recycling and/or recovery of the waste and to ensure the proper disposal of waste.

Technical description

A variety of techniques can be used for residue optimisation and they range:

- from basic housekeeping techniques;
- through statistical measurement techniques;
- to the application of clean technologies;
- the use of process chemicals before their expiry date;
- to the use of residues as fuel
- the reuse of packaging.

In particular, a residue management plan includes the following:

- Identifying, characterising and quantifying each of the waste streams generated (see Section 4.1.1.2). Maintaining a waste tracking system can help operators to record the quantity, nature, origin and, where relevant, the destination, frequency of collection, mode of transport and treatment method of any waste which is disposed of or recovered on that site.
- Identifying the current or proposed handling arrangements.
- Fully describing how each waste stream is proposed to be recovered or disposed of. If it is to be disposed of, the plan explains why recovery is not technically or economically
possible and then describes/explains the measures planned to avoid or reduce the impact on the environment.

Practical techniques to reduce the amount of waste sent for disposal may include the following:

- applying housekeeping operations; these can be as simple as sweeping prior to washing floors and can substantially reduce residue volumes;
- the maximum storage time of process chemicals is clearly established and is monitored to avoid the expiry date being exceeded;
- separate capture of high-loaded waste streams from low-concentrated effluent to allow more efficient treatment (see Section 4.1.7.2);
- separate collection of unavoidable solid waste (see Section 4.1.9.2);
- reduction of packaging;
- use of returnable containers;
- recycling of textile wastes (textile residues, spoilt work, raising, etc.).

Achieved environmental benefits
The steps above help to ensure the prudent use of natural resources and can reduce waste generation in the textile plant as well as helping to identify a good disposal route.

Environmental performance and operational data
No information provided.

Cross-media effects
None identified.

Technical considerations relevant to applicability
The level of detail of the waste management plan will generally be related to the nature, scale and complexity of the plant.

Economics
No information provided.

Driving force for implementation

Example plants
Plants from the data collection: BE007, BE008, BE009, BE010, BE011, BE013, BE014, CZ016, DE021, DE024, DE025, DE026, DE029, DE032, DE039, DE041, DE044, DE045, DE049, DE051, FR135, IT065, IT082, IT083, IT084, PT098, PT104, PT108, PT115, PT117, SE119, SE120, UK124, UK126 and UK129.

Reference literature
[29, COM 2018]
4.1.9.2 Management of hazardous waste

Description
Waste (e.g. liquid waste, paper, cloths, absorbent material, laboratory waste, sludge from waste water treatment) contaminated with hazardous chemicals (e.g. finishing agents like flame retardants, water and oil repellents) is collected and stored separately.

Technical description
Examples of waste containing residues of deca-BDE, HBCD, Sb$_2$O$_3$ and/or PFOS/PFOA include paper, cloths or other absorbent materials that are used for the dry removal of solid residues as well as laboratory waste.

NP/NPE are primarily released during washing processes on purchased tissues and yarns and are not used in the textile industry as such. PAHs originate from mineral oils and are present in purchased tissues and yarns, for example, or are formed on thermo-fixed tissues. Consequently, NP/NPE and PAHs are not likely to be found in solid waste.

Paper, cloths or other absorbent materials are stored in an appropriate manner, while awaiting to be disposed of by a qualified processing company. This waste can be stored, for example, in enclosed recipients in a specifically designated area.

Examples of liquid waste are spent finishing liquors (see Section 4.1.7.2).

Achieved environmental benefits
Prevention of the uncontrolled emissions of hazardous substances to air, water and soil.

Environmental performance and operational data
It is possible to prevent chemicals entering waste water and the soil by storing waste containing deca-BDE, HBCD, Sb$_2$O$_3$ and/or PFOS/PFOA in an appropriate manner and disposing of it via a qualified processing company.

In Flanders, the collection and disposal of process baths containing deca-BDE and/or HBCD and Sb$_2$O$_3$ is required by regulation and is normal practice.

Of three textiles companies in Flanders that discharge into surface water, and where deca-BDE is used for finishing activities, the average concentration of deca-BDE in the effluent, in the period prior to disposal of process baths, amounted to 155 µg/l on average (17 measurements) with a range of <1 µg/l to 1 153 µg/l. The deca-BDE concentration in the effluent of the same companies, in the period after disposal of the process baths, amounted to 42 µg/l on average (32 measurements), with a range of <1 µg/l to 370 µg/l. [27, Derden et al. 2010]

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
Waste disposal via a qualified processing company is accompanied by certain costs such as:

- the rental price of containers for storing industrial waste amounts to EUR 8 per month;
- the collection cost per ASP waste container amounts to EUR 75;
- the cost for rinsing and returning IBC containers to the market amounts to EUR 40;
- the processing costs for waste containing residues of deca-BDE, HBCD, Sb$_2$O$_3$ and/or PFOS/PFOA amount to:
  - EUR 0.75/l;
  - EUR 0.93/kg.
Concerning liquid waste, because the collection and disposal of rinsing water from process baths containing deca-BDE, HBCD, Sb$_2$O$_3$, PFOS and/or PFOA is a standard technique in Flanders, this measure is regarded as economically feasible for all textile companies that use such process baths.

The cost for disposing of process baths and rinsing water from process baths (with for example deca-BDE and Sb$_2$O$_3$) amounts to EUR 150-500 for 1 000 litres, depending on the solid matter content (the higher the solid matter content, the higher the price).

For process baths that contain hazardous substances, the price for disposal is higher: e.g. EUR 1 500 per 1 000 litres (in 2007, including handling costs for incineration using a chemical scrubber). Furthermore, in order to prevent concrete erosion, the cement industry also sets requirements for the amount of bromine in cement (< 50 ppm). [27, Derden et al. 2010]

**Driving force for implementation**
Environmental legislation.

**Example plants**
Plants DE024, DE030, DE039, DE40 and FR133 handle spent dye baths as waste.
Plants DE025, DE032 and DE049 handle spent printing pastes as waste.

**Reference literature**
[27, Derden et al. 2010]
4.2 Raw wool scouring

4.2.1 [Wool scouring with organic solvent]

Ex-Section 4.4.4 is proposed to be deleted because:
- the technique uses trichloroethylene which is now in Annex XIV of REACH
- no plant of the data collection has reported solvent scouring
- it is not clear whether solvent scouring is actually used in the sector.

4.2.2 Techniques to increase resource efficiency

4.2.2.1 [Use of]-Integrated dirt removal/grease recovery loops

Ex-Section 4.4.1.

Description
Waste water from wool scouring is treated (e.g. by a combination of centrifugation and sedimentation) to separate grease, dirt and water. Grease is recovered, water is partially recycled to scouring and dirt is sent to further treatment.

Technical description
As already described in Section 2.3.1.1 (see Figure 2.4), a wool scouring plant operating in countercurrent mode normally produces three liquid waste streams:

- a dirt-rich flow, from the bottoms of the scouring bowls;
- a less concentrated dirty flow, from the bottoms of the rinse bowls;
- a grease-rich flow, from the top of the first scouring bowl, or from the side tank of the first scouring bowl, which receives the liquor removed from the wool as it exits the bowl through the squeeze press.

All of these flows can be partially decontaminated and recycled to the scouring plant, by means of grease recovery and dirt removal loops.

There is no consensus on the best way to operate the loop(s). Some mills prefer to treat the dirt-rich flow and the grease-rich flow separately, whilst others combine the two streams and carry out sequential treatment, first for dirt removal, then for grease recovery.

For grease recovery, plate-type centrifuges are employed. They are usually protected from the abrasive effects of dirt by hydrocyclones in cases where separate rather than sequential grease recovery and dirt removal is practised. The centrifuge produces a top phase, known as ‘cream’, which is grease containing a small amount of water. This ‘cream’ is usually passed to a secondary centrifuge, which produces an upper, a lower and a middle phase. The upper phase consists of anhydrous grease, which can be sold as a by-product. The bottom phase is high in dirt and may be passed to the input side of the dirt recovery loop, or to the effluent treatment plant. The middle phase is impoverished in both grease and dirt and may be completely or partially recycled to the scouring plant, by addition to the first scouring bowl. A portion of the middle phase may flow to effluent treatment.

Dirt removal may employ gravity settling tanks, hydrocyclones or decanter centrifuges – or combinations of these methods.

In the case of Plant CZ016, the volume of waste water discharged is further reduced by evaporation. The remaining condensates are treated by stripping then by oxidation with ozone for deodorisation before being resued in the process.
In mills with more than one scouring line, the lines normally share dirt removal/grease recovery facilities.

For fine and extra-fine wool, when carried out using machinery that has a separate continuous sludge flow output, the wool grease recovery loop also allows the elimination of the very fine dirt fraction without the need for a separate loop for dirt removal.

**Main-Achieved environmental benefits**
- Reduction of water and energy consumption.
- Reduced waste water generation.
- Reduction of emissions to water.
- Resource efficiency.

**Environmental performance and operational data**
The implementation of dirt removal/grease recovery loops allows the following:

- A reduction in water consumption ranging from a minimum of 25% to a maximum of more than 50%, taking as a reference point the consumption of water of a conventional plant operating countercurrently (between 5 l/kg and 10 l/kg of greasy wool).
- A reduction in energy consumption equivalent to the amount of thermal energy carried by the recycled liquor (the liquor temperature is generally about 60 °C).
- The production of a valuable by-product: wool grease.
- A reduction in detergent and detergent builder consumption proportional to the water savings achieved.
- The conversion of suspended dirt into spadeable sludge.
- A reduction of the load (oxygen-demanding substances and suspended solids) sent to the effluent treatment plant, which means a reduction in the consumption of energy and chemicals for the treatment of the waste water. This reduction is proportional to the dirt removal and grease recovery rate achieved.

Medium to large scouring mills (say 15 000 – 25 000 tonnes of greasy wool per year) employing dirt removal/grease recovery loops should be able to achieve net specific water consumption figures of 2 – 4 l/kg of greasy wool for most types of wool. Both coarse and fine wool scourers in the survey are already achieving these figures. However, there is insufficient data to define whether these performances are also applicable to extra-fine wool scourers.

The amount of grease recovered as sellable by-product in the surveyed companies ranges between 10 and 35 g/kg of greasy wool. The best performance for a fine wool scourer is almost 35 g/kg greasy wool and for a coarse wool scourer about 13 g/kg. These recovery rates represent about 25% of the grease estimated to be present in the wool scoured.

Of the six wool scourers which took part in the data collection, four reported a grease recovery rate between 11 g/kg and 15 g/kg of raw wool for coarse wool and between 50 g/kg and 60 g/kg of raw wool for extra and super fine wool (see Section 3.7.1). [196, TWG 2019]

There is probably a maximum amount of grease that can be recovered centrifugally, which is governed by the ratio between hydrophobic and less-hydrophobic grease (top grease and oxidised grease) present on the scoured wool [187, INTERLAINE, 1999].

**Cross-media effects**
Consumption of energy by the centrifuges is one cross-media effect.
The dirt and part of the grease which is not recovered as by-product may be transferred as pollutant, from water to land.

The COD concentration of the effluent resulting from the dirt removal and grease recovery loop may be too high for on-site aerobic treatment plants. The installation of coagulation/flocculation
or anaerobic biological treatment before the aerobic biological plant would overcome this problem.

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique. This measure is applicable in all new and most existing wool scouring plants. For plants scouring hair, or wools giving low yields of poor quality grease, the measure might not be an economically attractive proposition.

**Economics**

A calculation of the net economic benefit per tonne of greasy wool can be done, based on the assumptions reported in Table 4.43. The unit costs refer to the situation in the UK at the time of the research (1999); therefore they can only be indicative of the European situation.

**Table 4.43: Estimate of the economic benefits achievable with the installation of integrated dirt removal/ grease recovery loops**

<table>
<thead>
<tr>
<th>Benefits per tonne of greasy wool processed</th>
<th>Unit cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water saved: 4 m³</td>
<td>EUR 0.68/m³ mains water</td>
</tr>
<tr>
<td>Energy saved: 836.8 MJ (*)</td>
<td>EUR 0.00245/MJ</td>
</tr>
<tr>
<td>Detergent saved: 1 kg</td>
<td>EUR 1.40/kg</td>
</tr>
<tr>
<td>Builder saved: 1 kg</td>
<td>EUR 0.27/kg (Na₂CO₃)</td>
</tr>
<tr>
<td>Avoided treatment of waste water: 4 m³</td>
<td>EUR 0.53/m³ water discharged (*)</td>
</tr>
<tr>
<td>Avoided disposal of sludge: about 150 kg (wet weight)</td>
<td>EUR 0.041/kg of sludge (wet weight)</td>
</tr>
<tr>
<td>Grease produced for sale:</td>
<td>EUR 2/kg of wool grease (+) (but very variable)</td>
</tr>
<tr>
<td>- 32.5-50-60 kg (fine wool scourers)</td>
<td></td>
</tr>
<tr>
<td>- 43-11-15 kg (coarse wool scourers)</td>
<td></td>
</tr>
</tbody>
</table>

(a) The energy saved to heat water to the operating temperature of 60 °C can be estimated at 209.2 MJ per m³ of saved water (using direct gas at 90 % efficiency).
(b) UK cost (1999) considering only the volume charge. In a real case, energy, chemicals, manpower, etc. should be taken into account.

Source: [187, INTERLAINE, 1999] except (c), I.M. Russell personal communication

It is estimated that the installation of dirt removal/grease recovery loops at a mill processing 15 000 tonnes to 25 000 tonnes per year of greasy wool would cost between EUR 400 000 and EUR 800 000 euros, depending on the nature, the quality and the capacity of the particular system chosen. The payback time for the installation, ignoring the benefits of reduced effluent disposal costs, would be between 2.04 and 4.08 years [187, INTERLAINE, 1999].

**Driving force for implementation**

The driving forces are economic benefits for medium and large mills, especially those processing fine (high grease content) wools. Economic benefit derives from savings in water, energy, sewage treatment and chemical costs and the proceeds from sales of wool grease. Disincentives are the high capital cost, high maintenance costs and complexity.

**Example Reference plants**

Many plants throughout Europe (see also survey referred to in Chapter 3). Plants from the data collection: CZ016, IT075, IT076, UK128 and UK129. In particular, Plant CZ016 uses evaporation to reduce even further the amount of waste water discharged.

**Reference literature**

[187, INTERLAINE, 1999] [ 196, TWG 2019 ]
4.2.2.2 [Use of integrated dirt removal/grease recovery loops combined with evaporation of the effluent and incineration of the sludge]

Ex-Section 4.4.2 is proposed to be deleted because only one plant worldwide was applying this technique at the time the original BREF was drafted and it is not clear whether it is actually used in the sector. Moreover, the text is largely outdated. One plant of the data collection has reported to use evaporation as waste water treatment though. This is reflected in the previous technique.

4.2.2.3 Biological treatment [Disposal] of wool scouring sludge [to agricultural land]

Ex-Section 4.10.11

Description
The wool scouring sludge is treated by composting or anaerobic digestion.

Technical description
In most member states, conditions set in existing regulations make it necessary to pretreat wool scour sludges before disposal to agricultural land. The pretreatment of choice appears to be composting, although anaerobic digestion (with recovery of the evolved methane) might conceivably be considered as an alternative. Material for composting should ideally have a C:N ratio of 25–30:1 between 20:1 and 35:1 ([29, COM 2018]), which means that wool scouring sludges need an addition of carbon-rich material. Green waste, sawdust, woodchip and straw have reportedly been used successfully. Some ‘structural material’ (size up to 50 mm) is needed in the co-composted material in order to allow the ready ingress of air. Optimum moisture content of the material for composting is 50–60%.

The residual grease content of the sludge sent for composting is a key control parameter. For coarse wool, this content is about of 10-12% by weight and may be higher for fine wool. With a higher content of residual grease, the composting time may be longer and the C:N ratio would need to be adjusted accordingly. Moreover, the sludge gets stickier and is therefore more difficult to handle mechanically. [176, Seaman 2019]

The composting process is described extensively in [29, COM 2018].

Aeration of the material is used to control the rate of composting and therefore the temperature. In the earlier thermophilic phase a temperature of 45–60 °C is optimum, whilst in the later mesophilic phase, lower temperatures (20–45 °C) are preferred.

There are many methods of composting in commercial production. They include methods described as follows:
• open air, turned windrows
• open air, with forced aeration
• covered building, forced aeration
• simple tunnel, non-turning
• complex tunnel, with turning
• enclosed hall, operating under negative pressure
• reactor systems.

Enclosed, or in-vessel composting systems have advantages over open air systems that make in-vessel composting particularly suited for industrial wastes. First, control of the process is improved, allowing the use of higher temperatures and higher rates of composting. Second, control of odours, dust and leachate is superior, allowing operation closer to industrial waste sources. The disadvantage of enclosed systems is their greater initial cost.

After composting, the compost must be allowed to mature for a number of weeks during which time, further (bio)chemical changes occur, making the compost more suitable for purpose.

Main-Achieved environmental benefits
Benefits include resource efficiency and reduction of the volume of waste sent for disposal.

It is believed that composting is a sustainable means of disposal of wool scour sludge, whilst at the same time producing a useful soil conditioner. The carbon which is decomposed by the composting process is converted aerobically into carbon dioxide, rather than methane (as in landfill). Carbon dioxide is a much less potent greenhouse gas than methane [187, INTERLAINE, 1999].

Environmental performance and operational data
For wool scouring sludges, the purpose of composting is to destroy, as far as possible, the components of the sludges which would be undesirable if spread on agricultural land. In the main, these are wool grease and ectoparasiticide residues. Composts produced from mixtures containing wool grease should therefore be periodically monitored for grease and ectoparasiticide content.

In composting trials carried out in the UK, similar results were achieved by composting for 6-7 weeks in a 10-tonne open windrow and for 14 days in an enclosed tunnel composter. The grease, organochlorine and synthetic pyrethroid ectoparasiticide content of the compost were reduced by 60% and organophosphate ectoparasiticides were reduced by 80%. Further reductions were expected during the maturation phase, but were not monitored. Interestingly, the woodchips and sawdust used as co-compostable material in this trial were found to be contaminated with lindane (OC) [187, INTERLAINE, 1999].

Cross-media effects
Composting can cause air pollution by odours and dust and water pollution via leachate (see [29, COM 2018]). In a well-conducted composting operation, however, these problems should not occur. The use of compost as a soil conditioner may also cause water pollution if ectoparasiticide residues are present. However, this is thought to be highly unlikely if the composts are used responsibly because of the very poor mobility of sheep ectoparasiticides in soil [187, INTERLAINE, 1999].

Technical restrictions related to applicability
Generally, there are no technical restrictions to the applicability of this technique. This measure is applicable on site by scourers who have the required sufficient space. Off site, it is widely available, though costs of transport costs (because of distance from merchant composters) might be a problem for some scourers.

Availability of this option, both on-site and merchant may increase after the implementation of the Landfill Directive (1999/31/EC).

Economics
Composting is not an inexpensive technique. Capital costs are reported in the next figure Figure 4 for recent composting plant start-ups, while Table 4.44 gives information for in-vessel systems.

\[\text{Madden, ENco, personal communication, 1998.}\]
The market for compost is uncertain. The Composting Association (UK) reports that no composting plant in the country can recover its costs through sales of compost. In fact, most plants receive no payment at all for their product. The cost of composting therefore has to be met through gate charges, or in the case of local authorities composting municipal waste, through local taxes.

Driving force for implementation
Costs of landfilling.

The implementation of the Landfill Directive will stop landfill of liquids. The future landfill of sludge is not clear. Composting provides a relatively low-tech, low-cost means of treating wool scour sludge to give a material that can be used or more readily disposed of to landfill.

Example Reference plants
Mills C, F, G and M in the survey reported in Section use this method of sludge disposal. Plants from the data collection: CZ016, IT075, IT076, UK128 and UK129.

Reference literature
[187, INTERLAINE, 1999] [176, Seaman 2019]
it is not clear whether it is actually used in the sector

4.2.3 Techniques to increase energy efficiency Minimising energy consumption in wool scouring installations

Ex-Section 4.4.3

Description
Set of measures to reduce energy consumption, including:

- heat recovery;
- covered scouring bowls;
- optimised temperature of the last scouring bowl;
- direct gas heating.

Technical description
Wool scouring is an energy-intensive process. In addition to the generally applicable good housekeeping techniques already mentioned, the biggest energy savings in a wool scouring process come from reducing effluent flowdown (and consequent heat losses) to drain or to on-site effluent treatment plant, by the installation of a dirt/grease recovery loop. Techniques include:

- Fitting of covers on scouring bowls to prevent heat loss by convection or evaporation. Retrofitting, however, is sometimes difficult on existing installations.
- Optimising the performance of the final squeeze press in order to improve mechanical removal of water from the wool before it enters the evaporative dryer. The presses used for squeezing wool usually have steel bottom rollers and a porous top roller. Traditionally, the top roller was a steel roller wound with a crossbred (coarse) wool top (a sliver of parallel fibres). More recently, this has been replaced with a blended top of wool and nylon (polyamide), a nylon top, or a square section rope, usually of a wool and nylon blend. The last option combines durability with good performance. Porous composition rollers are offered commercially, but no information is available on their performance in this application.
- Running the last bowl at relatively high temperature in order to improve squeezing efficiency. Many scouring plants are set to run with bowl temperatures decreasing from the first or second to last bowl. Last bowl temperatures in the survey ranged from ambient (say 20°C) to 65°C, with an average of 48°C. Since heat losses from the last bowl will increase as its temperature increases and heat consumption in the dryer will correspondingly decrease as the squeezing efficiency improves, it follows that there is an optimum temperature for the last bowl. It has been shown that this temperature is 60-65°C for wool throughput rates above about 500 kg/h.
- Retrofitting heat recovery units to dryers. However, this is expensive and the heat saving available is only about 0.2 MJ/kg. Scourers’ practical experience with heat recovery units on wool dryers is also negative; the units quickly become blocked with fibre and may even cause increases in energy consumption.
- Direct gas firing of scouring bowls and dryers in order to avoid the losses which occur in the generation and distribution of steam for use in direct or indirect steam heating. Retrofitting is not always possible in existing plant and the cost is relatively high. Energy saving is 0.3 MJ/kg.

Main-Achieved environmental benefits
Reduction in energy consumption which will have the effect of reducing emissions of CO₂, SOₓ and NOₓ, either from the scouring plant itself or off site.
Environmental performance and operational data

Energy savings from a dirt/grease recovery loop can be estimated as about 2 MJ/kg of greasy wool if a scouring plant with a loop and heat exchangers is used. It is assumed that a conventional scourer discharging 10 litres of water per kg of greasy wool needs 2.09 MJ to heat 10 litres of fresh water from 10 °C to 60 °C (209 kJ/l). A scouring installation with a loop and heat exchangers discharges only 2 l/kg (see Section 4.2.2.1) and recovers 80% of the heat contained in the effluent (the energy input needed becomes 0.084 MJ/kg of greasy wool).

It is also interesting to Table 4.45 shows the energy savings achievable in the dryer by operating the last bowl at optimum temperature (65 °C) as discussed earlier.

<table>
<thead>
<tr>
<th>Last bowl temperature (°C)</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings if the last bowl was operated at 65 °C instead, expressed in MJ/kg wool (¹)</td>
<td>0.42</td>
<td>0.25</td>
<td>0.12</td>
<td>0.04</td>
</tr>
</tbody>
</table>

(¹) Calculations were made considering an indirect steam dryer.


Energy savings for the other measures described have already been reported under the heading "Description".

Energy savings from direct gas firing of scouring bowls and dryers are 0.3 MJ/kg.

In conclusion, medium-to-large wool scouring plants can be operated with an energy consumption of 4-4.5 MJ/kg of greasy wool processed, comprising approximately 3.5 MJ/kg thermal energy and less than 1 MJ/kg electrical energy. Smaller plants may have higher limits for specific energy consumptions, but no information is available to confirm this [187, INTERLAINE, 1999].

Operational data

Many mills do not have separate metering for monitoring the energy consumption of individual machines or processes — or even whole departments. In these circumstances, it is difficult for mill personnel to identify potential energy savings or to become quickly aware of problems, such as loss of efficiency of a dryer. Installation of energy monitoring equipment would probably have an early payback, but little evidence is available to support this claim. In the absence of individual metering, whole-plant monitoring should be done on a frequent basis and any departures from the norm investigated [187, INTERLAINE, 1999].

Cross-media effects

Energy conservation has positive effects on emissions to air and land. No negative effects are to be expected.

Technical considerations relevant to applicability

The measures described here are of mixed applicability. Many are readily applicable in existing plant but some are not, or would involve such changes that the plant would, in effect, become a new plant. For many of the measures, applicability is discussed in the descriptions above [187, INTERLAINE, 1999].

Fitting of covers on scouring bowls or direct gas firing of scouring bowls and dryers may be only applicable to major plant upgrades or to new plants.


Chapter 4

Economics
The most important means for wool scourers to reduce energy consumption is by reducing water consumption and effluent volume. The economics of doing this by installation of countercurrent scouring and integrated dirt removal/grease recovery loops have already been discussed (Section 4.2.2.1). Information on the costs of other measures is not available at the time of writing [187, INTERLAINÉ, 1999].

Driving force for implementing these techniques
Savings in energy consumption.
Economic considerations are the major driving force from the industry’s point of view. From a governmental viewpoint, the main driving force is reduction of emissions to air, in order to achieve commitments made in international agreements [187, INTERLAINÉ, 1999].

Example Reference plants
All the measures discussed here are in operation in mills throughout the world, although there may be no one mill which operates all. An exception is the use of co-generation (combined heat and power) as no wool scouring mill is known to be operating such a system, though systems operate in other industries. It is likely that a scouring mill would generate an excess of power (electrical energy) and in most member states the excess could be sold and fed into the grid. For the wool scouring sector, co-generation must be regarded as an emerging technique [187, INTERLAINÉ, 1999].

Plants from the data collection: CZ016, IT061, IT075, IT076, UK128 and UK129.

Reference literature
[187, INTERLAINÉ, 1999]

4.2.4 [Waste water treatment in wool scouring installations]

From ex-Section 4.10.10
This technique is proposed to be deleted since integrated dirt/grease recovery is a separate technique (see above 4.2.2.1 and 4.2.2.2) and flocculation/coagulation and evaporation are in individual WWT techniques (see above 4.1.7.3.5 and 4.1.7.3.4.6).

Description
The INTERLAINÉ report describes a number of available options for the management of water emissions arising from wool scouring installations. Clearly not all options can be considered BAT. Nevertheless it is useful to discuss the environmental performances and economic implications involved in each of the following scenarios:

A. treatment in external municipal sewage treatment plant. It consists of screening the effluent to remove gross solids (>3 mm), perhaps cooling the effluent, and/or adjusting its pH to the sewerage undertaker’s requirements and disposing of the effluent to sewer
B. treatment in an integrated dirt removal/grease recovery loop followed by discharge to municipal sewer. It is assumed that the mill installs a dirt removal/grease recovery loop, which recovers 25 % of the grease and removes 50 % of the dirt and a further 10 % of the grease from its effluent as a sludge
C. treatment by coagulation/flocculation followed by discharge to municipal sewer. This technique supposes that the small scourer, rather than installing a dirt removal/grease recovery loop, opts to install on-site end of pipe effluent treatment, using coagulation/flocculation. Treated effluent is discharged to sewer
D. treatment in an integrated dirt removal/grease recovery loop followed by coagulation/flocculation before discharge to municipal sewer (B+C)
E. treatment by evaporation. The technique consists of evaporating the effluent, recycling the condensate if practicable and disposing of the residual concentrate or sludge. Not all mills analysed in the survey using evaporators recycle the condensates. It may be significant that the two mills analysed in the survey which do recycle the condensate, both employ a
biological treatment as well as evaporation within the effluent recycling loop. One mill uses anaerobic lagooning before evaporation and the other uses a rapid bio-reactor after evaporation. It is possible that the biological treatments destroy the compounds responsible for odours.

- treatment in an integrated dirt removal/grease recovery loop combined with evaporation (B+E)
- biological treatment (no data was made available for this technique).

**Achieved emission levels**

The environmental performance of the proposed techniques have been estimated based on the following assumptions:

- for coarse greasy wool: 315 g/kg COD with 50 g/kg of grease and 150 g/kg of dirt
- for fine greasy wool: 556 g/kg COD with 130 g/kg of grease and 150 g/kg of dirt
- untreated effluent contains 95 % of the COD and dirt from the fibre
- the sewage treatment plant removes 80 % of the incoming COD
- the dirt/grease recovery loop recovers 25 % of the grease and removes 50 % of the dirt. It is assumed that a further 10 % of the grease is removed from the effluent as a sludge, before discharge to the sewer. For scouring lines fitted with a dirt/grease recovery loop a net water consumption of 6 l/kg greasy wool has been assumed, but levels of 2–4 l/kg are possible
- the coagulation/flocculation treatment removes 89 % of the grease and 86 % of the suspended solids from the effluent
- in the absence of a dirt/grease recovery loop, effluent volume is assumed at 13 l/kg greasy wool
- evaporation does not entirely remove pollutants. Here it is assumed that the evaporator removes 99.3 % of the grease and 99.9 % of suspended solids. In trials at one mill, removal of sheep ectoparasiticides was: OCs, 96.5 %; OPs, 71.5 %; SPs 100 %. Water from the evaporator can be recycled. The residual COD (200–900 mg/l) and suspended solids (20–40 mg/l) in the condensate are no detriment to adding the recovered water to the rinse bowls of the scour (even the final rinse bowl operates at much higher contaminant levels than this). On the other hand, recycling requires an extra treatment process in order to avoid ammonia and odorous compounds being carried back to the scour. Water saving achievable by recycling of the condensate is not considered in the tables below.

The results of the calculations are reported in Table 4.46 and Figure 4.31 for coarse and fine wool scourers, respectively.

**Table 4.46: Waste water treatment techniques: Environmental performance – coarse wool**

<table>
<thead>
<tr>
<th>Coarse wool</th>
<th>Discharge to sewer</th>
<th>Dirt/grease loop</th>
<th>Flocculation</th>
<th>Dirt/grease loop + flocculat.</th>
<th>Evaporation</th>
<th>Dirt/grease loop + evaporati.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net water consumed (m³)</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>13</td>
<td>6↑1</td>
<td>13</td>
<td>6↑1</td>
<td>13</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>COD from the mill (kg)</td>
<td>299</td>
<td>203↑1</td>
<td>93↑1</td>
<td>81</td>
<td>3.2</td>
<td>2.7</td>
</tr>
<tr>
<td>COD to environment (kg)</td>
<td>60</td>
<td>44</td>
<td>40</td>
<td>46</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Sludge to dispose of (kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>from rec. loop (kg)</td>
<td>152</td>
<td>329</td>
<td>152</td>
<td>186</td>
<td>378</td>
<td>242</td>
</tr>
</tbody>
</table>
Removal of 35% of the grease and 50% of the dirt in the loop reduces the COD from 315 kg/t in the incoming wool to 203 kg/t in the effluent.

Removal of 89% of the grease and 86% of the dirt reduces the COD from 315 kg/t in the incoming wool to 93 kg/t of wool in the effluent.

Source: [187, INTERLAINE, 1999]

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Figure 4.31: Waste water treatment techniques: Environmental performance—fine wool

No precise information has been submitted for effluent treatment by biological processes. It is known that there are scourers in Europe using biological processes as their main methods of effluent treatment. Biological treatment of scouring effluent is particularly popular amongst Italian scourers. One medium-sized Italian mill is known to employ anaerobic biological treatment, flocculation and prolonged aerobic biological treatment in succession for effluent treatment (total biological treatment time is approximately 7 days). This mill claims to produce an effluent containing only 650 mg/l COD, which is discharged to sewer. Another Italian mill uses a 3-day anaerobic process, followed by coagulation/flocculation (FeCl₃) to produce an effluent containing 1000–1200 mg/l COD, which is again discharged to sewer [187, INTERLAINE, 1999].

Several remotely situated Australian mills use anaerobic/aerobic lagooning for effluent treatment, but it is doubtful if any European mill has the space for such a process, not to mention the lack of neighbours which its odour generation potential would affect [187, INTERLAINE, 1999].

Operational data

The concentrate or sludge from evaporation contains suint as well as dirt and grease. Sludges from coagulation/flocculation contain only dirt and grease because suint is highly water soluble and is not flocculated. The presence of suint (largely potassium salts) in the sludge from evaporation appears to alter its physical properties. Flocculated sludge is spadeable and, depending on its water content, varies in consistency from something resembling moist earth to semi-liquid mud. Evaporator condensate, however, may be liquid at relatively high temperature.
and solid at ambient temperature. It appears that the suint salts act as a flux at the temperatures prevailing in the evaporator. This makes evaporator sludge more difficult to handle and to dispose of.

The sludge has been reported to have been transported as a liquid in a heated tanker for disposal to a landfill accepting heated liquids ([187, INTERLAINE, 1999]). However, the implementation of the Landfill Directive (Council Directive 1999/31/EC) required the cessation of the landfilling of liquids (and other problem wastes) by July 2001. Alternatives need to be sought and include: incineration, pretreatment to an acceptable solid form prior to landfilling (e.g., by composting, see Section), or composting and use on land (see Section or use in other processes such as brick-making (see Section 4.2.2.4).

Cross-media effects

Options in which the effluent is treated on-site or off-site in municipal sewer, without dirt removal/grease recovery loop simply produce a shift of the organic load from the aqueous phase to the sludge.

Both mechanical and thermal energy are used in the process of evaporation. However, the mechanical energy is not high and most of the thermal energy is recovered in a well-designed evaporator [187, INTERLAINE, 1999].

Applicability

Apart from option A (treatment in external municipal sewer) which could find applicability only in cases where the discharge of the effluent would not cause environmental harm to the sewer (small scourer discharging effluent in a large sewage treatment plant), the other options are all applicable to any scouring mill.

Economics

The economics aspects involved for each of the proposed options have been discussed in detail (INTERLAINE, 1999 #187). Figure 4.33 and Figure 4.34 summarise the information in the reference for a small scouring plant (3500 tonnes/year) and a medium-sized plant (15000 tonnes/year), scouring coarse wool. Similar results can be found for fine wool scourers, except for the factors related to the higher grease content of fine wool: this produces negative on-site running costs (savings) for all options which include grease recovery. Economies of scale are not expected to increase very much for mills with higher throughput than 15000 tonnes/year.

The capital costs for installation of dirt/grease loops used in the tables below are 412500 euros for the small mill and 825000 euros for the medium mills. The loops in the larger mills carry a much greater flow and these costs are believed to be realistic. The capital cost of flocculation plants at the larger mills is believed to be about 275000 euros and it is not believed that a smaller capacity plant would be much less expensive.

The capital costs for evaporators are somewhat more speculative. The following costs are assumed: capacity 21000 m$^3$/year, cost 1.2 million euros; capacity 45500 m$^3$/year, cost 1.8 million euros; capacity 60000 m$^3$/year, cost 2.4 million euros; capacity 90000 m$^3$/year, cost 3.0 million euros; capacity 120000 m$^3$/year, cost 3.6 million euros.

On-site running costs are net of grease sales, hence the negative costs in some cases where grease recovery loops are installed. Calculations were based on the following unit costs.

<table>
<thead>
<tr>
<th>On-site unit costs</th>
<th>euros</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.68/m$^3$</td>
</tr>
</tbody>
</table>
Heat: 0.51/m³

Process chemicals:
- Detergent: 1400/t
- Soda: 268/t

Grease: 380/t

Running costs, dirt/grease recovery loop:
- Power: 0.56/m³
- Labour: 1800/yr
- Maintenance: 45000/yr

Running costs, flocculation plant:
- Chemicals: 2.74/m³
- Power: 0.28/m³
- Labour: 12000/yr
- Maintenance: 22500/yr

Running costs, evaporation plant:
- Chemicals: 1.82/m³
- Power: 18000/m³
- Labour: 65000/m³

Sludge (50% dry weight) disposal costs:
- Sludge from flocc. and dirt/grease recovery: 41/A
- Concentrate from evaporator: 95/A

Source: [187, INTERLAINÉ, 1999]

The price of the recovered grease is very variable: in Section 4.2.2.1 a price of 2 euros/kg (I.M. Russell personal communication) has been assumed for calculations.

Figure 4.32: Unit costs

Sludge disposal costs are those prevailing at present in UK for landfill (41 euros/t for wet sludge from flocculation and dirt/grease recovery plant and 95 euros/t for concentrate from the evaporator). They include landfill tax (15 euros per tonne) and transport.

Sludge disposal costs do not take account of any changes consequent to the introduction of the Landfill Directive.

Effluent disposal costs are also values from UK (calculated according to the standard Modgen strength formula) and are believed to reflect full economic cost [187, INTERLAINÉ, 1999].

<table>
<thead>
<tr>
<th>Item</th>
<th>Effluent-treatment technique</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Discharge to sewer</td>
</tr>
<tr>
<td>Costs, Unit: euro</td>
<td></td>
</tr>
<tr>
<td>Initial capital cost</td>
<td>0</td>
</tr>
<tr>
<td>Annual capital cost</td>
<td>0</td>
</tr>
<tr>
<td>On-site annual running cost</td>
<td>0</td>
</tr>
<tr>
<td>Annual sludge disposal cost (50% dry weight)</td>
<td>0</td>
</tr>
<tr>
<td>Annual effluent disposal cost</td>
<td>694515</td>
</tr>
<tr>
<td>Total annual cost</td>
<td>694515</td>
</tr>
<tr>
<td>Cost/tonne wool</td>
<td>198</td>
</tr>
<tr>
<td>NPV of 10yr cashflow (a)</td>
<td>6.1/m³</td>
</tr>
</tbody>
</table>

Source: [187, INTERLAINÉ, 1999]

(a) Net present value of 10 year cashflow at 3% interest rate.
### Figure 4.33: Costs of effluent treatment options for a scouring mill processing 3500 t/yr of coarse wool

<table>
<thead>
<tr>
<th>Item</th>
<th>Discharge to sewer</th>
<th>Dirt/grease loop</th>
<th>Floccul.</th>
<th>Dirt/grease loop and flocculator</th>
<th>Evaporat.</th>
<th>Dirt/grease loop and evaporat.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs, Unit: Euro</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial capital cost</td>
<td>0</td>
<td>825000</td>
<td>275000</td>
<td>1075000</td>
<td>3625000</td>
<td>3225000</td>
</tr>
<tr>
<td>Annual capital cost</td>
<td>0</td>
<td>82500</td>
<td>27500</td>
<td>107500</td>
<td>362500</td>
<td>322500</td>
</tr>
<tr>
<td>On-site annual running cost</td>
<td>0</td>
<td>31561</td>
<td>300480</td>
<td>99915</td>
<td>204980</td>
<td>133415</td>
</tr>
<tr>
<td>Annual sludge disposal cost (50 % dry weight)</td>
<td>0</td>
<td>102828</td>
<td>285932</td>
<td>279953</td>
<td>754418</td>
<td>562415</td>
</tr>
<tr>
<td>Annual effluent disposal cost</td>
<td>4203305</td>
<td>3559083</td>
<td>876175</td>
<td>644386</td>
<td>92852</td>
<td>53648</td>
</tr>
<tr>
<td>Total annual cost</td>
<td>4203305</td>
<td>3429696</td>
<td>1490086</td>
<td>931564</td>
<td>1414749</td>
<td>820148</td>
</tr>
<tr>
<td>Cost/tonne wool</td>
<td>389</td>
<td>162</td>
<td>90</td>
<td>62</td>
<td>94</td>
<td>55</td>
</tr>
<tr>
<td>NPV of 10yr cashflow(s)</td>
<td>36.9 m</td>
<td>21.4 m</td>
<td>13.1 m</td>
<td>8.3 m</td>
<td>12.9 m</td>
<td>7.6 m</td>
</tr>
</tbody>
</table>

Source: [187, INTERLAINE, 1999]

(a) Net present value of 10 year cashflow at 3 % interest rate.

### Figure 4.34: Costs of effluent treatment options for a scouring mill processing 15000 t/yr of coarse wool

For small mills processing coarse wool, from an economic point of view, the installation of a dirt/grease loop and a flocculation plant appears to be the best option. Rapid payback is achieved (versus discharge to sewer) and this option has the lowest total cost over 10 years as well as the lowest NPV of 10-year cashflow.

The environmental performance of an evaporation plant is far superior to that of the flocculation plant. However, the initial cost of the evaporation plant is much higher and payback (versus discharge to sewer) is not achieved for 4–5 years.

The value of installing a dirt removal/grease recovery plant is clearly illustrated in the costings, even for this small mill, processing wool with a low grease content. When used in combination with an evaporator, the loop enables a reduction in capital outlay because a smaller evaporator can be used.

For medium-sized mills, evaporation is slightly cheaper than flocculation over 10 years and has superior environmental performance. Again, the use of a dirt-removal/grease recovery loop enables a smaller evaporator to be installed and reduces initial capital outlay.

The use of a dirt-removal/grease recovery loop allows also a reduction in running costs thanks to the proceeds from the sales of the grease. This effect is more significant for fine wool scouring mills because of the higher percentage of good quality grease. The loop also has a significant effect in reducing sludge disposal costs when used in combination with the evaporator. This is because the physical properties of evaporator concentrate make its transport and disposal difficult and expensive, so it is sensible to remove as much material from the effluent as possible before it is evaporated.

### Reference literature

[187, INTERLAINE, 1999].
4.3 Production of yarn and fabric

4.3.1 Techniques to avoid or reduce the use of hazardous substances

4.3.1.1 Mineral-oil containing preparations

4.3.1.1.1 Mineral oils substitution in wool spinning lubricants

From ex-Section 4.2.2

Description
Mineral oils used as wool spinning lubricants are replaced by synthetic and ester oils.

Technical description
Spinning lubricants are usually removed during pretreatment to ensure uniform penetration of the dye and finishing agents and to avoid reaction and precipitation with them. Since in the case of wool the processes that take place first in the finishing mill are wet treatments (washing/scouring), the presence of lubricants primarily affects emissions to primarily water rather than air emissions.

In carded wool and wool blend yarns, where a higher load of lubricants is applied (compared to worsted wool), spinning oils (together with detergents used in the scouring process) may contribute up to 80% of the oxygen-demanding load in dyehouse waste water [32, ENco, 2001].

Mineral oil-based lubricants were once used universally in the wool sector. These substances may not be fully degraded in biological sewage treatment works.

Moreover, the formulations of conventional spinning lubricants may contain variable amounts of even more hazardous substances such as polyaromatic hydrocarbons and APEO or other ‘hard surfactants’ as emulsifiers (see Section 4.1.6.8.1 for the substitution of APEO and also Section 8.2).

Mineral oils have now largely been replaced with formulations based on glycols and this trend continues. Biodegradable substitutes are readily available [32, ENco, 2001]. APEO compounds can now also be substituted by less problematic surfactants.

Main-Achieved environmental benefits
Reduction of emissions to water.
Elimination of mineral oil from scouring and dyeing waste water and the effluents received by sewage treatment works.
Using APEO-free spinning lubricant formulations helps to reduce the amount of potentially toxic endocrine disrupters in the receiving water.

Environmental performance and operational data
In the carpet sector, the use of mineral oil-based lubricants is reported to have been in decline for some years, indicating that carpet yarn of commercial quality can be produced without the use of this material [32, ENco, 2001]. It is believed that the same is valid for the textiles sector.

Cross-media effects
Compared to mineral oil-based lubricants, increased foaming in the waste water treatment may be observed.

There is some evidence that mineral oil-based lubricants are more amenable to on-site treatment than are the more water-soluble glycol-based products. Where there is on-site pretreatment, the choice of lubricant may be critical and mineral oil-based products may be the more viable option. Further research may be required [32, ENco, 2001].
Technical considerations relevant to applicability

Spinning lubricants are applied during fibre blending. Undertakings Plants which include the manufacturing processes leading up to wet processing, such as sales yarn spinning, and vertically integrated companies have the means to control the use of these materials in house.

On the other hand, commission dyers receive yarn on which the lubricant is already present. In these cases, it would be necessary to work with clients to eliminate these materials from the supply chain [32, ENco, 2001].

Economics

The consequences of substituting one spinning lubricant for another are difficult to predict as the yarn yield (the quantity of yarn obtained from a given mass of raw fibre) is notoriously difficult to measure accurately and very small changes in yield markedly affect the economics of yarn production. The lubricant type and level of application can have a significant impact on yield [32, ENco, 2001].

Driving force for implementation

Environmental legislation.

Example Reference plants

Many plants in Europe.

Plants from the data collection: BE011, CZ016, CZ017, CZ020, IT075, IT076, IT082, IT097, PT108, PT111, SE120 and UK129.

Reference literature

[32, ENco, 2001]

4.3.1.1.2 Substitution of mineral oils [substitution in knitted] in fabric knitting [manufacturing]

From ex-Section 4.2.3, which has been split in 2 parts: one about the substitution of mineral oils in knitting and the other one about the washing of synthetic fibres before thermofixation.

Description

Mineral oils used as fabric knitting lubricants are replaced by synthetic and ester oils.

Technical description

The production of knitted fabric requires an efficient lubrication of the needles and mechanical elements of the knitting machine. The quantity of lubricants used depends on the technology of the machine and its speed.

The yarn driven by the needles during the manufacturing of the fabric carries part of the lubricant. As a result, the final knitted fabric can contain about 4-8 % w/w of lubricant oil that then needs to be removed during pretreatment.

Conventional knitting oils (mineral oil-based formulations) can only be removed through emulsification using detergents, emulsifiers and anti-redeposition agents. The process is carried out under alkaline conditions and at temperatures between 80 °C and 100 °C. Water consumption is approximately 10 l/kg of fabric, and the time required for the process is about 30-60 minutes.

The proposed technique suggests consists of using hydrosoluble oils instead of conventional lubricants.
Main-Achieved environmental benefits

- Reduction of emissions to water and to air.
- Reduction of water and energy consumption.

Environmental performance and operational data

Unlike conventional mineral oil-based lubricants, hydrosoluble oils can be easily washed out from of the fabric. This helps reduce water, energy and chemicals consumption along with processing time. Moreover, these oils are reported to be biodegradable according to OECD test 301C [295, Spain, 2002], which makes the resulting effluent suitable for treatment in a biological waste water treatment plant.

Operational data

The alternative hydrosoluble knitting oils described in this section produce emulsions which remain stable for 3 days [295, Spain, 2002].

As for the types of fibres, the referenced hydrosoluble oils are suitable for knitted fabrics made of cellulose fibres and blends, as well as fabrics made of synthetic fibres, mainly polyester and polyamide, and their blends with natural and synthetic fibres, including elastane.

More details are given in Section 4.10.9.

Cross-media effects

Provided that the water-soluble knitting oils used in substitution of the conventional ones are biodegradable and that the fabric is processed in high efficiency washing machines, a net environmental benefit is achieved.

None identified.

Technical considerations relevant to applicability

The technique is applicable to new and existing plants. However, corrosion problems have been observed in some existing plants.

Nevertheless, since the technique implies that the company has direct control of the type of lubricants used during the knitting process, implementation can be problematic for non-integrated mills and particularly for commission finishers. In particular, purchased tissues and yarns (imported from outside the EU for example) can still contain mineral oils. [27, Derden et al. 2010]. In these cases, it is would be necessary to work with clients to eliminate these materials from the supply chain.

Economics

The overall cost balance of this technique is comparable with the conventional one. The referenced water-soluble knitting oils are more expensive than the mineral oil-based ones, but this extra cost is compensated by the higher productivity and by the higher treatability of the effluent resulting from pretreatment.

Driving force for implementation

The strict limits set by Environmental legislation for emissions to air and water favour the implementation of this technique.

Example Reference plants

Many plants.

Plants from the data collection: BE010, CZ015, CZ017, DE034, IT082 and SE120.

Reference literature

[295, Spain, 2002]. [27, Derden et al. 2010]
4.3.1.2 Sizing agents

4.3.1.2.1 Selection of sizing agents [with improved environmental performance]

From ex-Section 4.2.4

Description
Sizing agents with improved environmental performance in terms of quantity needed, washability from the textile fibres, recoverability and/or biodegradability (e.g. modified starches, certain galactomannans, polyvinyl alcohol and certain polyacrylates) are used.

Technical description
Sizing agents are applied to warp yarn in order to prevent thread breakage during weaving. For subsequent processing, the sizing agents need to be removed almost completely from the fabric. This is done in the desizing step, often with a large amount of water and the addition of auxiliaries. The resulting effluent is responsible not only for a high COD/BOD load (about 30-70 % of the overall COD load), but also for the presence of difficult to degrade substances that may pass through not be abated by the final waste water treatment. In some cases, sizing agents may be recovered from the desizing liquor. More often, however, the effluent is treated in the waste water treatment plant.

Along with low add-on techniques such as pre-wetting (see Section 4.3.1.2.2), targeted selection of sizing agents may also contribute significantly to the reduction of the environmental impact of this operation.

Environmentally optimised sizing agents are:

- highly efficient with low add-on;
- completely and easily removed from the fabric;
- readily biodegradable or bioeliminable (ultimate aerobic biodegradability > 80 % after 7 days according to the Zahn-Wellens OECD test 302 B performed according to EN ISO 9888:1999).

It is now accepted that readily biodegradable and bioeliminable sizing agent formulations are available, covering all needs. Modified starches, certain galactomannans, polyvinyl alcohol and certain polyacrylates satisfy this requirement.

Furthermore, Latest-generation polyacrylates are able to fulfil all the requirements listed above. Firstly, The use of these high-efficiency synthetic sizes instead of conventional modified starches allows a reduction in size add-on without any decline in weaving efficiency (in some cases, increased weaving efficiency is observed). Secondly, In addition, new-generation polyacrylates are easy to wash out and can be removed with little water and without additional auxiliaries.

The new polyacrylates can be applied as almost universal sizing agents for all kinds of fibres.

For cotton, polyacrylates are applied in combination with other sizes, usually PVA, in order to increase the viscosity of the system.

Main Achieved environmental benefits
Reduction of emissions to water.

Environmental performance and operational data
The application of biodegradable and bioeliminable sizing agents leads to a significant reduction of the COD load that may pass undegraded through the waste water treatment plant and be discharged to natural waters.
Chapter 4

Additional advantages are achieved when using the highly efficient, easy-to-wash sizing agents. Lower add-on means reduced COD load in the discharged effluent, while the fact that they are easily washed out means that as significant savings can be obtained in chemicals, water and energy consumption. With advanced efficient washing machines only low quantities of water are needed to remove the size, without additional auxiliaries (e.g. emulsifiers) or long cycle times (lower energy consumption).

Polyacrylates, polyvinyl alcohol and modified starch are not only biodegradable and bioeliminable, but are also suitable for size recovery techniques. New polyacrylates have the additional advantage of being applicable as almost universal sizing agents. This means that they are potentially easy to reuse as sizes in weaving firms.

Operational data
The bioelimination curves of seven combinations of sizing agents based on modified starches, new-generation polyacrylates, polyvinyl alcohol and certain galactomannans, are shown in Figure 4.35. (see also “Reference Plants”).

Modified starches are water-removable (less easily than modified polyacrylates), without the need for enzymatic or oxidative desizing. They are bioeliminable, but they give rise to bulky, viscous and filamentous sludge that is difficult to settle.

Polyvinyl alcohol (PVA) is easy to wash out at mid-range pH and it is recoverable. In alkaline conditions, it swells and becomes highly viscous and difficult to remove. Polyvinyl alcohol is biodegradable only under specific system conditions such as adaptation of the activated sludge, temperatures not below 15 °C and particularly low food to microorganism ratios (F/M ratios) (see Section 4.1.7.3.5.4.1). In alkaline conditions, PVA gives results in settlement problems with separation.

As mentioned above, the new polyacrylates are highly efficient with lower add-on (see Table 4.47 below), they are removable with only water (no need for either enzymatic or oxidative desizing) and they also have high stability to when in contact with alkalis (it is possible to
bleach the fabric directly, without a preliminary scouring step. Unlike classic polyacrylates, the new ones are more than 90% eliminated under the conditions of the Zahn-Wellens test, even in high concentrations, by adsorption on the activated sludge. Furthermore, they become insoluble by forming complexes with iron. In this way, they can be precipitated almost totally with only a small amount of precipitant.

Table 4.47: COD reduction after replacement of conventional sizing agent by alternative recipe based on polyacrylates

<table>
<thead>
<tr>
<th></th>
<th>Common recipe (modified starch, wax)</th>
<th>Alternative recipe (modified polyacrylate, PVA, wax) (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size add-on</td>
<td>13</td>
<td>10%</td>
</tr>
<tr>
<td>Specific COD (g O2/100 kg warp yarn)</td>
<td>17 800</td>
<td>11 550</td>
</tr>
<tr>
<td>Total COD (t/yr) (2)</td>
<td>712</td>
<td>462</td>
</tr>
<tr>
<td>Reduction of COD load</td>
<td>Not applicable</td>
<td>35%</td>
</tr>
</tbody>
</table>

Notes:
(1) Typical operating conditions for sizing staple fibre yarn in air jet loom at 650 rpm are as follows: PVA: 7 kg; modified acrylate (liquid 25%): 7 kg; wax: 0.4 kg; volume sizing liquor: 100 l; nip pressure: 20 kN; sizing speed: 100 m/min.
(2) Calculated on an annual production of 4 000 t warp yarn.

Cross-media effects
The application of sizing agents with higher bioeliminability and biodegradability leads to an increased amount of sludge to be disposed of [179, UBA, 2001]. This sludge can be bulky, filamentous and difficult to settle.

Technical considerations relevant to applicability
Although the application of optimised sizing recipes is technically feasible for all sizing departments, the worldwide organisation of the textile chain makes it difficult for non-integrated mills and particularly for commission finishers to influence the upstream weaving mills [179, UBA, 2001]. In these cases, it is necessary to work with clients to eliminate these materials from the supply chain.

Raw material input control (beyond simple visual testing) is recommended but the client only rarely consents to being charged for the related additional expenses. [36, ÖKOPOL 2011]

The use of polyacrylates for Exceptions include filament polyester and some specific finishing treatments where the use of polyacrylates may give rise to quality problems. For example, technical problems in the finishing stage were experienced when using polyacrylates on cotton fibre that had to be submitted to pre-shrink finishing [281, Belgium, 2002].

Economics
In most cases, biodegradable and bioeliminable combinations of sizing agents are no more expensive than others that do not meet the high elimination rate requirement (> 80% after 7 days according to the Zahn-Wellens OECD test 302 B) [179, UBA, 2001].

Details are given in Table 4.48 below regarding, in particular, the application of alternative synthetic, high-efficiency sizes based on polyacrylates.
Table 4.48: Comparison between conventional and high-efficiency sizing agents

<table>
<thead>
<tr>
<th></th>
<th>Common recipe (modified starch, wax)</th>
<th>Alternative recipe (modified polyacrylate, PVA, wax) (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs for sizing agents (euros/yr)</td>
<td>260 850</td>
<td>325 850</td>
</tr>
<tr>
<td>Warp thread breakage (thread break/10^7 picks)</td>
<td>5.8</td>
<td>3.0</td>
</tr>
<tr>
<td>Savings due to minimised thread breakage (EUR/yr)</td>
<td>Not applicable</td>
<td>225 000</td>
</tr>
<tr>
<td>Total savings (EUR/yr) (1)</td>
<td>Not applicable</td>
<td>160 000</td>
</tr>
</tbody>
</table>

Notes:
(1) Cost savings are calculated for a typical weaving mill working 8 000 h/yr (100 weaving machines, 310 rpm).

Driving force for implementation
Environmental legislation is one of the driving forces for implementation. In general, the need to minimise discharged COD loads and increasing concern for environmental protection (see also EU Eco-label) are considered as the main driving forces in the selection of biodegradable/bioeliminable sizing agents [179, UBA, 2001].

The selection of biodegradable/bioeliminable sizing agents is also encouraged by initiatives at the European level such as EU Ecolabel, OSPAR, etc.

In addition, the substitution of conventional size recipes with highly efficient ones is economically motivated in weaving mills, especially in combination with pre-wetting techniques (see Section 4.3.1.2.2), which can reduce size consumption by a third or even more.

Example Reference plants
Environmentally optimised sizing agents are largely applied worldwide in weaving mills.

UBA reported on a voluntary initiative in Switzerland of 20 weaving mills. Seven different bioeliminable formulations of sizing agents have been developed (see also Figure 4.35) and are currently applied, which can cover all different kinds of substrates and weaving techniques. They are based on [179, UBA, 2001]:

- starches and starch derivatives;
- certain polycrylates;
- polyvinyl alcohol;
- certain galactomannans.

Plants from the data collection: CZ018, DE039, IT059, PT108, PT110, SE119 and SE120.

Reference literature

4.3.1.2.2 [Minimising sizing agent add-on by] Pre-wetting of the cotton warp yarns

From ex-Section 4.2.5

Description
The cotton warp yarns are dipped into hot water prior to sizing, which allows reducing the amount of sizing agents needed.
Technical description

It is well known that in cotton finishing mills the desizing process accounts for 50-70% of the total COD in the waste water. Minimising the amount of size applied on the warp yarn during fabric processing is one of the most effective pollution prevention techniques for reducing the organic load caused by sizing agents.

On-line monitoring/control of size add-on and pre-wetting technology are now available options.

The pre-wetting technology consists of running the warp yarn through hot water before the sizing process. The warp yarn is dipped into the hot water (an additional spraying of hot water may be possible), then a squeeze roller removes the surplus water before the sizing stage. Systems with two dipping and squeezing steps are also in use.

Pre-wetting allows a more homogeneous sizing effect, increased adhesion of the size and reduced hairiness of the yarn. From experimental analysis, it seems that a lower ‘core-sizing’ effect is produced. As a result, a reduced amount of size can be applied to the fibre without affecting the weaving efficiency. In some cases, an increase in weaving efficiency can even be observed.

Main-Achieved environmental benefits

A reduced size load on the yarn means that a lower amount of sizing agent is discharged in the water during the textile pretreatment, with immediate positive effects on the organic load of the final effluent.

Environmental performance and operational data

Depending on the setting of the warp beam and the type of yarn processed (e.g. density of the yarn, type of fibres in the blend), a reduction of the size add-on of about 20-50% is possible.

Pre-wetting has now been tested in practice with all types of cotton yarns and blends of cotton/PES and viscose. The best results are achieved with medium to coarse yarns. Application is possible for batches of more than 5,000 m to better than 10,000 m, both for ring-spun and OE-open-end yarns.

Technical problems may be observed in relation with the efficient measurement and control of high humidity percentages and with the calibration of the wetting device [281, Belgium, 2002].

Existing sizing machines with two sizing boxes can be reconstructed/upgraded by using the first sizing box for pre-wetting and the second one for sizing.

Cross-media effects

None believed likely.
None identified.

Technical considerations relevant to applicability

On the contrary, the technique is not applicable to small batches (<5,000 m) as the add-on cannot be controlled adequately. This is often the case for dyed yarns.
Generally, there are no technical restrictions to the applicability of this technique.

A high percentage of cotton fabric finished in Europe is actually imported from non EU-countries (e.g. India) where these control techniques are not yet widely used. As a result, from a practical point of view, this pollution prevention measure is more easily and immediately applicable in integrated mills than in commission finishers companies. In these cases, it is necessary to work with clients to eliminate these materials from the supply chain.
Economics
Sizing equipment with pre-wetting boxes is approximately EUR 25 000-75 000 more expensive than sizing equipment without a pre-wetting section. Operating costs are only marginally higher, because the additional expenditure for the pre-wetting water is compensated by the reduction in sizing liquor consumption.

A direct comparison between sizing with and without pre-wetting (operational data of an Italian weaving mill) shows cost savings of about 27 %, an increase in sizing machine speed of about 22 %, and an increase in weaving efficiency of about 0.2 % [179, UBA, 2001].

Driving force for implementation
- sizing agent savings;
- increase of weaving efficiency,
- as well as a reduction of waste water load (environmental cost savings) are driving forces for the implementation of the pre-wetting technology.

Example Reference plants
Worldwide about 160 pre-wetting boxes are in use worldwide. 100 pre-wetting boxes have been sold by Benninger Zell GmbH, Zell, Germany. About 60 pre-wetting boxes of Deutsche Babcock Moenus Textilmaschinen AG, Mönchengladbach are running in 40 plants. Another supplier for pre-wetting systems is Karl Mayer Textilmaschinenfabrik GmbH, Obertshausen, Germany [179, UBA, 2001].

Plants from the data collection: DE042, DE049 and SE120.

Reference literature
[179, UBA, 2001] [281, Belgium, 2002]

4.3.1.2.3 [Use of techniques that allow reduced load of sizing agents on the fibre]
Compact spinning

From ex-Section 4.2.6

Description
The fibre strands are compressed by suction or by using mechanical or magnetic compacting. This allows a reduction of the amount of sizing chemicals needed.

Technical description.
Normally, in ring spinning, after the draft system a spinning triangle is generated. At the moment, when they pass the spinning triangle, the fibres are not strengthened by twisting. Yarn breakage and yarn hairiness occur.

In compact spinning, the fibre strands are compressed after the draft system by means of pneumatic devices (application of low pressure suction on the fibre strands), mechanical compacting or magnetic compacting [179, UBA, 2001] [120, Alagirusamy 2013] with reference to “Artzt, 1995”.

A higher yarn quality results (increased fibre strength and elongation, reduced hairiness, increased abrasion resistance).

Figure 4.36 compares the operating principles of ring spinning and compact spinning.
Main-Achieved environmental benefits
Reduction of emissions to water and of chemical consumption.

Environmental performance and operational data
Compared to conventional ring-spun yarns, compact yarns have better running properties and less thread breakage during weaving, even when the size add-on is reduced by up to 50%. This leads to a considerable reduction in waste water load in desizing. Due to the reduced hairiness, application of paraffins to yarns is no longer necessary [179, UBA, 2001].

Operational data
No information was made available.

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
The applicability may be restricted by product specifications. Applicability is proved for pure cotton yarns. It has to be taken into account that the appearance and technological properties of compact spinning yarns (and fabrics made of them) are different to those of conventional manufactured yarns. The lower hairiness of the yarns is an undesired effect in the case of yarns produced for knitted goods.

Adaptation of existing spinning machines is partially may be possible [179, UBA, 2001].

Economics
Additional costs in yarn manufacturing are partially or totally offset by cost savings in the weaving mill, due to higher weaving efficiency and reduced size add-on. Reduced costs in finishing are expected (e.g. lower waste water treatment cost due to the lower amount of sizing agents).
Driving force for implementation
A better yarn quality and the possibility to create new effects and designs are the main reasons for installing compact spinning machines.

Example Reference plants
At present about 250,000 spindles are installed, mostly in Italy (“ITV, 2001”).

Compact spinning machines are manufactured by
- Rieter Textile Systems, CH-Winterthur
- Zinser Textilmaschinen, DE-Ebersbach
- Spindelfabrik Süssen, DE-Süssen

Plants from the data collection: PT108 and UK127.

Reference literature
[77, EURATEX, 2000], [179, UBA, 2001] [ 119, Textile Today 2011 ] [ 120, Alagirusamy 2013 ]

4.3.2 Techniques to increase energy efficiency

4.3.2.1 Optimisation of energy use in yarn production

Description
A set of technical measures identified in the energy efficiency plan (see Section 4.1.4.1) and which allow the reduction of the energy consumed by yarn production. This includes:
- reducing the volume of the production area to reduce the amount of energy needed for humidifying the ambient air;
- using advanced sensors that detect thread breaks to stop the machines.

Technical description
Electricity is the main type of energy used in spinning (see a schematic of ring spinning in Figure 4.37 below).

The factors which most affect the energy consumption in yarn production are the speed of machines, the yarn count (i.e. the yarn fineness) and the temperature for steps involving heat treatment (for example steaming). [ 33, CITEVE 2014 ]
Techniques to reduce energy consumption include the following:

**Carding**
- Use of a high-speed carding machine with a lower specific energy consumption.

**Roving**
- Installation of a photoelectric end-break stop-motion detector instead of a pneumatic suction tube detector.

**Ring and compact spinning**
- Use of lighter spindles and bobbins in the ring frame, which require less energy to be moved.
- Use of energy-efficient spindle oil, incorporating a dispersant agent.
- Ensuring an optimal oil level in the spindle bolster as an excessive level may cause resistance in the rotation of the spindle.
- Use of a synthetic spindle belt.
- Optimisation of the ring diameter with respect to the yarn count in ring frames. A larger ring induces a larger and heavier bobbin, thus higher energy consumption.
- Reduction of the energy for humidifying the ambient air of the spinning area by reducing the volume of the area (e.g. with a lower ceiling).
- Installation of energy-efficient motors.
- Installation of energy-efficient suction fans for the collection of loose fibres.
- High-speed ring spinning machine with lower specific energy consumption.
- Installation of a soft starter on motor drives which ensures a gradual acceleration of motors of the ring spinning machines.

**Winding**
- Installation of variable frequency drive in cone winding machines.
- Intermittent mode of movement of empty bobbin conveyor in the cone winding machines.

**Heat treatment**
- Replacement of the electrical heating system with a steam heating system for yarn drying, which reduces the overall energy use.
Achieved environmental benefits
Reduction of energy consumption.

Environmental performance and operational data
Examples of reduction of energy consumption are given in Table 4.49.

Table 4.49: Electricity savings made when applying measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Electricity savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy-efficient spindle oil</td>
<td>3-7 % of ring frame energy use</td>
</tr>
<tr>
<td>Installation of a false ceiling in ring spinning area</td>
<td>788 MWh/year</td>
</tr>
<tr>
<td>High-speed ring spinning frame</td>
<td>10-20 % of ring frame energy use</td>
</tr>
<tr>
<td>Installation of electronic roving end-break stop-motion detector instead of pneumatic system</td>
<td>3.2 MWh/year/machine</td>
</tr>
<tr>
<td>Installation of energy-efficient suction fans</td>
<td>5.8-40 MWh/year/ring frame</td>
</tr>
<tr>
<td>Installation of energy-efficient motor in ring frame</td>
<td>6.3-18.83 MWh/year/motor</td>
</tr>
<tr>
<td>Installation of variable frequency drive in cone winding machines</td>
<td>331.2 MWh/year (1)</td>
</tr>
<tr>
<td>Intermittent mode of movement of empty bobbin conveyor in the cone winding machines</td>
<td>49.4 MWh/year (1)</td>
</tr>
<tr>
<td>Optimisation of ring diameter with respect to yarn count in ring frames</td>
<td>10 % of ring frame energy use</td>
</tr>
<tr>
<td>Replacement of lighter spindle in place of conventional spindle in ring frame</td>
<td>23 MWh/year/ring frame</td>
</tr>
<tr>
<td>Replacement of the electrical heating system with steam heating system for yarn drying</td>
<td>19.5 MWh/year/machine</td>
</tr>
<tr>
<td>Synthetic belts for ring frames</td>
<td>4.4-8 MWh/year/ring frame</td>
</tr>
<tr>
<td>Use of lightweight bobbins in ring frame</td>
<td>10.8 MWh/year/ring frame</td>
</tr>
</tbody>
</table>

(1) The number of cone winding machines has not been reported.

Source: [152, Hasanbeigi 2010] [33, CITEVE 2014]

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
Examples of investment costs are given in Table 4.50.
Table 4.50: Investment costs of energy-saving measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Investment costs</th>
<th>Payback period (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-speed carding machine</td>
<td>USD 100 000/carding machine (1)</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>Installation of electronic roving end-break stop-motion detector instead of pneumatic system</td>
<td>USD 180/roving machine (1)</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Installation of energy-efficient suction fans in in the ring frame</td>
<td>USD 195-310/fan (1)</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Installation of energy-efficient motor in ring frame</td>
<td>USD 1 950-2 200/motor (1)</td>
<td>2-4</td>
</tr>
<tr>
<td>Installation of variable frequency drive in cone winding machines</td>
<td>USD 19 500 (1) (2)</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Intermittent mode of movement of empty bobbin conveyor in the cone winding machines</td>
<td>USD 1 100 (1) (2)</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Optimisation of ring diameter with respect to yarn count in ring frames</td>
<td>USD 1 600 / ring frame (3)</td>
<td>2</td>
</tr>
<tr>
<td>Replacement of lighter spindle in place of conventional spindle in ring frame</td>
<td>USD 13 500 / ring frame (1)</td>
<td>8</td>
</tr>
<tr>
<td>Replacement of the electrical heating system with steam heating system for the yarn drying</td>
<td>USD 980/machine (1)</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Synthetic belts for ring frames</td>
<td>USD 540-683/ring frame (4)</td>
<td>1-2</td>
</tr>
<tr>
<td>Use of lightweight bobbins in ring frame</td>
<td>USD 660 / ring frame (1)</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

(1) 2008 value.  
(2) The number of cone winding machines has not been reported. 
(3) 2010 value.  
(4) 2005 and 2008 values respectively. 

*Source: [152, Hasanbeigi 2010] [33, CITEVE 2014]*

Driving force for implementation
Savings in energy consumption.

Example plants
No information provided

Reference literature
[152, Hasanbeigi 2010] [33, CITEVE 2014]

4.3.2.2 Vortex spinning

Description
An air vortex is used to spin out the yarn.

Technical description
The vortex spinning technique utilises a high-speed airflow to twist the yarn. This greatly increases the rotational speed of the fibre strand, which can be as high as 200 000 turns/minute.

In the vortex spinning system, the spinning part is composed of an air-jet nozzle and a hollow spindle with a yarn passage through it. The core yarn fibres come from the front rollers, are held together (anchored and pulled through the hollow spindle) and represent the central yarn around which the outer fibres are twisted with the action of the high-speed airflow inside the nozzle. Fibres that whirl around the hollow spindle tip attach to the core fibres by wrapping onto them and yarn with a twisted structure is formed. The formed yarn is then delivered out of the nozzle through the yarn passage of the hollow spindle with the drag of the delivery rollers and fed to the winding part.
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Fibres that are 100% cotton can be spun at high speeds (500 metres/minute) and the yarn structure resembles the ring yarn structure rather than rotor yarns. The vortex system can have up to 96 spinning units; it includes a Spinning Tension Stabilising (STS) system, a spinning sensor and a spin cleaner.

Achieved environmental benefits
Lower energy consumption for the yarn production.

Environmental performance and operational data
There are many parameters influencing this twisting system, and consequently the vortex yarn. The number of jet orifices and the diameters of the orifices directly affect the vortex magnitude. The airflow characteristics depending on the nozzle pressure have an influence on the ratio of the wrapping fibres to the core fibres, which is a determining factor for the yarn fineness: a reduction of core fibres in the yarn structure may lead to deterioration in the yarn properties as the yarn gets finer.

Airflow-fibre-nozzle interactions in the yarn formation area need to be analysed carefully for the quality improvement of vortex yarn spinning.

It is to be noted that the drapability of the resulting fabric is poor due to the stiffer yarn structure.

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable to cotton fibres, synthetic fibres and blends thereof. [149, MURATA]

Economics
This technique can be carried out with a lower operational cost than conventional spinning due to the lower energy usage. The investment costs are nevertheless higher.

Driving force for implementation
This technology yields faster production processes and a significant reduction in opex costs.

Example plants
No information provided.

Reference literature
[135, RICARDO 2019] [134, Textilelearner 2019] [149, MURATA]

4.3.2.3 Optimisation of energy use in weaving

Description
A set of technical measures identified in the energy efficiency plan (see Section 4.1.4.1) and which allow the reduction of the energy consumed by weaving. This includes:

• avoiding excessive air pressure for air-jet weaving;
• using double-width loom for large-volume batch.

Technical description
The weaving process is run almost entirely on electricity only. This process is a major consumer of compressed air, particularly when the looms are air-jet. The amount of energy consumed by each loom during its weaving operation can be estimated from the motor capacity and weaving speed. Across the different weaving technologies, weft insertion systems consume a large share of the total electricity use of the equipment. Usually, lighting is significant in terms of electricity consumption, because the weaving sections have many lighting fixtures installed. On the other
hand, some thermal energy is consumed in sizing, as one of the possible preparatory operations for weaving. [33, CITEVE 2014]

Techniques to reduce energy consumption include the following:

- Optimisation of the air distribution for air-jet weaving. This is done by avoiding the use of excess air, using automatic pressure control valve and software to optimise the pressure distribution during weft insertion.
- Use of a double-width loom for large-volume articles, with a lower specific energy consumption.
- Reduction of the energy for humidifying the ambient air of the weaving area by reducing the volume of the area (e.g. with a lower ceiling).

**Achieved environmental benefits**
Reduction of energy consumption.

**Environmental performance and operational data**
No information provided

**Cross-media effects**
None identified.

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of this technique.

**Economics**
No information provided

**Driving force for implementation**
Savings in energy consumption.

**Example plants**
No information provided

**Reference literature**
[152, Hasanbeigi 2010] [33, CITEVE 2014]

### 4.3.3 Techniques to increase resource efficiency

#### 4.3.3.1 Seamless knitting

**Description**
Clothing is produced with whole-garment technologies like seamless (3D) knitting, which produces the garment in one step, without intermediary fabric manufacturing, fabric cutting and sewing steps.

**Technical description**
The whole-garment technologies use specific knitting machines with specialised circular looms to develop garments that adapt to the body shape. In these knitting machines, a computer controls and directs movement of hundreds of needles to construct and connect several tubular knitted forms and create a whole garment in a single production step. Whole-garment techniques are used to manufacture clothing (e.g. sportswear, sweaters) or technical textile products (e.g. car seats).

**Achieved environmental benefits**
- Reduction of textile waste.
Reduction of energy consumption

**Environmental performance and operational data**
The energy consumption is not necessarily high for the knitting process. However, knitting machines have also been undergoing a shift towards high-speed and large-capacity and fine-gauge features, as the current industry trend is for high added-value goods and multi-line, small-volume production based on advanced systems such as computer-controlled pattern-making mechanisms. Therefore, there is a potential tendency for increased energy consumption. [33, CITEVE 2014]

High speeds and a fine gauge produce knitted sweaters three times faster than conventional flat-bed machines. Energy consumption is reduced from 21 kWh/dozen knitted garments to 8.5 kWh simply by reducing idle machine time. Knitting speed improvements by reducing the time taken for the carriage to change direction (known as rapid response) improve efficiency by up to 8%. Reducing friction during the knitting process reduces energy consumption in a circular knitting machine by up to 20% and CO$_2$ emission by 1 500 kg per machine (needles’ lifetime based on 5 000 hours or 208 days). [135, RICARDO 2019].

**Cross-media effects**
None identified.

**Technical considerations relevant to applicability**
Generally applicable to garments that would otherwise require sewing and stiches (T-shirts, jumpers, etc.).

**Economics**
The machinery requires a significant amount of initial capital investment. However, these costs can be offset by long-term savings in labour and resource (e.g. energy, fibre) costs.

**Driving force for implementation**
- Reduction of production time to between 30-40% (if compared to cut and sew manufacture).
- Increased production yield.

**Example plants**
Industrial operators that have selected this technology: UK company Quantum knitwear (whose machinery plant consists only of whole-garment machines), and Patagonia (USA).

**Reference literature**
[122, Beton et al. 2014 ], [135, RICARDO 2019 ], [33, CITEVE 2014]
4.4 Pretreatment

4.4.1 [Application of the oxidative route for efficient, Universal size removal] Single desizing liquor

Ex-Section 4.5.2

Description
A single desizing liquor is used to remove different types of sizing chemicals. This solution is strongly alkaline (pH higher than 13) and contains hydrogen peroxide.

Technical description
Many woven fabrics contain a variety of different sizing agents, depending on the origin and quality of the substrate. Most textile finishers deal with many different types of fabrics, and therefore sizing agents, so they are interested in fast, consistent and reliable removal of non-fibrous material (be it the impurities and fibre-adjacent material or any preparation agent) independent of the origin of the fabric.

Enzyme desizing removes starches but has little effect in removing other sizes. Under specific conditions (above pH 13), H₂O₂ generates free radicals which efficiently and uniformly degrade all sizes and remove them from the fabric. This process provides a clean, absorbent and uniform base for subsequent dyeing and printing, no matter which size or fabric type is involved [189, D. Levy, 1998].

Recent Studies ([203, VITO, 2001]) show that above pH 13 the oxide radical anion O₂⁻ is the predominant form. This species is highly reactive, but it will attack non-fibrous material (sizing agents, etc.) rather than cellulose, for various reasons. First because it is negatively charged like the cellulose polymer in a strongly alkaline medium (coulombic repulsion effect) and secondly because, unlike the OH*, it does not react by opening the aromatic rings. The regulation of the pH is therefore important to avoid fibre deterioration by OH* radicals. [ 36, ÖKOPOL 2011 ]

It is recommended to first remove the Catalyst that is not evenly distributed over the fabric (e.g. iron particles, copper) is removed first as it may cause 'pitting corrosion' [ 36, ÖKOPOL 2011 ]. One possible process sequence would therefore be: removal of metals (modern pretreatment lines are equipped with metal detectors), oxidative desizing (peroxide and alkali), scouring (alkali), demineralisation (acid reductive or, better still, alkaline reductive/extractive), bleaching (peroxide and alkali), rinsing and drying.

Main Achieved environmental benefits
The proposed technique allows significant environmental benefits: the reduction of water and energy consumption along with improved treatability of the effluent.

Environmental performance and operational data
The oxidative route is an very attractive option where peroxide bleaching is carried out. Taking advantage of hydrogen peroxide also being used as an active substance for bleaching, it is advantageous to combine alkaline bleaching with scouring and regulate the countercurrent flow of alkali and peroxide through the different pretreatment steps, so as to save water, energy and chemicals.

Because of the action of free radicals generated by activation of hydrogen peroxide, the size polymers are already highly degraded. The process produces shorter and less branched molecules, glucose, more carboxylated molecules such as oxalate, acetate and formate, which are easier to wash out with a reduced amount of water in efficient washing machines.
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The pre-oxidation of size polymer is also advantageous at the waste water treatment level (improved treatability). With enzymatic desizing, starches are not completely degraded (the long molecules are not completely broken down after desizing). This means higher organic load to be degraded in the biological plant and it is often the cause of problems such as the production of bulky difficult-to-settle sludge.

Operational data

It is well known that in an oxidative alkaline medium (with hydrogen peroxide), there is a potential risk of fibre damage during bleaching if OH* formation is not controlled. The size and the cellulose have a similar molecular structure and therefore the attack of the cellulose polymer from non-selective OH* is possible. To achieve good results and avoid damage to the fibre when removing starch-like size, it is essential to add hydrogen peroxide at pH >13. These operating conditions minimise OH* radicals, which are responsible for cellulose damage.

An example of a desizing-bleaching padding recipe for PVA/starch blends is:

- detergent (0.3 %);
- sequestrant (0.1 %);
- sodium hydroxide (0.7-2.0 %);
- hydrogen peroxide (0.2-0.4 %);
- salt (0.04 %);
- emulsifiers as needed.

There is no need for sophisticated control devices as these are already be available for control of oxidative bleaching. Equipment is no different from modern preparation lines.

Cross-media effects

None believed likely. None identified.

Technical considerations relevant to applicability

The technique is particularly suitable for commission finishers (independently of their size), who need to be highly flexible because their goods do not all come from the same source (and consequently they do not have goods treated with the same type of sizing agents). In the interests of high productivity, these companies need to operate with a universally applicable technique to enable a right-first-time approach. Generally, there are no technical restrictions to the applicability of this technique.

Economics

The steps and liquors are combined so that the resource consumption is optimised at an overall minimal cost.

Driving force for implementation

With the increased usage of hydrogen peroxide as a replacement for hypochlorite in bleaching, the cost of hydrogen peroxide will continue to drop relative to other oxidants. Selective use of hydrogen peroxide (minimising non-selective reaction pathways) will be important for reducing reduction of overall costs, including raw material, energy and waste water treatment costs.

Example plants

Plants from the data collection: DE042, FR131, IT064, IT068, IT069, IT077 and PT109.

Reference literature

[203, VITO, 2001] with reference to:
4.4.2 Enzymatic desizing, bleaching, washing and scouring

From ex-Section 4.5.4

Description
Enzymes (e.g. amylases, pectinases and others) are used for desizing, bleaching, washing and scouring the textile fabric.

Technical description
Enzymatic desizing
Enzymatic desizing (by hydrolysis) using amylases is an established process that has been in use for many years. More recently, pectinases have shown promise in replacing the traditional alkaline scouring treatment. Some auxiliaries suppliers have introduced an enzymatic process to remove hydrophobic and other non-cellulosic components from cotton. The new process operates at mild pH conditions over a broad temperature range and can be applied using equipment such as jet machines. Enzyme desizing removes starches but has little effect in removing other sizes.

Enzymatic bleaching
It is claimed that, due to a better bleachability of enzyme-scoured textiles, bleaching can be carried out with reduced amounts of bleaching chemicals and auxiliaries. Enzymes actually make the substrate more hydrophilic (which could explain the better bleachability), but they are not able to destroy wax and seeds, which are therefore removed in the subsequent bleaching process.

Bleaching sensitive fibres with enzymes at temperatures of 65 °C and at neutral pH consumes less energy and water (compared to conventional bleaching) and results in high degrees of whiteness and minimal fibre degradation [36, ÖKOPOL 2011].

Enzymatic washing
Enzymes are used to catalyse the H$_2$O$_2$ bleaching process and to decompose residual peroxide (washing after bleaching, so-called bleach clean-up). For example, catalases/peroxidases are used to remove residual peroxide from fabric and liquor in an isothermal neutralisation step after bleaching (e.g. with phosphonic acid derivatives) [36, ÖKOPOL 2011].

Enzymatic scouring
Enzymatic scouring (discontinuous) with pectinases (alkali-free, especially qualified before dyeing of dark colours) and the subsequent bleaching process at lower temperatures (80 °C) and with shorter reaction times are used with some textiles. Enzymes decompose residual peroxide. [36, ÖKOPOL 2011].

Main/Achieved environmental benefits
Sodium hydroxide used in conventional scouring treatment is no longer necessary. Furthermore, the following advantages are reported over the traditional procedure (see next Table 4.51).
Table 4.51: Environmental benefits achieved with an enzymatic scouring process

<table>
<thead>
<tr>
<th></th>
<th>Enzymatic scouring</th>
<th>Enzymatic scouring + bleaching with reduced concentration of hydrogen peroxide and alkali</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in rinsing water</td>
<td>20 %</td>
<td>50 %</td>
</tr>
<tr>
<td>consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction in BOD load</td>
<td>20 %</td>
<td>40 %</td>
</tr>
<tr>
<td>Reduction in COD load</td>
<td>20 %</td>
<td>40 %</td>
</tr>
</tbody>
</table>

Source: [26, UBA, 2001]

Environmental performance and operational data
A typical process for a pad-batch process combining scouring and desizing in one single step is as follows [26, UBA, 2001]:

- impregnation at 60 °C (pH 8 - 9.5) with:
  - 2-3 ml/l wetting agent;
  - 2-5 ml/l emulsifier;
  - 5-10 ml/l enzymatic compound;
  - 4-6 ml/l amylase;
  - 2-3 g/l salt;
- storing for 3-12 hours, depending on the amount and type of starch;
- extraction and rinsing.

It is possible to combine all of the enzymatic pretreatment processes in one process step or combine them with the conventional (non-enzymatic) processes. The enzymatic treatment can be applied using jet, overflow, winch, pad-batch, pad-steam and pad-roll equipment.

Cross-media effects
The environmental benefits remain unclear as enzymes contribute to the organic load and their action is based on hydrolysis rather than oxidation. With enzymatic desizing, starches are not completely degraded (the long molecules are not completely broken down after desizing). This means higher organic load to be degraded in the biological plant and it is often the cause of problems such as the production of bulky difficult-to-settle sludge.

The organic load not removed with enzymatic scouring may appear in the later wet processing steps. A more global balance would probably reveal no significant improvement.

Technical considerations relevant to applicability
Generally applicable to all fibres (cellulosic, keratine and synthetic).

The enzymatic scouring process can be applied to cellulosic fibres and their blends (for both woven and knitted goods) in continuous and discontinuous processes. When enzymatic desizing is applied, it can be combined with enzymatic scouring. The process can be applied using jet, overflow, winch, pad-batch, pad-steam and pad-roll equipment.

Economics
Price performance is claimed to be economical when considering the total process costs. The benefits of enzymatic treatment versus conventional chemicals need to be weighed against their typically higher cost and their compatibility with other processing steps.

Driving force for implementation
- Reduced water, energy and chemicals consumption.
- Quality aspects (good reproducibility, reduced fibre damage, good dimensional stability, soft handle, increased colour yield, etc.).
- Technical aspects (e.g. no corrosion of metal parts). Ecological and
Economical aspects are reported as reasons for the implementation of the enzymatic scouring technique [26, UBA, 2001].

Reference-Example plants
Many plants in Europe [26, UBA, 2001].
A total of 19 plants (CZ019, DE022, DE026, DE047, DE049, FR136, IT064, IT065, IT068, IT069, IT077, IT078, IT094, PT108, PT109, PT111, PT114, SE120 and UK127) reported using enzymes for desizing (12 amylases).
Meanwhile, 8 plants (FR136, IT059, IT068, IT069, IT074, IT077, IT091, PT114 and SE120) reported using enzymes for scouring of cotton (amylases and cellulase).
And 6 plants (DE034, DE049, FR131, IT070, IT097 and PT108) reported using enzymes for bleaching (2 amylases, 2 catalase, 1 cellulase, 1 other).

Reference literature
[26, UBA, 2001], [36, ÖKOPOL 2011 ], [161, Saxena et al. 2017 ], [162, Cotton Incorporated 2009 ], [163, Cotton Incorporated 2018 ], [164, Novozymes 2019] with reference to:
"kahle, 2000"
Kahle, V.
Bioscouring ein neues, modernes Bio Tech Konzept

4.4.3 [One-step desizing, scouring and bleaching] Combined pretreatment of cotton fabric

Ex-Section 4.5.3

Description
Various pre-treatment operations of cotton textiles (e.g. desizing, scouring and bleaching) are carried out simultaneously.

Technical description
For cotton woven fabric and its blends with synthetic fibres, a three-stage pretreatment process has been the standard procedure for many years, comprising:
- desizing;
- scouring;
- bleaching.

Some techniques which combine all three steps are the following:

a) ‘Flash Steam’
New auxiliaries’ formulations and automatic dosing and steamers allow the so-called Flash Steam procedure which telescopes combines desizing, alkaline cracking (scouring) and pad-steam peroxide bleaching in a single step [180, Spain, 2001].

b) Semi-continuous enzymatic desizing, demineralisation and bleaching
Products as dispersing agents, sequestering agents for calcium (water-hardening substance) and for iron ions as well as peroxide stabilisers used together enable demineralisation combined with enzymatic desizing and bleaching with H2O2 in one bath [36, ÖKOPOL 2011 ]

c) One-step bleaching with high add-on impregnation
Using a one-step bleaching process reduces chemical consumption by approximately 30 % but the steaming time increases by 50 %. In order to avoid crease marks from longer steaming, a
high liquor pick-up impregnation is used. The liquor film around the fibres acts as a shield against undesired partial drying.

One-step bleaching involves the uniform application of a defined quantity of chemicals dissolved in water over the length and width of a wet or dry canvas cloth. During the reaction process in the steamer, the treatment chemicals are spread evenly across the fibre structure to achieve a homogeneous pretreatment effect over the fibre cross-section. [67, Benninger et al. 2016]

Main-Achieved environmental benefits

Combining three operations in one allows significant Reduction of water and energy consumption.

Environmental performance and operational data

Within the space time of 2-4 minutes (with tight strand guidance throughout), loom-state goods are brought to a white suitable for dyeing. This is a big advantage, especially when processing fabrics that are prone to creasing [180, Spain, 2001].

The chemistry is simple and completely automated with full potential for optimum use.

One of the possible recipes consists of:

- 15-30 ml/kg phosphorus-free mixture of bleaching agents, dispersant, wetting agent and detergent;
- 30-50 g/kg 100 % NaOH;
- 45-90 ml/kg 35 % H₂O₂.

The sequence of the ‘Flash Steam peroxide bleach’ is:

1. application of the bleaching solution;
2. steam for 2-4 minutes (saturated steam);
3. hot wash-off.

The specific water consumption for the combined pre-treatment of cotton textiles by bleaching, scouring and desizing is 9–20 m³/t. The lower end of the range is typically achieved with a continuous treatment. [196, TWG 2019]

Cross-media effects

None believed likely.
None identified.

Technical considerations relevant to applicability

Companies with new machinery suitable for this process can apply this technique [180, Spain, 2001]. No more detailed information was made available.

Economics

No information was made available.

Driving force for implementation

Increase in productivity.

Example Reference plants

Several plants in Europe.

Plants from the data collection: DE032, DE039, DE045, DE047, DE049, FR131, FR134, FR136, IT064, IT065, IT068, IT069, IT077, IT078, IT091, PT108, PT109, PT114, SE118 and SE120.

Reference literature
4.4.4 Optimisation of cotton warp yarn pretreatment

Description
Wetting, scouring and bleaching of warp yarn are combined in one step. Heat from the scouring/bleaching bath is recovered.

Technical description
In the production of white, undyed cotton sheets (e.g. sheets to be used under bed sheets and tablecloths), cotton warp yarn is bleached before weaving (for the production of this type of article the fabric does not need to be desized after the weaving process).

The conventional process consists of five steps, including wetting/scouring, alkaline peroxide bleaching and three subsequent rinsing steps. The last rinsing water is reused for making the first bath.

This process can be further improved by combining wetting, scouring and bleaching in one step and performing rinsing in two steps, reusing the second rinsing bath for making the bleaching/scouring bath (as above).

In addition, the energy consumption of the process has been reduced by heat recovery. The heat from the scouring/bleaching bath (110 °C) is recovered (by means of a heat exchanger) and used for heating the fresh water for the first rinsing. The bath is therefore cooled to about 80 °C, while the fresh water reaches a temperature of 60-70 °C.

This cooled scouring/bleaching bath is collected in a tank together with the warm rinsing water from the first rinsing step. This waste water still has a valuable energy content. Therefore, before being drained, this stream is used to heat the water from the second rinsing step (which is then used for making the bleaching/scouring bath as explained above).

Main-Achieved environmental benefits
- Reduction of water consumption.
- Reduction of the volume of waste water generated.
- Reduction of energy consumption.

Environmental performance and operational data
Water consumption and waste water discharge before and after optimisation can be seen from the following table in Table 4.52 below: a 50 % reduction of the water consumption is achieved.

Table 4.52: Optimisation of warp yarn scouring/bleaching: absolute and specific water consumption and waste water discharge before and after process optimisation

<table>
<thead>
<tr>
<th>Process</th>
<th>Water consumption in the conventional process (litres) (¹)</th>
<th>Water consumption in the optimised process (litres) (²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1 Wetting/scouring</td>
<td>6 400</td>
<td>6 400</td>
</tr>
<tr>
<td>Step 2 Bleaching</td>
<td>5 000</td>
<td>5 000</td>
</tr>
<tr>
<td>Step 3 Cold rinsing</td>
<td>5 000</td>
<td>5 000</td>
</tr>
<tr>
<td>Step 4 Warm rinsing</td>
<td>5 000</td>
<td>5 000</td>
</tr>
<tr>
<td>Step 5 Rinsing and pH adjustment with acetic acid</td>
<td>5 000</td>
<td>5 000</td>
</tr>
<tr>
<td>Total</td>
<td>26 400</td>
<td>16 400</td>
</tr>
<tr>
<td>Recycling of last rinsing bath</td>
<td>-5 000</td>
<td>-5 000</td>
</tr>
<tr>
<td>Total water consumption</td>
<td>21 400</td>
<td>11 400</td>
</tr>
<tr>
<td>Specific water consumption (800 kg yarn/batch)</td>
<td>26.8 l/kg</td>
<td>14.3 l/kg</td>
</tr>
<tr>
<td>Residual water content in the yarn</td>
<td>1 400</td>
<td>1 400</td>
</tr>
<tr>
<td>Waste water flow-volume</td>
<td>20 000</td>
<td>10 000</td>
</tr>
<tr>
<td>Specific waste water flow-volume</td>
<td>25 l/kg</td>
<td>12.5 l/kg</td>
</tr>
</tbody>
</table>

(¹) Data refer to a 800 kg batch.  
Source: [179, UBA, 2001]

The consumption of chemicals and energy has also been reduced drastically. The following savings are achieved [179, UBA, 2001]:

- process time: about 50 %
- water consumption/waste water discharge: about 50 %
- NaOH: about 80 %
- H₂O₂: no reduction
- complexing agents/stabilisers: about 65 %
- surfactants: about 70 %
- optical brightener: no reduction
- COD load of waste water: about 20 %
- energy: 1.2 kg steam/kg warp yarn.

Operational data

The operating conditions of the optimised process are illustrated in Table 4.53, which also contains the calculation of COD input and output.
Table 4.53: Optimisation of warp yarn scouring/bleaching: recipe and operating conditions for the optimised process

<table>
<thead>
<tr>
<th>Process input and operating conditions</th>
<th>Quantity</th>
<th>Specific COD (mg O₂/g)</th>
<th>COD load per kg of yarn (g O₂/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetting/scouring/bleaching</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Conditions: pH ca. 12, 110 °C, 10 min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Recipe:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- NaOH 38°Bé (33 %)</td>
<td>3.5 g/l</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>- H₂O₂ 35 %</td>
<td>3.0 g/l</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>- Sequestrant and stabiliser</td>
<td>1.0 g/l</td>
<td>85</td>
<td>0.6</td>
</tr>
<tr>
<td>- Surfactant</td>
<td>1.9 g/l</td>
<td>1610</td>
<td>24.2</td>
</tr>
<tr>
<td>- Optical brighteners</td>
<td>0.15 wt-%</td>
<td>2600</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>Total from auxiliaries</td>
<td>28.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extracted from cotton</td>
<td>70.0</td>
<td></td>
</tr>
<tr>
<td>First rinsing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions: 70 °C, 15 min</td>
<td>3000</td>
<td>18.7</td>
<td></td>
</tr>
<tr>
<td>Second rinsing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions: 70 °C, 15 min</td>
<td>1000</td>
<td>6.2</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>124</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NB: NA: Not applicable.
Source: [179, UBA, 2001]

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
The optimisation of the process is possible for both existing and new installations. For the recovery of heat, space for additional tanks is required, which may be a limiting factor in some cases. The impurities contained in quality of the cotton yarn have to be considered (as regards content of iron, seeds etc.) in order to make sure that the process can be applied.

Economics
The considerable savings of time, water, chemicals and energy make the process highly economical. The optimised process does not require new equipment for pretreatment, but tanks, heat exchangers, pipes and control devices for energy recovery from waste water are required.

Driving force for implementation
Environmental motivation has been the main driving force for the development of the process, but the economic benefit also justifies the investment of effort.
Environmental legislation and savings in water and energy consumption.

Example Reference plants
Two textile finishing plants in Germany are using the described optimised process successfully. Plant PT108.

Reference literature
[179, UBA, 2001] with reference to:

“van Delden, 2001”
van Deleden, S.
Prozessoptimierung durch Wasserkreislaufführung und Abwasservermeidung am Beispiel einer Kettenbaumbeleicht
4.4.5 Use of fully closed-loop installations for fabric [washing (scouring) with organic solvent] dry cleaning

Ex-Section 4.9.3.

Description
Textile fibres are washed in a closed-loop solvent washing system. The extracted air is recirculated in the washing unit after treatment with activated carbon adsorption.

Technical description
Continuously operating solvent scouring installations for open-width fabrics have been known used since the late 1960s. They have been used by the textile finishing industry in different production sectors for over 30 years mainly because of the advantages of organic solvents over water in solving technical and qualitative problems related to fabric cleaning.

The specific heat of PER (the solvent most commonly used) is about 1/5 a fifth of that of water and the latent heat of evaporation is over 10 times lower, resulting in about 90% reduction of the total heat requirement for evaporation in favour of PER. This means much faster and cheaper evaporation with significant savings in time and energy during drying.

The lower surface tension of PER results in a quicker and deeper fibre impregnation, thereby making any cleaning or finishing treatment more complete and uniform.

Nevertheless, the application of PER requires extreme care and sophisticated techniques for reducing and minimising its harmfulness potential for the environment and humans.

The following gives an insight into the features of the new generation of technologically advanced solvent treatment installations compared to the traditional ones.

In general terms, the components of a typical installation of the 1970s conventional installation are schematically represented in the diagram below (see Figure 4.38), are below.

S. — scouring unit
D. — drying unit
C. — cooling section

Solvent recovery equipment:
LR — liquid recovery / sludge disposal (1 distillation, 2 condensation, 3 water separation, 4 solvent tank)
GR — gaseous recovery (5 open-loop active charcoal filters)
S: Scouring unit.
D: Drying unit.
C: Cooling section.

Solvent recovery:
LR: liquid recovery / sludge disposal
1: distillation
2: condensation
3: water separation
4: solvent tank
GR: gaseous recovery
5: activated carbon filters

Source: [197, Comm., 2001]

Figure 4.38: General layout of a conventional solvent scouring installation

Request to TWG: please provide information about the use of water in the solvent washing. Does the technique correspond to dry cleaning (without the use of water) or to another process?

The components of a typical modern installation, schematically represented in Figure 4.39, are:
S: scouring unit
D: drying unit
C: cooling section

Solvent recovery equipment:
LR: liquid recovery / sludge disposal (1 main distillation, 2 sludge distillation, 3 condensation, 4 water separation, 5 solvent tank)
GR: gaseous recovery (6 closed-loop active charcoal filters)
W: water treatment
WD: decantation
The following solutions to the main emission and pollution sources have been developed in the new-generation equipment.

**Emissions to air (outside atmosphere)**

**Problem**
Open-loop *active charcoal* activated carbon filters used for the purification of the air stream release to the outside atmosphere between 500 g/h and 1 000 g/h PER, depending on the equipment size (at a solvent concentration in the region of 500-600 mg/m$^3$).

**Solution**
The new installations are fitted with closed-loop *active charcoal* activated carbon filters. The exhaust duct has been eliminated and the purified air is now recycled to the fabric deodorising / cooling section of the machine: this avoids any air stream exhaustion to the outside environment.

Moreover, with the closed-loop filters it has been possible to redesign more efficient sealing of the complete systems at the machine and at the inlet and outlet sides, with consequent benefits for the workplace as well.

**Emissions to water**
Problem
The so-called separation water produced by the solvent recovery system with an average flow of about 0.5 m³/h and a content of PER of between about 150 g/m³ and 250 g/m³ gives rise to an emission of 75-125 g/h PER. This effluent used to be drained to the sewer (in the worst case) or to the central waste water treatment plant. Since the solvent is not biodegradable, once it reaches the aquifer it accumulates, and lasts indefinitely.

Solution
A built-in, dedicated piece of equipment is now available to pretreat, extract and recover most of the water-dissolved PER, through a two-stage process involving:

1. stripping by means of an air stream;
2. absorption through active charcoal activated carbon cartridges, periodically changeable and rechargeable.

Again, the closed-loop active charcoal activated carbon filters are used to involved in purifying the polluted air stream from the first stage and to recovering the extracted solvent.

Waste
Problem
The high water content and the over 5 % by weight residual PER concentration in the sludge makes this waste difficult to manage at mill level and undesirable to most collectors. Landfilling creates soil or aquifer contamination, and PER may still be released to atmosphere in landfill gas. It is possible that implementation of the Directive 99/31/EC on the landfill of waste may prevent this material being landfilled in the future.

Solution
The complete redesign of the main distilling group (of the ‘forced circulation’ type) and, particularly, the redesign of the sludge distiller (of the ‘thin layer evaporator’ type), has drastically reduces the solvent residue in the sludge well below 10 000 mg/kg (1 %), producing a dry, thick waste. This reduces collection and disposal problems and cost. The PER supplier collects the sludge and the solvent is recycled.

Working environment
Problem
Solvent remains absorbed on fibres and this has had been evaluated to be in the range of 0.1-1.0 %. New systems allow residual concentrations of 150-250 ppm. [ 36, ÖKOPOL 2011 ]

Emission of this solvent to the surrounding environment is difficult to control. This also influences the air stream quality from the drying / heat-setting machines’ exhaust ducts.

Solution
The residual concentration in the fabric depends on the stenter capacity. Besides temperature, especially long curing times lead to a reduction of residual concentrations. It has to be noted that the amount of residual PER can be significantly higher in extremely dense and heavy fabrics.

New systems with continuous measuring devices activate the alarm automatically if specified limits are reached.

The sealing systems at the machine inlet and outlet sides have been redesigned to further improve the solvent vapours’ pick-up efficiency. This results in a much safer environment and better preservation of human health. A typical TLV-TWA value all PER concentration in ambient air around the installation is now not higher than 50 mg/m³.

Concerning workers'safety, dry cleaning and textile finishing machines are equipped with an electronic interlock device: the loading door is locked until the PER concentration after completion of the drying process is below 2 g/Nm³. The concentration is continuously measured within the drum. [ 250, UBA 2019 ]
Main Achieved environmental benefits
The environmental benefits of scouring with organic solvent lie essentially in the following points:

- Reduction of both water and energy consumption, due to the dry-to-dry processing and to the heat requirement for solvent evaporation compared to water.
- Reduction in auxiliary usage (e.g. surfactants used as detergents, emulsifiers, etc.). A high amount of auxiliaries is needed for difficult-to-remove preparation agents such as silicone oils present on elastane fibres and their complete removal with water washing is not possible. As a result, the remaining preparation agents are released to the exhaust air from stenters in the subsequent thermal treatments.
- Reduction of the organic load sent to the waste water treatment plant (the impurities are disposed of in a concentrated form as sludge).

Environmental performance and operational data
The system is able to ensure a residual PER content into the draining water not higher than 0.005 mg/l (emission in the water ≤ 0.5 g/h PER). [36, ÖKOPOL 2011]

Nevertheless, since the water flow is fairly low (≤ 0.5 m³/h) advanced oxidation processes (e.g. the Fenton process) are suitable for treating such low water flows on site [281, Belgium, 2002].

Apart from the above-mentioned contact-water drain, a solvent installation, either old or new, does not generate any other water effluent.

As a whole, the total solvent consumption of the solvent treatment installation has been reduced from the 3–5% (by weight of fabric produced) typical of traditional equipment to 0.8–1.5%. Further improvement is likely in the near future.

New systems are completely closed. Therefore, only the fabric or the sludge (recycling) are responsible for emissions. Consequently, the solvent consumption is reduced to approximately 0.002% (referring to the textile weight). [36, ÖKOPOL 2011]

As a matter of comparison, in the case of the open circuit, PER emissions to air are reported to be between 2.5 mg/Nm³ and 11.9 mg/Nm³ (Plant IT074). [196, TWG 2019]

Solvent treatment of textiles includes all those applications where the solvent (PER) is able to perform better than water, particularly in terms of the solvency power of hydrophobic substances. The cleaning treatment of loom-state fabrics as a preparation for dyeing or printing is the most typical application of this technique, provided that some hydrophilic (water-soluble) substances, such as warp sizing agent, are not present as well.

The main application of solvent is for knitted fabrics, particularly in man-made fibres.

In the particular case of elastic knits (elastane blended fibres), the solvent pretreatment is particularly indicated because it is able to remove efficiently the silicone oils contained in the elastomeric fibres efficiently while conferring optimal shrinkage properties. Thanks to those features, solvent scouring is often extended to the cotton/elastane blends as well.

In woven fabric processing, scouring of loom-state wool cloth, both grey and dyed tops/yarn dyed, either worsted or woollen, is widely used provided that sizing agents are not present.

More recent production of wool elastic fabrics (elastane/wool and wool-polyester blends) requires an after-dyeing solvent treatment to increase the fabric colour fastness.

Particularly in the case of woollen fabrics, solvent scouring can be combined with aqueous carbonising in a single processing line (see Section 2.6.2.1).
Cross-media effects
Organic halogenated solvents are non-biodegradable and persistent substances. Unaccounted losses from spills, scouring unit filters, fabric, etc. may give rise to diffuse emissions, resulting in groundwater and soil pollution. In the UK, municipal water abstraction has been stopped from aquifers contaminated in this way and compensation claims can threaten companies’ economic viability.

Moreover, textiles treated with perchloroethylene have the potential to release it in the later thermal treatments. In directly heated stenter frames, dioxins and furans may be formed. In Germany, legislation forbids treating textile substrates which have been pre-cleaned with PER in directly heated stenters or comparable equipment. High emissions of PER in the exhaust gas (0.1-0.8 g PER/kg of textile substrate and emission mass flows of up to 0.3 kg PER/h) have been observed in some installations, thereby creating difficulties in meeting the emission limit values [280, Germany, 2002].

As far as the problem of the solvent retention by the fibres is concerned, studies and experimentation are in progress, which aim at reducing the solvent content basically by means of a final fabric treatment under heat and moisture conditions. It seems that the solvent abatement level in the fabric can reach over 90 %.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability.

Economics
The following tables Table 4.54 and Table 4.55 attempt to evaluate the economic aspects of the solvent system by comparing it with the aqueous system in a parallel operation with the same fabric quality and at the same production rate.

Two fabrics with the same fibre composition and different construction (one knitted and one woven) have been selected, both in the range of medium-light weight (240 g/m), thus allowing the two systems to produce about 0.8 tonnes/hour each at the same speed of 55 metres/minute.

Since all the machines in the two systems have a nominal production capacity up to 1 tonne/hour, the comparison has been made at 80 % efficiency.

Both systems comprise a washing installation and a heat-setting installation, but:

- the aqueous process uses heat-setting for drying as well;
- the solvent process, including a built-in drying unit, uses heat-setting for this purpose only.

The consumption figures have been taken from the technical characteristics supplied by the relevant machinery manufacturers (Sperotto Rimar Spa for the solvent installation and Santex AG for the washing range and the stenter frame).
Table 4.54: Consumption data: aqueous system and solvent system

<table>
<thead>
<tr>
<th>Utilities</th>
<th>Unit</th>
<th>Aqueous system</th>
<th>Solvent system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Washer</td>
<td>Stenter</td>
<td>Total</td>
</tr>
<tr>
<td>Labour</td>
<td>h</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Electricity</td>
<td>KW/h</td>
<td>94</td>
<td>158</td>
</tr>
<tr>
<td>Thermal energy</td>
<td>MJ/h</td>
<td>2 160</td>
<td>6 669</td>
</tr>
<tr>
<td>Steam</td>
<td>kg/h</td>
<td>950</td>
<td>2 940</td>
</tr>
<tr>
<td>Water supply</td>
<td>m³/h</td>
<td>8</td>
<td>NA</td>
</tr>
<tr>
<td>Waste water</td>
<td>m³/h</td>
<td>8</td>
<td>NA</td>
</tr>
<tr>
<td>Detergent</td>
<td>kg/h</td>
<td>16</td>
<td>NA</td>
</tr>
<tr>
<td>PER</td>
<td>kg/h</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Sludge</td>
<td>kg/h</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

¹ Cooling water, fully recoverable 40-45 °C.
² PER is not used up, the value refers to the intrasystem flow.

NB: NA: Not applicable.
Source: [197, Comm., 2001] [36, ÖKOPOL 2011]

Table 4.55: Hourly cost figures: aqueous system and solvent system

<table>
<thead>
<tr>
<th>Utilities</th>
<th>EUR/ unit</th>
<th>Aqueous system</th>
<th>Solvent system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Washer</td>
<td>Stenter</td>
<td>Total</td>
</tr>
<tr>
<td>Labour</td>
<td>16/h</td>
<td>16.00</td>
<td>16.00</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.10/kWh</td>
<td>9.40</td>
<td>15.80</td>
</tr>
<tr>
<td>Steam</td>
<td>0.03/kg</td>
<td>28.50</td>
<td>88.20</td>
</tr>
<tr>
<td>Water supply</td>
<td>0.30/m³</td>
<td>2.40</td>
<td>NA</td>
</tr>
<tr>
<td>Waste water</td>
<td>0.78/m³</td>
<td>6.24</td>
<td>NA</td>
</tr>
<tr>
<td>Detergent</td>
<td>1.55/kg</td>
<td>24.80</td>
<td>NA</td>
</tr>
<tr>
<td>PER</td>
<td>0.40/kg</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Sludge</td>
<td>0.78/kg</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Total</td>
<td>EUR/h</td>
<td>87.34</td>
<td>120.00</td>
</tr>
</tbody>
</table>

NB: NA: Not applicable.
Source: [197, Comm., 2001]

The thermal energy consumption figures have been calculated from the heating capacity performance and expressed as steam consumption for an easier cost determination.

The detergent usage for the aqueous system and the PER consumption for the solvent system are classified as ‘chemicals’ consumption.

The water purification for the aqueous system corresponds broadly with the sludge disposal for the solvent system.

As stated earlier, the water supply in the solvent system is used for cooling purposes only and can be fully recovered, unpolluted, to be reused in the dyehouse or even recycled in the solvent installation after suitable cooling.

The unit costs are based on current prices in Italy, although they fluctuate over time and vary with textile type. Local prices can easily be substituted.

The disposal cost for the sludge is compensated by the savings achievable in:

- heating energy (steam);
- total water (supply + purification);
chemicals (detergent and PER).
On the whole, the solvent system can ensure a total saving of about 17\%, i.e. EUR 35 euros/working hour.

The high investment cost is sometimes a disincentive, but the payback period is short (usually no longer than 2-3 years), particularly for medium-large installations and big companies with an annual production of at least 3 000 tonnes of fabric [197, Comm., 2001].

**Driving force for implementation**
Reducing emissions to air of pollutants seems to be, at the moment, the priority for an investment decision. Second are market requirements, as new textile products are developed, creating the need for solvent systems development. Running cost reductions are also a factor.

**Example Reference plants**
It is estimated that at least 200 plants, either old or new, are presently operating worldwide [197, Comm., 2001].
Plants from the data collection: IT063, IT074, IT078, PT111 and PT114.

**Reference literature**
[197, Comm., 2001] with reference to:
- [36, ÖKOPOL 2011 ] [ 62, Germany 2001 ] [ 101, TWG 2002] [ 250, UBA 2019 ]

### 4.4.6 Washing of synthetic textile fibres

**Description**
Synthetic textile materials are washed prior to thermal treatment. If needed, the washing water is sent to treatment.

**Technical description**
With knitted fabrics *made of cotton or cotton blends with synthetic fibres*, these hydrosoluble oils can be easily washed out with water at 40 °C. This makes it possible to scour and bleach the fabric in one single step, thus saving time, water and energy.

Knitted fabrics *made of synthetic fibres* (e.g. polyester or polyamide) are often thermofixed before being washed. If conventional oils are present on the fabric, an intense emission of fumes is generated and the remaining oil becomes more difficult to remove from the fabric in the subsequent washes.

Also in this case it is often possible to use water-soluble oils instead of conventional lubricants and to carry out the washing step before thermofixation. Washing takes place in a continuous high-efficiency washing unit (e.g. TVE-Escalé type). After this step, the fabric is sent to the stenter and then dyed, washed and finished. In this way, emissions of fumes from the stenter are minimised.

**Main-Achieved environmental benefits**
Reduction of emissions to air.
Environmental performance and operational data
With synthetic knitted fabric, one of the advantages of carrying out the washing step before thermofixation is that emissions to air from the stenter can be significantly reduced without the need for air emission abatement equipment.

Operational data

Some synthetic knitted fabrics need to be thermofixed before washing. In this case, another option is the ‘dry route’: the fabric is submitted to thermofixation before washing and the resulting fumes are treated in an electrostatic precipitator with subsequent recovery of the oil. The advantage is that the recovered oil can be disposed of separately, thereby reducing the contamination of the water effluent. Energy recovery is another feature of this technique. More details are given in Section 4.10.9.

Cross-media effects
Provided that the water-soluble knitting oils used in substitution of the conventional ones are biodegradable and that the fabric is processed in high-efficiency washing machines, a net environmental benefit is achieved. Water-soluble oils are contained in the waste water.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
No information provided.

Driving force for implementation
The strict limits set by Environmental legislation for emissions to air and water favour the implementation of this technique.

Example Reference plants
Many plants.
Plants from the data collection: BE010, CZ015, CZ017, DE034, IT082 and SE120.

Reference literature
[295, Spain, 2002]. [27, Derden et al. 2010]

4.4.7 Techniques to avoid or reduce the use of harmful substances

4.4.7.1 [Substitution for sodium hypochlorite and chlorine-containing compounds in bleaching operations] Chlorine-free bleaching

Ex-Section 4.5.5

Description
Bleaching is carried out with chlorine-free bleaching chemicals (e.g. hydrogen peroxide, peracetic acid), possibly catalysed with enzymes.

Technical description
The application of hypochlorite gives rise to subsidiary reactions, leading to the formation of a number of chlorinated hydrocarbons such as the carcinogenic trichloromethane (which is also the most frequently formed as it is the end of the reaction chain). Most of these by-products can be detected as adsorbable organic halogens by means of the sum parameter AOX. Similar contributions to the formation of hazardous AOX come from chlorine or chlorine-releasing compounds and strong chlorinated acids (e.g. trichloroacetic acid). Halogenated solvents are a different category of problematic AOX (See also Section 2.6.1.2.)
Sodium hypochlorite was for a long time one of the most widely used bleaching agents in the textile finishing industry. Although it has been largely replaced in Germany and many other European countries, it is still in use not only as a bleaching agent, but also for cleaning dyeing machines or as a stripping agent for recovery of faulty dyed goods.

In certain conditions, sodium chlorite may also give rise to the formation of AOX, although to a lesser extent than hypochlorite. However, recent investigations have shown that the cause is not sodium chlorite itself, but the chlorine or hypochlorite present as impurities (from non-stoichiometric production) or used as an activating agent. Recent Technologies (using hydrogen peroxide as the reducing agent of sodium chlorate) are now available to produce ClO₂ without generation of AOX [18, VITO, 1998], [59, L. Bettens, 2000].

Hydrogen peroxide is now the preferred bleaching agent for cotton and cotton blends as a substitute for sodium hypochlorite.

When a single-stage process using only hydrogen peroxide cannot achieve the high degree of whiteness required, a two-stage process with hydrogen peroxide (first step) and sodium hypochlorite (second step) can be applied, in order to reduce AOX emissions. In this way, the impurities on the fibre – which act as precursors in the haloform reaction – are removed, thus producing a reduction in AOX in the effluent.

Waste water from sodium hypochlorite bleaching is separated from other streams and from the combined waste water to reduce the generation of hazardous AOX compounds. [ 36, ÖKOPOL 2011 ]

Nevertheless, a two-stage bleaching process using only hydrogen peroxide is also today possible, thus completely eliminating the use of hypochlorite (cold bleaching at room temperature followed by a hot bleaching step).

There is also increasing support for Hydrogen peroxide bleach under strong alkaline conditions, which also achieves a high degree of whiteness after careful removal of catalysts by a reduction/extraction technique. The additional advantage claimed is the possible combination of scouring and bleaching. The reduction/extraction followed by a strong oxidative combined bleaching/scouring step (high alkali and high active oxygen concentration) is applicable for bleaching highly contaminated textiles in all make-ups and on all types of machines (discontinuous and continuous). This method takes the oxidative route and uses the active oxygen (see Section 4.4.1).

Main Achieved environmental benefits

The presence of hazardous AOX such as trichloromethane and chloroacetic acid in the effluent is avoided.

Environmental performance and operational data

Particular attention needs to be paid to the combination or sequence of pretreatment operations and to the mixing of streams containing hypochlorite or chlorine. For example, the application of the two-step bleaching method where hypochlorite as well as peroxide is used is potentially hazardous if the hypochlorite bleaching is performed when large quantities of organohalogen precursors are still present on the substrate. The risk would thus be reduced if hypochlorite bleaching came as the last step after an alkaline peroxide bleach that removes the precursors from the fibre. However, no data were made available that show the importance of reversing the sequence of the two steps from hypochlorite to peroxide into peroxide to hypochlorite. It is actually more important to avoid mixing hypochlorite bleach waste water with certain other streams and mixed effluents, in particular from desizing and washing, even when the right sequence of pretreatment and bleaching is adopted. The formation of organohalogenes is highly possible likely in combined process streams.
For chlorite bleach, handling and storage of sodium chlorite needs particular attention because of toxicity and corrosion risks. Machinery and equipment need to be inspected frequently because of the high stress to which they are subjected (see also Section 0).

Cross-media effects

Complexing agents (e.g. EDTA, DTPA, phosphonates) are normally applied as hydrogen peroxide stabilisers.

In Germany, a regulation prohibits EDTA and DTPA from being discharged to the waste water. [36, ÖKOPOL 2011]

The main concerns associated with the use of complexing agents arise from their ability to form stable complexes with metals (remobilisation of heavy metals), their N and P content and their often low biodegradability and bioeliminability. The addition of strong sequestering agents, however, can be avoided by fine control of the pH conditions during the bleaching process (see Section 4.4.7.2) and with the assistance of silicates, magnesium, acrylates or biologically degradable carboxylates, slowing down the uncontrolled decomposition of hydrogen peroxide (see Section 4.1.6.8.2).

Optical brighteners are often applied when peroxide bleaching is not sufficient to achieve the required level of whiteness, which results in a The resulting COD load in the waste water and smoke emissions to air during fixation in the stenter have to be taken into account. Moreover, optical whiteners are potentially irritating and thus not always acceptable for white goods coming into close contact with the skin (e.g. underwear, bedsheets).

Technical considerations relevant to applicability

Substitution of hypochlorite by hydrogen peroxide as the bleaching agent is applicable to both new and existing installations.

Hydrogen peroxide is a valid substitute for bleaching yarn and woven fabric made of mostly of cellulosic and wool fibres and most of their blends. Today a full hydrogen peroxide bleaching process is also applicable to cotton and cotton-blend knitted fabric and a high degree of whiteness (> 75 BERBER Berger Whiteness Index) can be obtained (with a strong alkaline scour/bleach after removal of the catalyst).

Exceptions are flax and other bast fibres that cannot be bleached using hydrogen peroxide alone. Unlike chlorine dioxide, the anionic bleaching agent is not strong enough to remove all coloured material and does not preferentially access the hydrophobic region of the fibre. Two-step hydrogen peroxide-chlorine dioxide bleaching is an option for flax.

It is claimed that a sequence where precursors of halogenation are removed with a peroxide bleach followed by a hypochlorite bleach (or a peroxide pre-bleach followed by a combined hydrogen peroxide/hypochlorite bleach) is still necessary for high whiteness and for fabrics that are fragile and would suffer from depolymerisation.

Sodium chlorite is an excellent bleaching agent for flax, linen and some synthetic fibres.

Economics

In general, bleaching with hydrogen peroxide is no more expensive than bleaching with hypochlorite because of market saturation.

The two-stage bleaching process with hydrogen peroxide proposed for knitted fabric is reported to be from two to six times more expensive than the conventional process using hydrogen peroxide and hypochlorite [179, UBA, 2001].

If using chlorine dioxide as bleaching agent, investment may be needed (in existing installations) for equipment resistant to the highly corrosive conditions in which this bleaching agent is used.
As far as the production of elemental chlorine-free chlorine dioxide is concerned, this process is fully investigated and described in another BREF (pulp & paper industry).

**Driving force for implementation**

Market demands for chlorine-free bleached textiles and the requirements set by legislation (regarding waste water discharge) are the main driving forces for the implementation of this technique.

**Example Reference plants**

Many plants in Europe and worldwide largely use substitutes for sodium hypochlorite as a bleaching agent.

Plants from the data collection: CZ019, FR131, IT059, IT068, IT069, IT070, IT071, IT072, IT088, IT094, PT102, PT108, and SE118.

Of the 57 plants from the data collection which carry out bleaching, 4 reported using sodium chlorite and 1 reported using sodium hypochlorite.

**Reference literature**

[179, UBA, 2001], [51, OSPAR, 1994], [203, VITO, 2001], [65, Jacobs et al. 1998], [66, Bettens 2000].

#### 4.4.7.2 Optimised hydrogen peroxide bleaching

**Description**

The use of complexing agents can be completely avoided or minimised by reducing the concentration of hydroxyl radicals during bleaching. This is achieved by:

- use of demineralised water;
- prior removal of metal impurities from textile materials (e.g. by magnetic separation or chemical extraction);
- controlling the pH and the peroxide concentration during bleaching.

**Technical description**

When bleaching with hydrogen peroxide, oxygen species of differing reactivity may be present in water (O$_2$*, H$_2$O$_2$/HOO-, H$_2$O/ OH-, HOO*/O$_2$*, OH*/O*, O$_3$/O$_3$*). The kinetics of formation and disappearance depend on the concentration of oxygen, energy for activation, reduction potential, pH, catalyst and other reagents. These processes are very complex and can only be explained with dynamic simulation models.

It is widely accepted that the OH* radical is responsible for attacking the cellulose fibre and leading to its damage (depolymerisation). As the formation of the OH* radical is mainly due to the reaction of H$_2$O$_2$/HOO with transition metals such as iron, manganese and copper, the prevention of ‘catalytic’ damage of the fibre as a consequence of the uncontrolled formation of the OH* radical is usually achieved by using complex formers that inactivate the catalyst (stabilisers). See also Section 8.5.

Complexing agents (see Figure 4.19) that are typically applied in finishing mills are based on polyphosphates (e.g. tripolyphosphate), phosphonates (e.g. 1-hydroxyethane 1,1-diphosphonic acid) and amino carboxylic acids (e.g. EDTA, DTPA and NTA). The main concerns associated with the use of these substances arise from their N and P content, their often-low biodegradability/bioeliminability and their ability to form stable complexes with metals, which may lead to the remobilisation of heavy metals (see also Section 8.5).

In Germany, a regulation prohibits EDTA and DTPA from being discharged to the waste water.}

[36, ÖKOPOL 2011]
The use of high quantities of sequestering agents can be avoided by removing the responsible catalysts from the water used in the process and from the textile substrate and by scavenging away the OH*.

Softening of fresh water is largely applied by textile mills to remove the iron and the hardening alkaline-earth cations from the process water (magnesium hydrate has a stabilising effect and techniques that remove transition metals and calcium are therefore preferred).

Iron carried with the raw fibre can be present as fibre impurity, rust or coarse iron particles on the surface of the fabric. The latter can be detected and removed by a dry process using magnetic detectors / magnets (modern continuous lines are equipped with magnetic detectors). This treatment is convenient when the process starts with an oxidative scouring/desizing step, because otherwise a huge amount of chemicals would be required to dissolve these coarse iron particles in a wet process. On the other hand, the previous removal of coarse iron particles is not necessary when an alkaline scouring treatment is carried out as a first step before bleaching.

Magnetic sensors cannot detect non-ferromagnetic particles and magnets cannot remove the iron that is inside the fibre (fibre impurities and rust in heavily contaminated goods). This iron fraction has to be solubilised and removed from the substrate by acid demineralisation or reductive-extractive treatment before bleaching. In the case of acid demineralisation, Fe(III) oxide, iron metal and many other forms of iron (some organic complexes) are solubilised in strongly acid conditions (by hydrochloric acid at pH 3). This means that the metal parts of the equipment must withstand these conditions. The advantage of the reductive treatment is that there is no need to use strong corrosive acids. Moreover, with the new non-hazardous reductive agents (see Section 4.5.4.2), it is possible to avoid a drastic change of pH.

As mentioned above, OH* radicals can be scavenged away in order to minimise fibre damage without the need for complexing agents.

In-depth research into the reactivity of hydrogen peroxide (SYNBLEACH EV5V-CT94-0553 EC funded research project) has shown that the control of the process is fundamental to prevent uncontrolled decomposition of hydrogen peroxide and to allow optimum use of hydrogen peroxide.

Figure 4.40 shows that under optimal conditions (pH approximately 11.2, homogeneously distributed catalyst and controlled peroxide concentration) the hydroxyl radical OH* is scavenged away by hydrogen peroxide, forming the true bleaching agent, the dioxide radical ion (maximum formation of dioxide radical anion O$_2^{-}$ in accordance with the peak). Under these conditions, hydrogen peroxide itself acts as a scavenger and the reaction product is the active bleaching agent itself (which allows optimal use of hydrogen peroxide). The addition of formic acid (formate ion) as a scavenging agent is also useful to further control the formation of the OH* radical, generating more O$_2^{-}$ and even repairing damage to the fibre. [203, VITO, 2001].
Figure 4.40: Production of the peroxide radical ion by scavenging hydroxyl radicals (OH\(^{-}\)) using hydrogen peroxide

**Main-Achieved environmental benefits**
No or reduced emissions to water of complexing agents.

**Environmental performance and operational data**
With the proposed technique, it is possible to bleach cellulose in full and even to a high whiteness, without damage to the fibre with:

- no use of hazardous sequestering agents;
- minimal consumption of peroxide (< 50 % compared with uncontrolled conditions);
- (pre-)oxidation of the removed substances.

**Operational data**
As mentioned above, as an alternative to acid demineralisation, pre-cleaning of heavily soiled fabric (rust) is possible in more alkaline conditions using non-hazardous reducing agents, without any need for a drastic change in pH. The reduction/extraction is effective for all types of substrates and qualities of fabrics (highly contaminated, uneven distribution of iron rust). This step is easy to integrate with discontinuous and continuous processes following the oxidative route under mildly or strongly alkaline bleach conditions [203, VITO, 2001].

**Cross-media effects**
None to be expected.
None identified.

**Technical considerations relevant to applicability**
The measures described in this section may be generally applicable to existing and new plants. However, fully automated equipment is necessary for the application of hydrogen peroxide under controlled process conditions. Dosing of the bleaching agent, controlled by a dynamic simulation model, is still limited [203, VITO, 2001].

**Economics**
Reduction of peroxide consumption by more than 50 % is possible. There is no increase, but rather a decrease in organic load, along with better treatability of the effluent. The chemistry
needed is not expensive and is reliable, provided that there is a good knowledge of the complex control parameters [203, VITO, 2001].

**Example Reference plants**
The technique described in this section is provided directly by some auxiliaries suppliers. With the help of dynamic simulation models they are able to prepare a recipe that is suitable for the specific substrate, equipment used, etc. under defined process conditions.

Plants from the data collection: DE032, DE039, DE047, IT064, IT065, IT068, IT069, IT071, IT072, IT077, IT078, IT088, IT089, IT090, IT097, PT102, PT105, PT108, SE120 and UK127. Of these plants, six reported not using complexing agents at all.

**Reference literature**
[203, VITO, 2001] with reference to:


[ 36, ÖKOPOL 2011 ]

### 4.4.7.3 Ozone bleaching

**Description**
Ozone is used to bleach fabrics or garments and improve their absorption properties.

**Technical description**
In the case of bleaching or whitening the cotton fabric (e.g. for denim), ozone is used either as gas or dissolved in water (forming hydroxyl radicals). Ozone is generated on site by corona discharge and injected in a closed chamber as gas or dissolved in water for use in a washing machine. Ozone reacts with (oxidises) the surface of fibres and thereby removes natural impurities (e.g. oils, waxes, pectins) or dyes (e.g. indigo) present on the fibre and improves its whiteness and hydrophilicity (absorption or pickup for liquids).

**Achieved environmental benefits**
- Reduced consumption of water.
- No use of chlorinated chemicals.

**Environmental performance and operational data:**
Ozone processes can be performed at room temperature. Conventional bleaching methods require much higher temperatures; longer reaction times (1-2 hours), large amounts of water and chemicals. Whiteness grades obtained after bleaching with ozone are close to the degree of whiteness after conventional bleaching, while the absorbency is lower but still acceptable.

The bleaching performance might be limited for certain man-made fibres depending on their degree of polymerisation.

**Cross-media effects**
Health and safety issues related to the use of ozone.

**Technical considerations relevant to applicability**
Generally applicable to cellulose, keratin and synthetic fibre.

**Economics**
- Reduced expenses for water consumption and waste water treatment.
- No energy is needed for heating the baths.
The cost of ozone is comparable to the cost of bleaching chemicals (e.g. chlorine dioxide).

**Driving force for implementation**
- Environmental legislation.
- Reduced expenses for water and energy.

**Example plants**
No industrial site located in the EU was identified. One plant in Ksar Hellal, Tunisia, uses this technique.

**Reference literature**
[ 135, RICARDO 2019 ] [ 136, Inditex 2019 ] [ 137, Clothing industry 2019 ] [ 138, Körlü 2018 ], [ 172, Puchol et al. 2017 ]

### 4.4.8 Techniques to increase resource efficiency

#### 4.4.8.1 Recovery and reuse of water-soluble sizing chemicals [agents by ultrafiltration]

**Ex-Section 4.5.1**

**Description**
When desizing is carried out by washing with hot water, water-soluble sizing chemicals (e.g. polyvinyl alcohol and polyacrylates) are recovered from the washing water by ultrafiltration. The concentrate is reused for sizing, whereas the permeate is reused for washing.

**Technical description**
Sizing agents are applied to warp yarn in order to protect it during the weaving process and have to be removed during textile pretreatment, thus giving rise to 40-70% of the total COD load of woven fabric finishing mills.

Water-soluble synthetic sizing agents such as polyvinyl alcohol, polyacrylates and carboxymethyl cellulose can be recovered from washing liquor by ultrafiltration. More recently, it has been confirmed that modified starches such as carboxymethyl starch can also be recycled.

The principle of recovery by ultrafiltration is shown in Figure 4.41. After sizing and weaving, sizing agents are removed during textile pretreatment by hot washing with water in a continuous washing machine (in order to minimise water consumption, the washing process may need to be optimised). The sizing agents concentration in the washing liquor is about 20-30 g/l. In the ultrafiltration plant, they are concentrated to 150-350 g/l. The concentrate is recovered and can be reused for sizing, whereas the permeate can be recycled as water in the washing machine. Note that the concentrate is kept at a high temperature (80-85°C) and does not need to be reheated, which results in less energy consumption. [179, UBA, 2001], [ 36, ÖKOPOL 2011 ]
Figure 4.41: Recovery of sizing agents by ultrafiltration

**Main Achieved environmental benefits**

- Resource efficiency as sizing agents are recovered.
- Reduction of the pollutant loads in the waste water.
- Reduction of energy consumption.

In addition, sizing agents in waste water do not need to be treated. Thus energy consumption for treatment is reduced significantly as well as quantity of sludge to be disposed of [179, UBA, 2001].

**Environmental performance and operational data**

Figure 4.42 shows the mass balance of sizing agents and water for the process with and without recovery in a representative case study. It can be noticed that, even with recovery, some losses of sizing agent still occur at various steps/stages of the process, especially during weaving. Furthermore, a certain amount of sizing agent still remains on the desized fabric and a fraction ends up in the permeate. In conclusion, the percentage of sizing agents which can be recovered is 80-85 %. 

Source: [179, UBA, 2001]
Rapid and complete removal of the size may be achieved by using new washing systems with, for example, a steamer or vacuum suction. The steamer facilitates the delamination of the size, improving the removal before the fabric runs into the washing process. This results in an increase in washing efficiency, water and energy savings of the following washing process. This process is particularly gentle to fabrics and therefore suited for fine fabrics [36, ÖKOPOL 2011].

**Operational data**

In order to minimise scaling and fouling, fibres have to be removed before ultrafiltration. The same applies to fine particles, such as singeing dust. A pre-filtration step is carried out for this purpose.

When desizing coloured woven fabric (dyed warp yarn), the desizing liquor becomes slightly coloured. Dyestuff particles are more difficult to remove and the liquor needs to be submitted to microfiltration (which is more complex, but still feasible) [179, UBA, 2001].
The operation/management of ultrafiltration units for recovery of sizing agents requires qualified staff and accurate maintenance. Cleaning of ultrafiltration units is carried out once a week automatically with addition of surfactants and citric acid. [36, ÖKOPOL 2011]

Ultrafiltration is very efficient in reducing the high organic load from textile mills. The COD load of waste water from finishers of woven fabric is reduced by 40-70% due to size recovery. However, it has to be remembered that the polymers used for recoverable sizing agents are also widely applied in products such as household detergents, which are found in great quantities in other effluents. [61, L. Bettens, 1999].

Ultrafiltration needs energy, but the amount consumed is much less than the energy required to produce new sizing agents (if they are not recovered) and to treat them in a waste water treatment plant [179, UBA, 2001].

Reuse in the weaving plant is not always without problems. Stock and The recovered size needs to be kept under sterile conditions when stored and mixed with virgin fresh size. In the past, failure of protection against bacterial growth (biological degradation of concentrates and contamination of the ultrafiltration equipment) resulted in the shutdown of a recycling plant in Belgium [61, L. Bettens, 1999]. Nowadays, recovered sizing agents are kept at temperatures above 75 °C. It is reported that under these conditions there are no problems of microbial attack and therefore no addition of biocides is needed to maintain sterile conditions [280, Germany, 2002].

Cross-media effects
None identified.

Technical considerations relevant to applicability
As explained earlier, this technique is suitable only for specific types of sizing agents. These are water-soluble synthetic sizing agents such as PVA, polyacrylates and carboxymethyl cellulose. Recently, it has been confirmed that as well as some kind of modified starches such as carboxymethyl starch can also be recycled.

Limitations in the applicability of this technique may arise from cases where the auxiliaries applied to the yarn are not only sizing agents, but also waxes, antistatic agents, etc. These compounds remain in the concentrate after UF. The concentrate can be reused for sizing, but limitations can be found when reusing the same concentrate for different kinds of yarns (with different applications and end uses) which may need specific additives [281, Belgium, 2002]. To date, the weavers’ acceptance of recovered size is still limited. Weavers are concerned about the quality of the recovered size. Furthermore, certain effects such as minting can only be carried out with non-desized fabric. For these reasons, reuse of the concentrate is typically applied in integrated companies with a uniform production, recovery and reuse of sizing are only technically and economically feasible for integrated finishers with weaving and finishing processes nearby. Furthermore, the sizing recipe must remain unchanged.

A further issue to consider is the transport distances. Long distance shipments cancel out any ecological advantages because the liquor needs to be transported in adequate conditions in insulated tankers [179, UBA, 2001]. Although, there are mills where recovery is carried out in spite of a considerable distance between the weaving and finishing departments (up to 300 km in one company in the USA), sizing agents are usually recovered in integrated mills having a weaving and a finishing section at the same site.

When weaving and finishing (desizing) take place in completely different places, a more practicable option would probably be to remove and recover the sizing agents directly in the weaving mill, which would therefore produce desized fabric. However, while the quantity of processed fabric must be higher than 1 000 t/yr to make the process cost-effective in an integrated mill, the minimum amount in a weaving mill producing desized fabric is much higher (about 5 000 – 8 000 t fabric/yr) because, in addition to the ultrafiltration plant, a washing machine and a dryer have to be installed [179, UBA, 2001]. Additionally, however, textile
finishers’ acceptance of already desized fabric is still limited. and certain effects such as minting can only be carried out with non-desized fabric.

Economics

The following table Table 4.56 presents a typical example of the annual savings achievable when introducing recovery of sizing agents [179, UBA, 2001].

Table 4.56: Typical example of annual savings achievable when introducing recovery of sizing agents

<table>
<thead>
<tr>
<th>Input for sizing</th>
<th>Without recovery (annual basis)</th>
<th>With recovery (annual basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantity</td>
<td>Cost (EUR)</td>
</tr>
<tr>
<td>Produced woven fabric</td>
<td>8 750 t</td>
<td>261 435</td>
</tr>
<tr>
<td>Quantity of warp yarn</td>
<td>5 338 t</td>
<td>722 500</td>
</tr>
<tr>
<td>Load of sizing agents(4,5)</td>
<td>13.8 %</td>
<td>60 770</td>
</tr>
<tr>
<td>Recovered sizing agent</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Starch derivative</td>
<td>470 t</td>
<td>261 435</td>
</tr>
<tr>
<td>PVA</td>
<td>264 t</td>
<td>722 500</td>
</tr>
<tr>
<td>Polyacrylates (100 %)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Wax</td>
<td>59 t</td>
<td>135 040</td>
</tr>
<tr>
<td>Fresh water</td>
<td>5 075 m³</td>
<td>5 840</td>
</tr>
<tr>
<td>Steam</td>
<td>890 t</td>
<td>10 780</td>
</tr>
<tr>
<td>Electricity</td>
<td>155 680 kWh</td>
<td>8 560</td>
</tr>
<tr>
<td>Manpower</td>
<td>4 450 h</td>
<td>58 700</td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td><strong>1 200 855</strong></td>
<td></td>
</tr>
</tbody>
</table>

NB: NA: Not applicable.
Source: [179, UBA, 2001]

The cost-benefit assessment analysis above should take into account not only the costs of ultrafiltration, but also the recipe and overall process and treatment costs especially when considering that changing over from starch and starch derivatives to synthetic sizing agents also has implications for weaving efficiency. Synthetic sizing agents are more expensive than starch-based sizing agents, but they are applied in lower amounts and the weaving efficiency may be higher.

In the example given in the table, there will be additional savings because of the higher weaving efficiency and the reduced cost of pretreatment (time savings and significantly reduced consumption of chemicals for degradation and removal of size compared to starch-based products) and waste water treatment. The payback time of an ultrafiltration plant may then be less than 1 year [179, UBA, 2001], which suggests that in most cases companies primarily invest in this technique not because of the environment, but because of the economical benefit.

The investment costs for the ultrafiltration plant referred to above—illustrated above—are the following [179, UBA, 2001]:

- ultrafiltration plant: 1 000 000 EUR
- equalisation tank: 105 000 EUR
- installation: 77 000 EUR
- start-up: 27 500 EUR
- miscellaneous: 27 500 EUR
- **total investment cost:** 1 237 000 EUR
Purchasing such equipment is only technically and economically feasible for integrated plants processing correspondingly large batch sizes. [36, ÖKOPOL 2011]

**Driving force for implementation**

Environmental legislation and savings in raw material.

Waste water problems and cost reductions have been the most important driving forces to implement recovery of sizing agents [179, UBA, 2001].

**Example Reference plants**

The first plant for recovery of polyvinyl alcohol went into operation in 1975 in the USA. Meanwhile, there are two plants that have been in operation in Germany for many years and various plants are now in operation in Brazil, Taiwan and the USA. There are not many suppliers of ultrafiltration plants [179, UBA, 2001].

**Reference literature**

[61, L. Bettens, 1999], [179, UBA, 2001], with reference to:


“Technical information BASF, T/T 372a, July 2000”

“Size UCF 4, Techn. Info BASF (2000)”

[36, ÖKOPOL 2011] [280, Germany, 2002].

### 4.4.8.2 Recovery of alkaline caustic soda used for mercerising

#### Ex-Section 4.5.7

**Description**

Caustic soda is recovered from the rinsing water by evaporation and further purified, if needed.

**Technical description**

During the mercerisation process, cotton yarn or fabric (mainly woven fabric but also knitted fabric) is treated under tension in a solution of concentrated caustic soda (270-300 g NaOH/l, or also 170-350 g NaOH/kg textile substrate) for about 40-50 seconds. The textile substrate is then rinsed in order to remove caustic soda. This rinsing water is called weak lye (40-50 g NaOH/l) and can be concentrated by evaporation for recycling. The principle is shown in the figure Figure 4.43 below.
Figure 4.43: Representation of the Caustic soda recovery process by evaporation followed by lye purification

After removal of lint, fluff and other particles (using self-cleaning rotary filters or pressure microfiltration), the weak lye is first concentrated, for instance in a three-stage evaporation process. In many cases, purification of the lye is required after evaporation. The purification technique depends on the degree of lye contamination and can be simple sedimentation or oxidation/flotation with injection of hydrogen peroxide.

Before evaporation, fluff, fibres, and other solid particles are removed by self-cleaning curved screens and microfiltration. In the pre-cleaning stage with curved screens, crystallisation of caustic soda occurs via contact of the lye with the carbon dioxide contained in air, resulting in a higher cleaning efficiency compared to rotary filters. More pollution is reduced by the installation of a sedimentation tank.

Weak lye is concentrated in two, three or four steps in the downstream evaporation plant. In the final purification stage, oxidation with hydrogen peroxide destroys the unwanted yellow colour of the strong lye. If the lye is reused after oxidative desizing (see Section 4.4.1), decolouring can be achieved without any addition of auxiliaries because the bath contains an excess of hydrogen peroxide.

Subsequent cleaning is done by flotation. The recovered lye is cooled before reuse. Subsequently, the cooling water can be used for hot processes. [36, ÖKOPOL 2011]

Main Achieved environmental benefits
The alkaline load of the waste water is reduced drastically and the acid required for waste water neutralisation is minimised.

Concentration of the weak lye results in savings of resources (no add-on of new products) and energy (less energy consumption compared to white liquor production). [36, ÖKOPOL 2011]

Environmental performance and operational data
The concentration of weak lye is usually 5-8 °Bè (30-55 g NaOH/l) and is increased may be up to 25-40 °Bè (225-485 g NaOH/l), depending on the mercerising process applied. When mercerisation is carried out on the greige dry textile substrate (raw mercerisation), it is possible to the achievable a concentration of caustic soda is not higher than 25-28 °Bè, whereas a concentration of 40 °Bè can be obtained in non-raw mercerisation. In raw mercerisation, the concentration of impurities is significantly higher, as is the viscosity, which makes it difficult to
Chapter 4

reach higher concentrations (because the circulation in evaporators is less efficient disturbed) [179, UBA, 2001].

For example, a four-step evaporation plant with a capacity of approximately 5 t/h is run by an excess pressure of 2 bar, is charged with lye concentrated at 8 °Bé (approximately 5 % lye) and returns lye at a concentration of 40 °Bé (approximately 35 % lye), for the concentration in the mercerising bath to be 28 °Bé.

For the evaporation, approximately 0.3 kg steam per kg vaporised water are needed corresponding to 1 kg steam/kg recovered NaOH at 28 °Bé or 1.85 kg steam/kg NaOH at 40 °Bé. [ 36, ÖKOPOL 2011 ]

The higher the number of stages for evaporation, the more often the heat is reused, the lower the steam consumption and, therefore, the running cost. Investment, however, obviously increases with the number of stages [179, UBA, 2001].

Table 4.57 shows the percentage of alkali recovered at six plants from the data collection in 2016, 2017 and 2018.

Table 4.57: Alkali recovered from mercerising

<table>
<thead>
<tr>
<th>Plant</th>
<th>% of alkali recovered</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2016</td>
</tr>
<tr>
<td>DE030</td>
<td>75</td>
</tr>
<tr>
<td>ES058</td>
<td>95</td>
</tr>
<tr>
<td>PT108</td>
<td>75</td>
</tr>
<tr>
<td>UK127</td>
<td>95</td>
</tr>
</tbody>
</table>

Source: [ 196, TWG 2019 ]

Cross-media effects
Evaporation requires approximately 0.3 kg steam/kg water evaporated in a 4-stage evaporation plant. This corresponds to 1.0 kg steam/kg of recovered NaOH at 28 °Bé or 1.85 kg steam/kg of recovered NaOH at 40 °Bé.

In the case of lye purification with hydrogen peroxide, additional auxiliaries are needed. [ 36, ÖKOPOL 2011 ]

Energy is needed for the evaporation of the weak lye.

Technical considerations relevant to applicability
The technique is applicable to both existing and new installations.

Due to the action of active oxygen generated by the decomposition of hydrogen peroxide it is possible to recover and decontaminate coloured alkali for reuse (hydrogen peroxide is already used in the water stream when applying the oxidative route – see Section 4.4.1).

Economics
Investment costs mainly depend on the plant size and purification technique and typically vary from EUR 200 000 to EUR 800 000 euros. The payback time depends on the plant size and operating time per day. Usually, if mercerisation is practised carried out around 400 hours per year full time, the payback period is less than 1 year. In companies where non-recovered caustic soda lye has to be neutralised with acid, the payback time is less than 6 months. Thus, from the economic point of view, caustic soda recovery may be very attractive [179, UBA, 2001].
In one plant, maintenance costs for curved screens and microfiltration are around EUR 80/week. Investment costs for recovery of 4 000 kg/h of lye are around EUR 330 000 and for 5 700 kg/h around EUR 350 000. [36, ÖKOPOL 2011]

**Driving force for implementation**
High alkali content of waste water and economic aspects of caustic soda losses are the main driving forces [179, UBA, 2001].

**Example Reference plants**
The first caustic soda recovery plant went into operation more than one hundred years ago. Today, there are more than 300 plants in operation worldwide, especially for recovery of caustic soda from woven fabric mercerisation and yarn mercerisation and some from knit fabric mercerisation (the latter process is not applied very often). Plants from the data collection: AT003, BE013, DE030, DE039, DE044, DE047, FR134, IT064, PT108, PT109 and UK127.

Some other example plants are:
- Gebrüder Otto, DE-89165 Dietenheim;
- Brennet, DE-79704 Bad Säckingen;
- Langheinrich, DE-36110 Schlitz.

Main suppliers in Europe are:
- KASAG Export AG, CH-9259 Kaltenbach, Switzerland
- Körting Hannover AG, DE-30453 Hannover, Germany

**Reference literature**
4.5 Dyeing

4.5.1 General techniques

4.5.1.1 Selection of dyes without dispersing agents [with higher bioeliminability in dye formulations]

Ex-Section 4.6.3

Description
Dyes without dispersing agents are used or, where this is not possible, with dispersing agents that are easily biodegradable (e.g. based on fatty acid esters).

Technical description
Dispersing agents (see Section 8.6.3) are present in disperse, vat and sulphur dye formulations (and they are further added in the subsequent steps) to ensure uniform dispersion throughout the dyeing and printing processes. Disperse dyes in powder or granulated form contain 40-60\% (in some cases up to 70\%) dispersing agents, whereas liquid formulations contain 10-30\% (see also Table 2.18 in Section 2.7.8). Usually, in the case of dark shades, no additional dosage of dispersing agents is required, whereas this may be necessary for pale shades. The quantities in vat and sulphur dyestuffs may be similar but precise information is not available.

Nowadays, pre-reduced liquid sulphur dyes without dispersing agents are provided for all kinds of fabric. [36, ÖKOPOL 2011]

The dispersing agents do not have affinity for the fibres and they are therefore found in the final effluent. Due to the significant amounts applied and to their often-low biodegradability/bioeliminability, they contribute to most of the recalcitrant organic load originating from dyeing and printing processes.

In particular, the lignosulphonates and the condensation products of naphthalene sulphonlic acid with formaldehyde, which are widely applied as dispersing agents, show specific COD levels as high as 1 200 O\(_2\) mg/g (for lignosulphonates) and 650 O\(_2\) mg/g (for naphthalenesulphonic acid condensation products). Elimination in biological waste water treatment is insufficient for both products. Thus, they contribute to residual (recalcitrant) COD in treated waste water [179, UBA, 2001].

Improved dispersing agents are now available that can substitute conventional dispersing agents in the dye formulations up to a maximum of 70\%. Two options are possible [179, UBA, 2001]:

Option A (to date only applicable to liquid formulations of disperse dyestuffs): it consists in the
a) Partial substitution of conventional dispersing agents with optimised products based on fatty acid esters
A mixture of dispersing agents is used, where fatty acid esters represent the main components. The dispersing effect of the product is improved compared to conventional dispersing agents, which means that the amount of dispersing agent in the formulation can be significantly reduced. The tinctorial strength of the dye is also improved (from 100\% to 200\%) due to the correspondingly higher concentration of the dyestuff in the formulation ("Grütze, 2000"). [179, UBA, 2001]

Option B (applicable to common dispersing agents in powder and granulate formulations): it consists in
b) Application of dispersing agents based on mixtures of the sodium salts of aromatic sulphonic acids ("Kilburg, 1997").
It is reported that these products are modified compounds of the common condensation products of naphthalene sulphonlic acid with formaldehyde. This chemical modification leads to
higher bioelimination rates because of increased adsorption rate to the biomass. However, they remain non-biodegradable compounds. [179, UBA, 2001]

These dispersing agents can be used both for disperse and vat dyes (solid and liquid formulations).

**Main-Achieved environmental benefits**

Reduction of emissions to water.

**Environmental performance and operational data**

Option a) According to the modified Zahn-Wellens Test (OECD 302 B), bioelimination rates are between 90 % and 93 %. A comparison between conventional disperse dyes and optimised formulations (average values considering the whole dye range) is given in Figure 4.44. Differences in tinctorial strength are taken into account.

![Figure 4.44: Comparison between the composition of conventional and new liquid formulations of liquid disperse dyes, before and after biological treatment](image)

NB: The (%) in the y axis indicates the percentage of dispersing agents related to the overall formulation. **Source:** [179, UBA, 2001]

Option b) Figure 4.45 compares the bioelimination rates of conventional condensation products of naphthalene sulphonate acid with formaldehyde and the modified optimised ones. The degree of bioelimination of the modified dispersing agent is about 70 % (test method according to OECD 302 B) compared to 20-30 % for the conventional one.
Figure 4.45: Comparison of the bioelimination rates of conventional and modified dispersing agents, both based on condensation products of naphthalenesulphonic acid with formaldehyde

**Operational data**

The application of environmentally optimised dispersing agents proposed does not imply changes in the process compared to the application of conventional products.

**Cross-media effects**

None believed likely.

None identified.

**Technical considerations relevant to applicability**

*Option A)* These dispersing agents can only be used for liquid formulations of disperse dyes; there is no restriction regarding the application, but the dyestuff palette is currently limited. Generally, there are no technical restrictions to the applicability of this technique.

**Economics**

Dye formulations containing dispersing agents with improved bioeliminability are in general more expensive than conventional ones [179, UBA, 2001].

**Driving force for implementation**

Environmental legislation.
The improvement of the environmental performance is the main driving force encouraging finishing mills to select dyes containing dispersing agents with a better degree of bioelimination.

Example Reference plants
Many plants in Europe.
Plants from the data collection: AT005, BE011, CZ020, IT064, IT068, IT071, IT072, IT077, IT078, IT089, IT090, PT099, PT105, PT115 and SE120.

Reference literature

4.5.1.2 One-step continuous vat dyeing [in-pastel to pale shades]

Ex-Section 4.6.4

Description
Vat dyes are selected to enable dyeing carried out in one step, without subsequent steaming, oxidising and washing.

Technical description
The conventional pad steam process with vat dyes (see Section 2.7.3) includes the following steps:

- padding of dyestuff pigments;
- intermediate drying;
- padding of chemicals/auxiliaries (reducing agents);
- steaming;
- oxidising;
- washing (several washing and rinsing steps).

In some cases the process can be carried out without steaming and subsequent washing, according to the following simplified sequence (similar to the dyeing process with pigments):

- padding of dyestuffs and chemicals/auxiliaries in one step;
- drying;
- fixation.

Special selected vat dyes with a low tendency to migration need to be used. Moreover, auxiliaries based on polyglycols and acrylic polymers are necessary, which improve pad liquor stability and provide a high fastness level.

Request to TWG: please provide information about the characteristics of the vat dyes which can be used.

Main Achieved environmental benefits
Savings in water, energy and chemicals consumption.

Environmental performance and operational data
A number of steps, in particular the washing operations, are avoided. As a result, only the residual padding liquors have to be disposed of at the end of the process and water consumption is minimised to approximately 0.5 l/kg of textile [179, UBA, 2001].
Savings in chemicals and energy are also obtained.

**Operational data**

A typical recipe for the padding liquor includes [179, UBA, 2001]:

- binder: 30-40 g/l;
- sodium sulphate: 5-10 g/l;
- antimigrant: 10-20 g/l;
- dyestuff: up to 2.5 g/kg.

Among typical process parameters, the pick-up should be is as low as possible (50-65 %) and the liquor temperature should be is kept below 35 °C. Intermediate drying is carried out at 100-140 °C, while thermofixation conditions are typically 30 s at 170 °C for cellulose and 30 s at 190 °C for polyester/cellulose blends [179, UBA, 2001].

**Cross-media effects**

None believed likely.

None identified.

**Technical considerations relevant to applicability**

The technique is suitable for cellulose and cellulose/polyester blends. The applicability, however, is restricted to pastel to pale shades (up to approximately 5 g/l of dyestuff at 50 % liquor pick-up). May not be applicable to dyeing with dark shades.

**Economics**

Significant benefits are achieved compared to the conventional pad-steam method, thanks to savings in energy, time, water and chemicals.

**Driving force for implementation**

Economic benefit is the main motivation for the implementation of this technique. Savings in energy, time, water and chemicals.

**Example Reference plants**

Many plants in Germany and world-wide [179, UBA, 2001].

Plant PT105.

**Reference literature**


4.5.1.3 Minimisation of dye liquor losses in pad dyeing techniques

**Ex-Section 4.6.7**

**Description**

The pad dye impregnation is carried out in a nip or in a trough with a reduced volume. This is combined with an on-line system for individual dosage of dyestuffs and auxiliaries and pick-up measurement devices for preparation of the next comparable batch.

**Technical description**

The main emission sources in pad dyeing processes arise from the discharge of the residual dyeing liquor contained in the pad, pumps and pipes at the end of each lot when a new colour is started (see Chapter 3 for further details about emission and consumption levels).
Reduction of These losses can be achieved by carrying out the impregnation step in a nip (see configuration B in Figure 4.46 below) or by minimising the capacity of the dip trough with, for example, e.g. flex-shaft, or U-shaft systems (see configuration A in Figure 4.46 below).

Figure 4.46: Representation of U-shaft (A) and nip (B) dye liquor application systems

U-shaft is used in semi-continuous dyeing of cotton fabrics with reactive dyes (cold pad-batch). Often the U-shaft is combined with a dosing system and, shortly before the application, dye and alkali solution are mixed together in a static mixer. In that case, the residual liquor is lost because, after mixing of dye and alkali solution, hydrolysis of the reactive dyes starts immediately and recovery for reuse is impossible. [36, ÖKOPOL 2011]

Further reduction of losses can be achieved by the following means of:

- Systems for controlled dosage of the input raw materials. The dyestuff solution and auxiliaries are dosed, based on the specific recipe, and are dispensed as separate streams, being mixed only immediately before being fed to the pad.
- Dosage of the padding liquor based on measurement of the pick-up. The amount of dyeing liquor consumed is measured by reference to the quantity of processed fabric by measuring the length of the fabric times and multiplying it by its specific weight. The resulting values are automatically processed and used for the preparation of the next comparable batch in order to minimise residues of unused dyeing liquor. This system, however, cannot avoid the presence of residual dye liquor in the feeding tank. The rapid batch dyeing technique represents a further improvement in this respect. In this case, rather than prepared in one single step (for the whole batch) before starting the dyeing batch, the dyestuff solution is prepared just in time, in several steps, based on on-line measurement of the pick-up.

See also Section 4.1.6.6.

Main Achieved environmental benefits
- Resource efficiency.
- Reduction of emissions to water.

Environmental performance and operational data
Conventional pad-bath troughs have a capacity ranging from 30 litres up to 100 litres. Changing over to U-shaft troughs (12-litre capacity) will enables a reduction of the residues of unused liquor from 60 % to nearly 90 % per batch, compared to the conventional system. Correspondingly, in the case of nip dyeing (5-litre capacity), up to 95 % reduction will be achieved.
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Separate dispensing of chemicals and colourants avoids unnecessary wastage of raw materials that cannot be considered for further reuse, if already pre-mixed. The preparation of the dye liquor batch based on on-line measurement of the pick-up allows a reduction of the residual dye liquor in the feeding tanks from up to 150 litres down to 5-15 litres, and for very wide fabrics down to 50 litres. [36, ÖKOPOL 2011]

Furthermore, modern dyeing ranges are operated with a minimised flow of rinsing water, which allows an additional 25% water saving.

Operational data

Routine maintenance is essential in order to ensure the precision and proper performance of the equipment. In particular, the precision of the dosage system (e.g. pumps) and pick-up measurement should be checked at regular intervals. In measuring the pick-up, the specific weight of the fabric has to be determined on the fabric before dyeing and not on the raw material before pretreatment.

Cross-media effects

None believed likely.
None identified.

Technical considerations relevant to applicability

The described techniques described are recommended applicable both for new and existing continuous and semi-continuous dyeing machines ranges. However, it is often more convenient to wait and install completely new machinery, where all the recommendations have already been taken into account, rather than upgrading parts of the existing machine [59, L. Bettens, 2000].

Dyeing in the nip is not suitable for light fabrics (below 220 g/m) or fabric with good wettability. With brushed or sheared textiles, the pick-up time may be too short and reproducibility is adversely affected [179, UBA, 2001].

Due to the short contact time with the fabric liquor, dyeing in the nip is not widely used: based on a roller diameter of approximately 20 cm, the filling level for the liquor contact is only 10 cm and the resulting contact time for a conventional production rate of 60 m/min is only 0.1 seconds). [36, ÖKOPOL 2011]

Special attention has to be paid to knit and elastic fabrics.

Economics

The investment cost for an automated dosage system and a volume-minimised trough (e.g. U-shaft) is about EUR 85 000 euros (taking as a reference a width of 1 800 mm). On the other hand, annual savings of EUR 85 000 euros are already achieved in the case of finishing mills performing dyeing 15 batches per day (assuming savings of 50 litres per batch at a cost of the dye liquor cost of EUR 0.5 euros/l). This means a short payback time. [179, UBA, 2001]

Furthermore, the additional benefits are achievable thanks to the reduced volume of waste water to be treated have to be taken into account.

Driving force for implementation

Environmental legislation and savings in raw material.

The restrictions set by environmental legislation (e.g. colour in the effluent) have certainly encouraged mills to apply measures aimed at reducing the emission of concentrated effluent. However, they are not to be regarded as the only driving force. The avoided wastage of expensive raw materials (colourants and auxiliaries) together with the increased reproducibility
(right-first-time) and productivity achieved thanks to improved process control—play an important role in the implementation of this technique.

**Example Reference plants**
In Europe and countries outside Europe, there are about 40 plants successfully operating the described technique. These plants are equipped with the on-line system for individual dosage of dyestuffs and auxiliaries combined with pick-up measurement devices for preparation of the next comparable batch. The rapid batch dosing system for liquid dyes is successfully operating in at least one finishing mill in Europe.

Plants from the data collection: BE011, IT059, IT064, IT065, IT068, PT109, PT115 and UK127.

The rapid batch dosing system is supplied by [179, UBA, 2001]:
- E. Kusters Maschinenfabrik GmbH & Co. KG, division textile, D-47805 Krefeld
- Kleinewefers Textilmaschinen GmbH, D-47803 Krefeld
- Seybert & Rahier GmbH & Co. Betriebs KG, 34376 Immenhausen

**Reference literature**

**4.5.1.4 [Enzymatic] Optimised removal of unfixed dyestuff [after-soaping] in reactive dyeing**

**Ex-Section 4.6.8**

**Description**
Unfixed dyestuff is removed from the textile materials by using enzymes and/or vinyl polymers. This reduces the number of rinsing steps needed.

**Technical description**
Dyeing and printing with reactive dyes entails a number of soaping and rinsing steps to remove from the substrate the amount of unreacted and hydrolysed dye. The removal of all unfixed dyestuff from the fibre is essential for obtaining optimum wet-fastness, while contributing significantly to the energy, water and chemicals consumption of the overall dyeing process.

The suggested technique consists in adopting An enzymatic treatment to removes the non-fixed dyestuff not only from the fibre, but also from the exhausted dye bath. Enzymatic decolourisation of reactive dyestuffs has been proved with Levafix, Remazol, Cibacron, Procion and Synozol types [179, UBA, 2001].

In addition, newly developed products for after-soaping based on vinyl polymers (e.g. poly(vinylpyridine-N-oxide) and poly(vinylpyridine betaine) poymers) prevent renewed uptake of unfixed dyestuff on the fibre in shortened rinsing passages. [ 254, Amin et al. 2015 ]

The number of rinsing baths depends on the depth of shade. Significant savings can be reached for light shades by minimising the number of rinsing baths. [ 36, ÖKOPOL 2011]

The application of the enzymatic compounds usually takes place in the fourth or fifth rinsing step (see Table 4.58 below).
Table 4.58: Comparison of the sequence steps between a conventional and an enzymatic after-soaping treatment (exhaust dyeing)

<table>
<thead>
<tr>
<th>Typical sequence in the case of conventional after-soaping</th>
<th>Sequence in the case of enzymatic after-soaping</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 min overflow rinsing</td>
<td>5 min overflow rinsing</td>
</tr>
<tr>
<td>10 min 40 °C</td>
<td>10 min 40 °C; neutralisation</td>
</tr>
<tr>
<td>10 min 40 °C; neutralisation</td>
<td>10 min 60 °C</td>
</tr>
<tr>
<td>10 min 95 °C</td>
<td>10 min 95 °C</td>
</tr>
<tr>
<td>10 min 95 °C</td>
<td>15 min 50 °C; enzymatic treatment</td>
</tr>
<tr>
<td>10 min 50 °C</td>
<td>10 min 30 °C</td>
</tr>
<tr>
<td>10 min 30 °C</td>
<td></td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001] with reference to "Bayer, 2000"

The application of the products based on vinyl polymers usually takes place in the third rinsing step (see Table 4.59 below). [36, ÖKOPOL 2011]

Table 4.59: Comparison of the sequence steps between a conventional soaping treatment and a soaping treatment with vinyl polymers (exhaust dyeing)

<table>
<thead>
<tr>
<th>Typical sequence in the case of conventional after-soaping</th>
<th>Sequence in the case of optimised after-soaping with vinyl polymers</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 min overflow rinsing</td>
<td>10 min 30 °C</td>
</tr>
<tr>
<td>10 min 40 °C</td>
<td>10 min 70 °C; neutralisation</td>
</tr>
<tr>
<td>10 min 40 °C; neutralisation</td>
<td>10 min 95 °C; treatment with vinyl polymers</td>
</tr>
<tr>
<td>10 min 95 °C</td>
<td>10 min 70 °C</td>
</tr>
<tr>
<td>10 min 95 °C</td>
<td>10 min 30 °C</td>
</tr>
<tr>
<td>10 min 50 °C</td>
<td></td>
</tr>
<tr>
<td>10 min 30 °C</td>
<td></td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001] [36, ÖKOPOL 2011]

**Main-Achieved environmental benefits**
- Reduction of emissions to water.
- Reduction of water consumption.

**Environmental performance and operational data**
As Table 4.58 and Table 4.59 show, one or two of the hot rinsing steps can be avoided when using enzymatic after-treatment or vinyl polymers respectively. In the latter case, overflow rinsing is also avoided. Savings in water, energy and detergent consumption are the main advantages achievable with this technique [179, UBA, 2001].

**Operational data**
The enzymatic treatment is carried out as follows (batch process) [179, UBA, 2001]:
- filling with fresh water (50 °C);
- addition of a buffer for adjusting the pH;
- control of pH (addition of acetic acid, if necessary);
- addition of the enzymatic compound (0.25 g/l);
- running: 10 min;
- draining.

The treatment with vinyl polymers is carried out as follows (exhaust process): [36, ÖKOPOL 2011]
- filling with fresh water (30 °C);
neutralisation with acetic acid to adjust to a pH value of 8;
addition of after-soaping agent (1-3 g/l).

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
The technique is already applicable to exhaust dyeing with reactive dyestuffs. Application to continuous dyeing and printing is currently under development.

Most of the reactive dyestuffs can be enzymatically decolourised. However, a precautionary test on a laboratory scale is recommended.

Economics
Savings in water and energy consumption and reduced process time are among the economic benefits achievable.
No information has been made available about the cost of the enzymatic compounds.

Driving force for implementation
Cost-saving potential and improved quality (higher fastness) of the final product [179, UBA, 2001].

Example Reference plants
Plants from data collection [196, TWG 2019]: IT089 and IT090.
Enzymatic after-treatment is applied in Germany in several finishing mills and world-wide [179, UBA, 2001].

Reference literature
[179, UBA, 2001] [36, ÖKOPOL 2011], [196, TWG 2019], [254, Amin et al. 2015]

4.5.1.5 pH-controlled batch dyeing [techniques]

Ex-Section 4.6.14

Description
For textile materials with zwitterionic characteristics, dyeing is carried out at constant temperature and controlled by gradually lowering the pH of the dyeing liquor below the isoelectric point of the textile materials, which avoids the use of levelling agents.

Technical description
Fibres such as wool, polyamide and silk contain weak acid and weak base alkali groups (e.g. carboxylic and amino functions). Just like the parent amino acids from which all proteins are derived, these fibres show zwitterionic characteristics at pH values close to the isoelectric point (i.e. the pH at which the fibre contains equal numbers of protonated base alkaline and ionised acidic groups).

At a pH below the isoelectric point, the carboxylate anions are progressively neutralised by the adsorption of protons and the fibre acquires a net positive charge (see equation 1):

(1) $\text{H}_3\text{N}^+-(\text{fibre})-\text{COO}^- + \text{H}^+ = \text{H}_3\text{N}^+-(\text{fibre})-\text{COOH}$

Conversely, as the pH rises above the isoelectric point, the fibre becomes negatively charged as a result of the dissociation of the carboxylic acid groups (equation 2) and deprotonation of the amino groups by adsorption of hydroxide ions or other anions as shown below in equation 3:

(2) $\text{H}_3\text{N}^+-(\text{fibre})-\text{COOH} + \text{OH}^- = \text{H}_3\text{N}^+-(\text{fibre})-\text{COO}^- + \text{H}_2\text{O}$
Based on these reactions, fibres with zwitterionic characteristics can be dyed by imposing a pH profile at iso-temperature, instead of a temperature profile at iso-pH.

The dyeing process is started in alkaline conditions, above the isoelectric point. At this pH, the carboxylic groups become dissociated and the anionic charged groups repulse anionic dyes. This makes it possible to control the adsorption of the dye on the fibre by gradually decreasing the pH.

At a low enough pH when the number of cationic charges on the fibre increases, the dye becomes attracted to the fibre via coulombic interactions, which provides additional bonding forces that cannot be broken by thermal agitation.

At iso-pH, part of the carboxylic groups are neutralised and at higher temperatures, the dye can move rapidly and with minimal energy through the fibre.

The main difference between temperature- and pH-controlled dyeing is that in the temperature-controlled dyeing the process is controlled by the dye bath exhaustion and thermal migration of the dye, whereas with a pH-controlled profile the dyeing process is controlled by the adsorption of the dye onto the ionic fibre.

The pH profile can be controlled during the dyeing process either by dosing a strong acid or base or by creating a buffer system during the dyeing process (mixture of a weak acid and their conjugates base or vice versa). Two methods are normally used to generate a buffer system. One method is to dose a weak acid (e.g. acetic acid) starting from an alkaline bath containing a strong base (or a strong acid starting from a weak base); another method consists in using acid or base donors for pH sliding (ammonium sulphate and hydrolysable organic esters are examples of acid donors).

**Main Achieved environmental benefits**
- Reduction of emissions to water.
- Reduction of energy consumption.

**Environmental performance and operational data**

One of the advantages of iso-thermal dyeing is that the use of special organic levelling agents or retarders (typically added to the dye bath to allow even dyeing) can be avoided.

Time and energy use with pH-controlled dyeing is lower than with the temperature-controlled process. Energy is saved because the dye bath (and the machine) do not need to be heated from room temperature up to the migration temperature (above the optimum dyeing temperature). Time is saved because the heating and cooling phases are shorter and no extra time is required for the migration process.

Moreover, this technique offers new opportunities for recycling and recovery of spent dye baths. With a pH-controlled system, the hot spent bath can be recycled as such for the next batch, instead of being cooled down before reuse. This is not possible in a temperature-controlled dyeing system because in that case the dyeing cycle cannot be started at the so-called treatment temperature, but must be started at a lower temperature (e.g. 50 °C) in order to prevent uneven dyeing.

**Operational data**

As stated earlier, the pH steering during batch dyeing can be performed by fitting the machine with dosing systems for acids and alkalis. This is the best and most effective method because it minimises the amount of chemicals consumed to shift the pH. However, precise control of the pH profile with this method is difficult as the pH must be measured continuously and the bath must be fully homogenised. This technique is therefore limited to machines where the goods textile and liquor are well mixed, such as jets and modern carpet winches. Moreover, if a
mineral acid (e.g. sulphuric acid) and an alkali are used, the salt content of the dye bath may increase above acceptable levels when recycling water.

Instead of using pH-measuring instrumentation, another technique is the generation of a pH buffer during the dyeing process. In this case, there is no need to measure the pH in a fully contained system. In fact, pH chemistry and dynamic mass-balancing can predict pH and, more importantly, can create a consistent, repeatable pH profile [171, GuT, 2001]. For these reasons this technique, although more expensive (higher consumption of chemicals) and more polluting (higher organic load in the effluent), tends to be preferred by companies in the sector.

The use of decarbonated water is the best way to ensure optimal pH control, especially when weak acid donors are used (when process water is not decarbonated the acid will be consumed in the formation of CO\textsubscript{2} rather than for shifting the pH of the bath).

The pH-controlled dyeing process is less common for fibres with only basic alkaline or only acidic functional groups. Nevertheless, it is also advantageous for dyeing acrylic fibres with basic-alkaline dyes and in principle it can be used for all types of fibres with ‘neutral pH-dyeable’ reactive dyes.

The referenced technique is generally considered the most valuable technique in batchwise and continuous carpet dyeing and may set an example for other textile products [59, L. Bettens, 2000].

**Cross-media effects**

The application of the proposed technique doesn’t give rise to significant cross-media effects. Consumption of chemicals is a cross-media effect.

In addition however, the thermal splitting of ammonium sulphate releases ammonia to the atmosphere.

**Technical considerations relevant to applicability**

The pH-controlled process is applicable to fibres with zwitterionic behaviour such as wool, polyamide, silk, etc. The technique is commonly applied in uni-dyeing processes, whereas it presents some limitations when blends of fibres are dyed to obtain differential shades (differential dyeing). Here, if the two (or more) fibre types do not have compatible pH-exhaustion and adsorption profiles, dyeing at iso-pH may be preferable.

**Economics**

The bath does not need to be warmed up and cooled down according to a preset temperature profile. The resulting saving in energy and processing time is therefore one major economic advantage of this technique.

Additional benefits in terms of time and energy savings can be achieved when the hot spent dye bath is recycled because the dye liquor can then be reused for the next dyeing cycle without the need to cool it down and warm it up again.

Investment costs, although fairly acceptable, are associated with fitting the dyeing machine with dosing and pH-control units.

No investment is needed cost is required when the pH control takes place via buffer systems or acid/alkali donors.

**Driving forces for implementation**

Time and energy savings are the main driving forces for the implementation of this technique. Moreover, the technique overcomes the limited potential for dye bath recycling often found with temperature-controlled dyeing processes.
Example Reference plants
The technique has been applied by many dyehouses (especially in the carpet sector) since the early seventies.
Plants from the data collection: AT005, BE007, BE008, BE011, CZ015, CZ017, DE034, DE042, DE047, FR133, IT064, IT067, IT068, IT070, IT078, IT089, IT090, IT094, PT098, PT099, PT109, PT115, SE119 and UK124.

Reference literature
[171, GuT, 2001], [59, L. Bettens, 2000]

4.5.1.6 [Equipment]-Optimisation [in]-of batch dyeing

Ex-Section 4.6.19

Description
Optimisation of batch dyeing includes techniques such as:

- maintaining a constant and low liquor ratio;
- separating the exhausted dye bath and the rinsing water;
- mechanical or pneumatic extraction of the liquor from the fabric;
- shortening the dyeing cycle, e.g. by draining and filling baths with pumps, by using tanks to prepare the liquor in parallel with an ongoing cycle, using cooling water for rinsing;
- dispensing dye and chemicals automatically;
- controlling the liquor level and temperature automatically;
- using indirect heating and cooling systems;
- enclosing the dyeing machines.

Technical description
Textile equipment manufacturers are becoming more and more aware of the need to conserve water, chemicals and energy. These are key objectives that new machine technologies help to achieve. Moreover, optimisation of equipment benefits not only environmental aspects, but also process economics.

The liquor ratio is one of the parameters that influence the environmental performance of the batch dyeing processes and, recently, a distinct trend has developed among equipment manufacturers toward reducing bath ratios. Terms like ‘low’ and ‘ultra-low’ liquor ratio are commonly used by equipment manufacturers to define the characteristics of batch dyeing machines (see Section 2.7.8.2 for the definition of these terms).

Moreover, an outstanding feature of modern machines is that they can be operated at an approximately constant liquor ratio whilst being loaded at a level as low as 60% of their nominal capacity (or even 30% of their nominal capacity with yarn dyeing machines). Even small size lots can therefore be dyed at the optimal/nominal liquor ratio. This is particularly important especially for commission companies, which need high production flexibility.

Low-bath-liquor-ratio dyeing machines conserve chemicals as well as water and energy and also achieve a higher fixation efficiency. However, as already explained in other parts of this document (see Section 4.1.3.1), the total water consumption is determined not only by the liquor ratio of the dyeing step, but also by the rinse and wash processes.

The correlation between bath-liquor ratio and total water use is not always exact and factors other than liquor ratio should be taken into account are important when assessing the environmental performance of a batch dyeing machine.
One important factor is the maximum cut-off between different batches and, in particular, the maximum separation between the exhausted dye bath and the rinsing water.

In some modern batch dyeing machines, instead of rinsing by overflow or by draining the bath and refilling the vessel with rinsing water, the textile material is rinsed in a continuous mode in a separate stream, thus avoiding cooling or dilution of the exhausted bath. In this way, the hot exhausted dye liquor and the rinsing waters are kept as separate streams, which allows them to be reused or at least to be treated separately and thermal energy to be recovered.

Moreover, various techniques can be applied in order to increase rinsing efficiency. When applicable, mechanical liquor extraction is a possible method for reducing the unbound water retained by the fabric, which is otherwise carried over by the substrate to the next step. Expression. Suction and blowing air through the fabric are also all available techniques. Vacuum technology is the most efficient, but it is not applicable to all types of fabric and it consumes more energy than expression-mechanical extraction.

Another factor affecting specific water and energy consumption in dyeing processes is the duration of the cycle. Short cycle times mean not only higher productivity, but also a reduction in the electrical and thermal energy consumption. Various techniques can be applied to reduce downtimes in the working cycles. These typically include pumped draining and filling options (see Section 4.1.3.3.1) with pumps, charge tanks (which are used for the preparation of the liquor in parallel with other process operations), combined cooling and rinsing systems, etc. In the latter, the cooling water is passed through the machine heat exchanger during the cooling step and is then fed directly into the jet as hot fresh rinsing water. The quantity of rinsing water can be controlled, depending on the end temperature, the desired rate of cooling and, in some machines, also on the desired quality of rinsing.

Further reduction of the cycle times can be achieved by improving the textile/liquor contact to achieve homogenisation of the bath more rapidly (i.e. by shortening the transition time) after a change in operating conditions (e.g. alkali/dyestuff injection, temperature increase/decrease).

Additional common features of modern batch dyeing machines include the following:

- **Automated systems for chemical and dye dispensing and dyeing cycle control**: this allows improvement of the efficiency and reproducibility of the process. In addition, overuse of chemicals, handling losses and equipment clean-up requirements are reduced.

- **Automatic controllers to facilitate of liquor level and temperature measurement and control**: where machines are equipped only with manual water control valves, there is potential for overfilling and unnecessary wastage of water during filling and rinsing operations. Spillage may also result from excessive boiling during the final stages of dyeing. Modern machines are fitted with process control equipment capable of accurately controlling the level of the liquor and the steam supply.

- **Indirect heating and cooling systems**: indirect heating and cooling is now common practice in modern batch dyeing equipment to overcome dilution and spillage of water.

- **Hoods and doors**: vapour losses can be significantly reduced by full closure of the machines.

**Main-Achieved environmental benefits**

The technological optimisation of dyeing machines described above leads to improved environmental performance in terms of both consumption of resources (water, energy and chemicals) and water pollution. Reduced spillages (overflows) also reduce potential emissions to soil and groundwater.

**Environmental performance and operational data**

These aspects are summarised in the following Table 4.60 below.
Table 4.60: Environmental benefit performance associated with optimisation of batch dyeing machines

<table>
<thead>
<tr>
<th>Aspect/Technique</th>
<th>Basis Conventional technology</th>
<th>Technological improvement</th>
<th>Environmental benefit performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dosing of dyes and chemicals</td>
<td>Manual</td>
<td>Automated, microprocessor-controlled</td>
<td>Reduced spillage, handling and residues of chemicals which are ultimately discharged to water</td>
</tr>
<tr>
<td>Control of liquor level and temperature</td>
<td>Manual</td>
<td>Automated, microprocessor-controlled</td>
<td>Reduced spillage and wastage of water</td>
</tr>
<tr>
<td>Heating</td>
<td>Direct steam, boiling</td>
<td>Indirect heating</td>
<td>Reduced dilution and spillage of water</td>
</tr>
<tr>
<td>Hoods, doors</td>
<td>Open</td>
<td>Fully closed</td>
<td>Reduced energy and vapour losses</td>
</tr>
<tr>
<td>Liquor ratio</td>
<td>Higher</td>
<td>Lower</td>
<td>Reduced use of:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- water in the dyeing step;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- energy to heat the dye bath;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- chemicals in the dyeing step.</td>
</tr>
<tr>
<td>Constant liquor ratio across variable load size</td>
<td>Machine needs to be filled with the same volume regardless of the size of the lot</td>
<td>The machine can maintain a constant liquor ratio whilst being loaded at a level as low as 60 % of its nominal capacity</td>
<td>Maintains the same benefits as those achievable with a low liquor ratio (see above) but at reduced loading</td>
</tr>
<tr>
<td>Sequence of the batches and rinsing operations</td>
<td>Mixed batches</td>
<td>Separate streams (maximum cut-off between different batches)</td>
<td>Avoids contamination of the rinsing water.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Avoids contamination and cooling of the hot dye bath.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Possibility of reuse of the dye bath ((^1)).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Improved treatment of the concentrated streams.</td>
</tr>
<tr>
<td>Rinsing</td>
<td>By overflow or drain and fill techniques</td>
<td>High-efficiency rinsing techniques (e.g. by mechanical extraction)</td>
<td>Reduced water &amp; energy consumption in rinsing operations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower volume of waste water to be handled</td>
</tr>
</tbody>
</table>

\(^1\) In particular, The full separation of exhausted hot bath from rinsing water is especially advantageous when dyeing under pH-controlled conditions. In this case, the hot exhausted bath can be directly reused for making up the next batch because dyeing is started at high temperature (see Section 4.5.1.5).
Source: [171, GuT, 2001]

**Operational data**

Most of the principles techniques described in this section are used for all types of batch dyeing equipment. Indeed, The extent to which the liquor ratio can be reduced depends on the type of substrate to be processed. Nevertheless, today equipment manufacturers can offer, for each substrate, machines with increasingly reduced liquor ratios compared to conventional machines, whilst maintaining the same quality standard of the final product.

Variable according to the type of equipment considered. (More information can be found about different types of equipment for the examples presented in Sections 4.5.1.6.1 to 4.5.1.6.2.2).

**Cross-media effects**

None believed likely.
None identified.
Technical considerations relevant to applicability

Examples of batch dyeing machines where the principles described are applied are reported in Sections 4.5.1.6.1 to 4.5.1.6.2.2. Generally, there are no technical restrictions to the applicability of this technique.

Economics

Variable according to the type of equipment considered (more information can be found for the examples presented in Sections 4.5.1.6.1 to 4.5.1.6.2.2. above).

Driving force for implementation

- High productivity and reproducibility of the process, still remain the main driving forces, followed by
- Savings in water, chemicals and energy consumption.

Example plants

Plants from the data collection: AT005, BE011, CZ015, FR131, FR133, IT059, IT064, IT067, IT068, IT070, IT071, IT072, IT077, IT078, IT082, IT085, IT087, IT089, IT090, IT091, IT092, IT094, IT096, IT097, PT099, PT109, PT114, PT115, SE119 and UK124.

Reference literature

[176, VITO, 2001], [171, GuT, 2001], [177, Comm., 2001], [179, UBA, 2001], [116, MCS, 2001], [120, Brazzoli, 2001], [127, Loris Bellini, 2001].

4.5.1.6.1 [Equipment] Optimisation applied to winch beck dyeing machines

Ex-Section 4.6.20

Description

The principles described in Section 4.5.1.6 are applied to winch beck machines:

- indirect heating and cooling;
- improved liquor/goods contact;
- low and constant liquor ratio;
- extraction of the liquor from the goods by vacuum and reuse of the extracted liquor;
- enclosure with hoods;
- automated dosing and process control systems.

Technical description

Winch beck dyeing machines are described in detail in Section 10.3.1.1 and represented in Figure 4.47 below. In many sectors of the textile industry they have been superseded by other types of equipment (e.g. jet), but winch dyeing still remains an important technology when dyeing in piece voluminous textile pieces such as carpets, upholstery, terry towels and tubular fabrics. In these types of textiles, the softness is determined by the bulk given during dyeing and the winch machine has the advantage of imposing low tension on the fabric while maintaining great mechanical action.

A number of technological improvements have been introduced in this dyeing technique, principally in the following areas [171, GuT, 2001]:

- **Heating:** the liquor in the early winches was usually heated by direct steam injection through a perforated pipe. This system provided both rapid heating and vigorous agitation in the beck, but the dilution effect has to be taken into account. Indirect heating/cooling is now more commonly used to overcome dilution and spilling water.
Chapter 4

- **Liquor/goodstextile contact**: in modern winches both the liquor and the fabric are circulated to improve the liquor/goodstextile exchange. The carpet is cycled-circulated through the dye liquor, which is in turn continually pumped through a drum filter to remove the lint. This circulation system ensures a more rapid homogenisation of the bath and an even distribution of the colour throughout the carpet.

- **Liquor ratio**: recent winch becks operate at liquor ratios that are significantly reduced compared to conventional machines. Moreover, an outstanding feature is that small batches can be dyed with approximately the same liquor ratio as for maximum load.

- **Rinsing**: modern winches are designed to remove the carpet without discharging the bath and to avoid cooling or diluting it the bath with rinsing water. Thanks to the ‘hot-drawing-out system’, the carpet is automatically taken out of the beck and passed over a vacuum extractor which removes the unbound water. The recovered liquor is diverted back recirculated to the dye bath. The carpet is then sprayed and passed over a second suction section where the rinsing water is collected.

In addition to the above, modern winches are fitted with hoods to help maintain temperature and minimise losses. They are also equipped with automated dosing and process control systems for full control of the temperature profile and chemicals injection during the dyeing process.

![Supraflor carpet winch](image)

*Source: [171, GuT, 2001]*

**Figure 4.47: Supraflor carpet winch**

The advanced concept applied in this type of winch beck is that the rinsing step is no longer carried out in batch, but rather in continuous mode in a separate section of the equipment without contact between the substrate and the bath. In this way there is no mixing between the rinsing water stream and the hot exhausted bath, which makes it possible to reuse both streams and to recover the thermal energy.

**Main-Achieved environmental benefits**

The features described above bring about substantial savings in terms of Reduction of water, chemicals and energy consumption.

**Environmental performance and operational data**

Reductions of 40 % to 50 % in fresh water consumption for the total dyeing process (up to 94 % savings in rinsing water) and 30 % in electricity consumption are claimed by the machines’ manufacturers [171, GuT, 2001].
Operational data

Liquor ratios used in carpet winches are typically 1:30 or higher. Recent open-width winch becks operate at liquor ratios of 1:15 to 1:20, depending on the substrate type, loading and fabric construction. A new type of winch beck for open-width dyeing of carpet operates at liquor ratios ranging from 1:9.5 to 1:19 and is used successfully in several installations.

In textile dyeing, liquor ratios for conventional winch becks are typically in the region of 1:15 to 1:25. Recent textile winch becks have a nominal liquor ratio as low as 1:5 to 1:8 (depending on the type of substrate) [171, GuT, 2001].

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
New generation winch becks can replace old machines in all applications where the use of winch becks is still necessary (e.g. bulky textile such as carpets, upholstery, terry-towels). The fundamentals of the new equipment cannot be retrofitted onto existing dyeing machines, which need to be replaced. However, some types of older machines can be upgraded with the special ‘hot-drawing-out system’.

Economics
No information provided—data were made available.

Driving force for implementation
- High productivity and reproducibility of the process, still remain the main driving forces, followed by
- Savings in water, chemicals and energy consumption.

Example Reference plants
Many are in operation in textile finishing industries worldwide. Examples are the Supraflor and the Novacarp Carpet Winch.
Plants from the data collection: BE008, IT059, IT070, IT071, IT072, IT077, IT089, IT090 and PT114.

Reference literature
[171, GuT, 2001]

4.5.1.6.2 [Equipment] Optimisation applied to jet dyeing machines

Ex-Section 4.6.21

New concepts have been introduced in jet machines, which can significantly improve not only the productivity but also the environmental performance of the dyeing process for fabrics that are treated in rope form. Some examples of available techniques are presented in the following sections.
4.5.1.6.2.1 Airflow jet dyeing machines

**Description**
Dyestuffs are injected with air into the fabric which is not in contact with the dye bath.

**Technical description**
Jet dyeing is now a mature technology. There is, however, a fundamental innovation, which is the use of air, either in addition to or instead of water, as the motive force in driving the fabric rope (air-jet).

In the latest development, the fabric is moved by means of moisturised air, or a mixture of steam and air, in the total absence of liquid. The dyestuffs, chemicals and auxiliaries are injected into the gas stream. Liquor ratios of 1:2 may be reached for woven PES fabric, while 1:4.5 is the lowest limit achievable for woven cotton fabric with such air-jet machines.

The following Figure 4.48 below shows that the bath level is always below the level of the processed textile. The fabric no longer stays in contact with the liquor (the bath is below the basket holding the fabric in circulation). This means that the bath conditions can be changed without changing the process phase of the substrate (for example, cooling the bath while the substrate is still at high temperature for prolonged fixation, adding chemicals, interchanging the bath with another one).

![Figure 4.48: Illustration of an airflow dyeing machine with indication of air circulation and injection of the bath](image)

Source: [280, Germany, 2002]

The bath-less dyeing operation is one of the main features of this machine; the other one is the separate circuit for liquor circulation without contacting the textile. By contrast with conventional machines, during the whole rinsing process (see Figure 4.49), the bottom valve is open and the rinsing water, initially sprayed onto the fabric when it enters the jet, is immediately drained without additional contact with the fabric. Thus, rinsing is no longer a batch operation, but instead offers all the potential advantages of continuous processing (time...
saving, possibility of discharging the bath after high-temperature dyeing at 130 °C for optimum heat recovery, maximum cut-off between hot bath liquors and rinsing water, etc.).

**Main Achieved environmental benefits**
Reduced consumption of chemicals, energy and water.

**Environmental performance and operational data**
The extremely low liquor ratio and the continuous rinsing system results in a virtually non-stop process with:

- less energy needed thanks to quicker heating and cooling and optimum heat recovery from hot exhausted dye liquors;
- reduced consumption of those chemicals (e.g. salt) for which dosage is based on the amount of dye bath (about 40 % reduction); [179, UBA, 2001]
- less water (up to 50 % water savings are achieved compared to conventional machines operating at L.R. a liquor ratio of 1:8 to 1:12) [179, UBA, 2001].

In addition, the release of the exhausted dye bath at process temperature and without dilution by rinsing water opens the way for a very efficient and cost-effective degradation of the remaining dyes and other difficult-to-treat auxiliaries, using the advanced radical treatment process ‘ETP & ETF’ (Enhanced Thermal Fenton reaction and Enhanced Photo Fenton reaction).

**Operational data**

Table 4.61 shows specific input data ranges for cotton dyeing with reactive dyestuffs in a conventional jet operating at L.R. a liquor ratio of 1:8 to 1:12 and in the airflow machine described above. The data are derived from measurements taken at production sites.
It is worth adding that the model of airflow described in this section is also designed to maintain its low liquor ratio even with the machine well underloaded.

Table 4.61: Comparison of specific input data for cotton dyeing with reactive dyestuffs in a conventional jet (L.R. liquor ratio 1:8 to 1:12) and in the airflow machine described above

<table>
<thead>
<tr>
<th>Input</th>
<th>Unit</th>
<th>Conventional jet operating at L.R. liquor ratio 1:8 - 1:12</th>
<th>Airflow jet operating at L.R. liquor ratio 1:2 - 1:3 (PES) - 1:4.5 (CO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>l/kg</td>
<td>100-150 (1)</td>
<td>20-80 (2)</td>
</tr>
<tr>
<td>Auxiliaries</td>
<td>g/kg</td>
<td>12-72</td>
<td>4-24</td>
</tr>
<tr>
<td>Salt</td>
<td>g/kg</td>
<td>80-960</td>
<td>20-320</td>
</tr>
<tr>
<td>Dyestuffs</td>
<td>g/kg</td>
<td>5-80</td>
<td>5-80</td>
</tr>
<tr>
<td>Steam</td>
<td>kg/kg</td>
<td>3.6-4.8</td>
<td>1.8-2.4</td>
</tr>
<tr>
<td>Electricity</td>
<td>kWh/kg</td>
<td>0.24-0.35</td>
<td>0.36-0.42</td>
</tr>
<tr>
<td>Time(2)</td>
<td>min</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) Including rinsing.
(2) Including loading/unloading.
(3) The variation in water consumption is to be read as 20 l/kg in the case of PES and 80 l/kg in the case of cellulose. The airflow machine can use as little as 16 l/kg for peroxide bleaching against 32.5 l/kg for a conventional jet and 26.6 l/kg for reactive dyeing/wash-off against 43 l/kg for a conventional jet [176, VITO, 2001].

Source: [179, UBA, 2001]

This machine can be used both for knitted and woven fabric and for nearly all types of fibres. Fabrics containing elastane fibres, which are always difficult to dye, due to dimensional stability, can be dyed successfully using the airflow system.

The technique has been tested approved for silk, but it is rarely applied.

A process has been developed to minimise the oxidation of vat and sulphur dyes by the oxygen in the injected air.

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
Limitations to the use of this machine are found with wool and wool blends with a percentage of wool higher than 50 % because of felting problems. This technique cannot be recommended is not used for dyeing linen fabric because the linen lint causes scaling of the machine.

Existing machines cannot be retrofitted.

Economics
The application of this technique means investment in new equipment.

The cost for one machine ranges from about USD 190 500 to USD 362 000 (2005 value), depending on the number of storage chambers and total capacity, Investment cost for this type of machine is around one third higher than conventional jets, but due to the high significant savings the payback period is relatively short. [179, UBA, 2001] [ 152, Hasanbeigi 2010 ]

Driving force for implementation
- High productivity and reproducibility of the process. still remain the main driving forces,
  followed by
- Savings in water, chemicals and energy consumption.

Example Reference plants
Airflow dyeing machines are in operation in many textile finishing mills worldwide. Bath less airflows, such as the one described in this section, where the textile is moved by air only, are produced by THEN GmbH, D-74523 Schwäbisch Hall. ATYC SA Terrassa Barcelona produces an ULLR airflow (AIRTINT EVO H.T. machine) where the fabric is driven by air and water in separate jets. Other producers of machines using air and water for moving the fabric, with reduced and variable bath (e.g. Thies GmbH, 48653 Coesfeld; MCS, I-24059 Urgnano – Bergamo; Scholl AG, CH-5745 Safenwil).

Plants from the data collection: IT070 and PT099.

Reference literature
[179, UBA, 2001], [176, VITO, 2001], [36, ÖKOPOL 2011][152, Hasanbeigi 2010].

4.5.1.6.2.2 Soft-flow dyeing machines with no contact between the bath and the fabric

Ex-Section 4.6.21.2

Description
Dyestuffs are injected with water into the fabric which is not in contact with the dye bath.

Technical description
This model of jet uses water to keep the fabric in circulation. The concept that distinguishes this equipment from conventional jets operating with a hydraulic system is that the fabric rope is kept in circulation during the entire processing cycle (from loading to unloading) without stopping either the liquor or the fabric circulation for normal ‘drain and fill’ steps.

The principle behind this technique is that fresh water enters the vessel via a heat exchanger and arrives at a special interchange zone whilst at the same time the contaminated spent liquor is channelled to the drain without coming into contact with the fabric or with the new bath in the machine.

Rinsing is carried out in continuous mode, as in the airflow machine described earlier. The rinsing efficiency is increased thanks to the application of a special countercurrent system.

Main achieved environmental benefits
Reduction of water and energy consumption.

Environmental performance and operational data
The features of this machine lead to significant savings in processing time (17-40 %), water (about 50 %) and steam consumption (11-37 %), compared with other soft-flow machines of the same category (see Table 4.62 below). Performance data are reported under “Operational data”.

The efficient separation of the different streams offers further advantages such as optimum heat recovery and the possibility of reuse or dedicated waste water treatment.

Operational data
Table 4.62 shows the results of a comparison that has been made by running the same dyeing procedure on a conventional machine, on a new-generation machine (typified equipped with...
Table 4.62: Comparison of the performance for cotton dyeing with reactive dyestuffs in a conventional machine, a new-generation machine (typified by having charge tanks, pumped drain & fill options and continuous rinsing systems) and the referenced a contactless soft-flow machine

<table>
<thead>
<tr>
<th>Input</th>
<th>Unit</th>
<th>Conventional jet machine</th>
<th>New-generation jet machine</th>
<th>Referenced Contactless soft-flow machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (1)</td>
<td>(l/kg)</td>
<td>82</td>
<td>87</td>
<td>42</td>
</tr>
<tr>
<td>Auxiliaries</td>
<td>(g/kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dyestuffs</td>
<td>(g/kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td>(kg/kg)</td>
<td>3.95</td>
<td>4.84</td>
<td>3.07</td>
</tr>
<tr>
<td>Electricity</td>
<td>(kWh/kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (2)</td>
<td>min</td>
<td>472</td>
<td>341</td>
<td>284</td>
</tr>
</tbody>
</table>

(1) Including rinsing.
(2) Including loading/unloading.
Source: [176, VITO, 2001]

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
Typical applicability of soft-flow machines.
Existing machines cannot be retrofitted.

Economics
The application of this technique means investment in new equipment. No data regarding investment costs for this type of equipment were made available.
No information provided.

Driving force for implementation
Increased productivity.

Example Reference plants
Plants from the data collection: IT070 and PT099.

The machine described in this section is produced by Sclavos (VENUS™ with Aquachron™ process).

Reference literature
[176, VITO, 2001]

4.5.1.6.2.3 Single-rope flow dyeing machines

Ex-Section 4.6.21.3

Description
Only one fabric rope passes through all flow groups and compartments of the rope dyeing machine and returns to the first compartment to complete another lap.

Technical description
The configuration of this jet machine is reported in Figure 4.50. The way in which it handles the fabric and the dyeing cycle is very different from conventional rope dyeing machines. Firstly, there is only one fabric rope which passes through all flow groups and compartments, returning to the first compartment after the lap is complete.
The single rope approach ensures both the optimum uniformity of the system and the repeatability of the results.

High uniformity is achieved because the fabric passes continuously through all the different nozzles and different troughs in each lap. Whilst in multi-rope machines different conditions are generated in each compartment for various reasons (e.g. different speed of the ropes due to different nozzle flows, etc.), the single rope approach ensures homogeneous operating conditions in the system as whole. This also means that the bath reaches equilibrium more rapidly when the operating conditions change (e.g. alkali/dyestuff injection, temperature increase/decrease). An immediate consequence is that chemical injection can be much faster and temperature gradients can be significantly increased without damage to the fibre.

This single-rope technique introduces a new concept in securing allows high repeatability by the use of the number of laps, rather than hold time, for controlling the process. Except for time for fixation, which remains a time-dependent parameter, addition of dyes and chemicals into the machine, temperature increase/decrease, etc. are done over a number of laps, instead of by a preset time. The counting of laps is very easy and ensures that from dye lot to dye lot the fabric always undergoes an equivalent process. Another advantage of the application of this lap-counting approach is that the cycle time is automatically adjusted to the speed of the rope and the load of the machine (the shorter the length of the rope, the lower the machine cycle time).

A lot of the latest time-saving devices are also incorporated, such as power filling and draining carried out with pumping, a full volume heated tank, advanced rinsing programmes, etc.

The machine can maintain a constant liquor ratio (typically 1:6) whilst being loaded at a level as low as 60 % of its nominal capacity.

![Representation of the single-rope dyeing machine](image)

**Source:** [177, Comm., 2001]

**Figure 4.50:** Representation of the single-rope dyeing machine

**Main-Achieved environmental benefits**

Very short cycles and other features described above result in significant water and energy savings (up to 35 %) compared to conventional multi-rope machines.
Environmental performance and operational data

High repeatability and reliability of the final results bring about additional environmental benefits. ‘Right-first-time’ production is one of the most effective pollution prevention measures because it avoids additional consumption and waste of chemicals and resources for corrective measures such as rework, re-dyes, stripping, shade adjustments, etc. A reduction of reworks from 5% to 2% has been observed in companies where this technique is applied [177, Comm., 2001].

Last but not least, the use of a single-rope machine reduces the amount of sewing and cutting at the end of each dyeing cycle. On average, 1-1.5 metres of fabric are wasted for each join. A typical three-rope machine performing three dyeing cycles per day for 300 days/year would waste 2,700 metres of fabric per year more than the same process carried out in a single-rope machine. For a medium-size finishing mill, this is equivalent to about 3,000-4,500 kg/year of wasted fabric [177, Comm., 2001].

Operational data

The Table 4.63 below shows the results of the same dyeing process in a conventional machine (L.R. liquor ratio 1:10 to 1:12), a new-generation machine (typified by L.R. with a liquor ratio of 1:8 and fitted with the latest time-saving devices) and the single-rope machine described above (L.R. liquor ratio 1:6). The data are derived from measurements taken at production sites.

<table>
<thead>
<tr>
<th>Input</th>
<th>Unit</th>
<th>Conventional jet machine</th>
<th>New-generation jet machine</th>
<th>Single-rope jet machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water ((^1))</td>
<td>l/kg</td>
<td>100-130</td>
<td>50-90</td>
<td>30-70</td>
</tr>
<tr>
<td>Auxiliaries</td>
<td>g/kg</td>
<td>15-75</td>
<td>8-40</td>
<td>5-25</td>
</tr>
<tr>
<td>Dyestuffs</td>
<td>g/kg</td>
<td>10-80</td>
<td>10-80</td>
<td>10-80</td>
</tr>
<tr>
<td>Auxiliaries</td>
<td>g/kg</td>
<td>100-900</td>
<td>80-640</td>
<td>60-480</td>
</tr>
<tr>
<td>Steam</td>
<td>kg/kg</td>
<td>4-5</td>
<td>2-3</td>
<td>1.5-2.5</td>
</tr>
<tr>
<td>Electricity</td>
<td>kWh/kg</td>
<td>0.34-0.42</td>
<td>0.26-0.32</td>
<td>0.18-0.22</td>
</tr>
<tr>
<td>Time ((^2))</td>
<td>min</td>
<td>510-570</td>
<td>330-390</td>
<td>210-220</td>
</tr>
</tbody>
</table>

\(^1\) Including rinsing.
\(^2\) Including loading/unloading.

Source: [177, Comm., 2001]

The single-rope machine is used successfully for processing both knitted and woven fabric of nearly all types of fibres. Unless the horizontal model of this machine is used, limitations are observed when dyeing wool, silk and blends of these two fibres.

Cross-media effects

None believed likely.
None identified.

Technical considerations relevant to applicability

Existing machines cannot be retrofitted.

Economics

Investment cost for this type of machine is 20-30% higher compared to new conventional-type machines, but thanks to savings and the higher productivity the payback period can be less than 10 months.
Driving force for implementation

- High productivity and reproducibility of the process. Still remain the main driving forces, followed by
- Savings in water, chemicals and energy consumption.

Example Reference plants

Many are in operation in textile finishing industries world-wide.

The single rope machine described in this section is produced by MCS Urgnano (BG) Italy. Plants from the data collection: IT082, PT114 and UK124.

Reference literature

[177, Comm., 2001], [116, MCS, 2001], [176, VITO, 2001].

4.5.1.7 Water Reuse/recycling of spent baths in batch dyeing processes

Ex-Section 4.6.22

Description

Spent dye baths or spent rinse baths are reused for the next dye bath, after analysis and make-up if needed.

Technical description

Opportunities to minimise water consumption in dyeing processes may be found in dye bath reconstitution and reuse or reuse of the rinse water for the next dyeing.

Dye bath reuse is the process by which exhausted hot dye baths are analysed for residual colourant and auxiliary concentration, replenished and reused to dye further batches. Two procedures are possible:

- With the first method. The dye bath is pumped to a holding tank (or to a second identical machine) while the product is rinsed in the same machine in which it was dyed. The dye bath is then returned to the machine for the subsequent batch of material.
- With the second option. The product is removed from the exhausted dye bath and placed in another machine for rinsing. In this case no holding tank is required, but the material needs additional handling.

Dye bath analysis can be performed using a spectrophotometer and/or may be determined by production experience based on exhaustion level, volatilisation and dye liquor drag-out [11, US EPA, 1995].

Since the spent dye bath is usually hot, it is of course convenient to save time and energy by dye bath reuse. However, to assure level even dyeing it is normally necessary to start the dyeing process at 50 °C. Therefore, the hot spent bath is cooled down and then warmed up again. In some cases, this can be avoided.

New technologies have been developed which allow dyeing to start at process temperatures. Instead of piloting the temperature, one can control the chemical potential of the dye (which is what happens, for example, by adding the sodium hydroxide to reactive dyes) (see Section 4.5.1.5). These techniques are suitable for wool dyeing with acid dyes, acrylic dyeing (this would exclude the addition of levelling agents) and for cotton in the case of sulphur dyeing or reactive exhaustion dyeing processes [204, L. Bettens, 2000].

The second technique proposed here is similar, but this time the spent rinse bath is reused to form the next dye bath.
Main-Environmental benefits

- Reduction in water and chemicals consumption.
- Energy saving (reuse of the hot dye bath) is also possible, in some cases (see above) when dye adsorption is controlled by pH and the bath becomes nearly completely exhausted without cooling down at the end of dyeing.

Environmental performance and operational data

Operational data are have been reported by UBA for a plant dyeing PES and wool loose wool fibre. Wool is dyed with afterchrome or with metal-complex dyes, whereas PES fibre is dyed with disperse dyes. Both dyes are characterised by high exhaustion rates, which allows reuse of the spent dye bath for the next batches. All dyeing machines with a capacity ranging from 50 kg to 100 kg (L.R. liquor ratio of 1:8) have been fitted with holding tanks, temperature and pH control devices and automated dosage systems for formic acid. Most of the holding tanks are constantly used for the same type of dyes and shades (e.g. afterchrome bath for dark shades, etc.). As a result of the improvements, the company has achieved a decrease in specific water consumption from 60 l/kg to 25 l/kg[179, UBA, 2001].

Another operational experience is has been reported by ENco for a mill dyeing loose wool fibre. The company operates conical pan-type machines and loads the fibre carriers with dry fibre. The mean specific water consumption figures for the conventional dyeing and rinse cycle are 9.5 l/kg and 7.8 l/kg, respectively (1.7 l/kg is retained by the fibre load between dyeing and rinsing). The overall water consumption for a conventional cycle would be 17.3 l/kg.

When reusing the rinse liquor for the next dyeing, it is necessary to add on average 1.7 l/kg fresh water to the dye to make up for the water lost when the wet fibre from the previous dyeing is removed. Experience indicates that on average only four cycles of the same shade can be sustained with reuse. The overall water consumption for this four-batch dyeing system is reduced by approximately 33 % when compared with the conventional cycle [32, ENco, 2001].

For reusing water in dyeing processes (both techniques), holding tanks are normally needed to store the spent baths. Some models of modern batch dyeing machines (e.g. jiggers, jets and winches) have built-in holding tanks, thus allowing for uninterrupted automatic separation of concentrates from rinsing water.

When using top-loading dyeing machines (typically used for loose fibre and in some cases for yarn), the rinse bath can be retained in the machine at the end of the process and reused for dyeing the next lot of material without the need for holding tanks.

The reuse of dye baths and rinsing waters involves some fundamental differences from to the use of fresh bath. The easiest systems to manage are dye classes which have high affinity (exhaustion) and which undergo minimum changes during the dyeing process. Examples are acid dyes for nylon and wool, basic dyes for acrylic, direct dyes for cotton and disperse dyes for synthetic fibres. The easiest situation is to reuse a dye bath to repeat the same shade with the same dyes and equipment and the same fibre. Some production planning to progress from pale to deep shades is required needed (which may somewhat limit the flexibility of batch dyeing operations).

The number of reuse cycles is limited by build-up of impurities from several sources. One source is represented by the impurities present on the textile material, which include natural impurities in cotton and wool, knitting oils, fibre preparation agents, etc. Impurities can also accumulate from components of dye formulations, auxiliaries (e.g. levelling agents), electrolytes, salt build-up from addition of acids and bases for pH control, etc.

In conclusion, the limitations are less severe where machinery is available for internal separation of contaminated spent bath and rinsing water, where trichromatic dye systems are used and dye adsorption is controlled by pH (saving the hot dye bath) and where the bath...
becomes nearly completely exhausted without cooling down at the end of dyeing [204, L. Bettens, 2000].

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
Applicable to new plants and major plant upgrades.

Economics
Direct savings are related to both process water purchase price and effluent disposal costs. Prices vary from country to country. UBA reports, for In the case of the first example plant described above, savings of EUR 3.20 euros/m³ have been reported (EUR 0.6 euros/m³ for fresh water, including treatment, and EUR 2.60 euros/m³ for disposal fee). ENco indicates UK costs in the region of 1.09 euros/m³ for town water and average effluent disposal cost of about 1.62 euros/m³ (calculated according to the standard Modgen strength formula) [32, ENco, 2001].

In the same example plant reported by UBA, investment costs for the tanks, piping and control devices amounted to EUR 0.8 million euros [179, UBA, 2001].

Example Reference plants
Many plants in Europe.
Gerhard van Clewe, DE-46499 Dingden [ 36, ÖKOPOL 2011]
Plants from the data collection: BE011, CZ015, FR133, IT071, IT072, IT073, IT077, IT089, IT090, IT091, PT114 and PT115.

Reference literature

4.5.1.8 Optimisation of energy use in dyeing

Description
A set of technical measures identified in the energy efficiency plan (see Section 4.1.4.1) and which allow the reduction of the energy consumed by dyeing.

Technical description
A significant share of thermal energy in dyeing is lost through waste water discharge, heat released from equipment, exhaust gas loss, idling, evaporation from liquid surfaces, unrecovered condensate, loss during condensate recovery, and during product drying (e.g. by overdrying).

The factors which most affect the energy consumption for dyeing are the process temperature, the liquor ratio for batch dyeing, the type of fibre and the machine type.
[ 33, CITEVE 2014 ]

Techniques to reduce energy consumption include the following: [ 152, Hasanbeigi 2010 ]

- Using water for rinsing after dyeing at a reduced temperature of about 50 °C instead of 60 °C.
- Installation of covers or hoods on open batch dyeing machines.
- Avoiding overheating in open batch dyeing machines. The maximum achievable temperature in an atmospheric vessel is 95-100 °C. Once the dye liquor is boiling, further heat input will not raise the temperature, but will increase evaporation. Although a faster
boil does lead to greater agitation of the fabric, this can be achieved more efficiently by installing a circulator. In addition, at temperatures above 80 °C, as much as 15% of uncondensed steam can be lost in the case of direct steam heating with spargers.

- Using cold pad-batch dyeing for cotton fibres (see Section 2.7.3.1). [ 162, Cotton Incorporated 2009 ]

**Achieved environmental benefits**
Reduction of energy consumption.

**Environmental performance and operational data**
Using covers or hoods can reduce evaporative losses by approximately half. Evaporation is particularly important in processes with temperatures above 60 °C. [ 152, Hasanbeigi 2010 ]

Table 4.64 shows the steam used by a jigger for direct heating at different temperature and enclosure conditions. The energy savings are significant.

<table>
<thead>
<tr>
<th>Operating temperature (°C)</th>
<th>Typical steam use (kg/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>Open hood</td>
</tr>
<tr>
<td>90</td>
<td>50</td>
</tr>
<tr>
<td>95</td>
<td>61</td>
</tr>
<tr>
<td>100 (simmer)</td>
<td>73</td>
</tr>
<tr>
<td>100 (vigorous boiling)</td>
<td>91</td>
</tr>
</tbody>
</table>

**Table 4.64:** Steam used by a jigger with different temperature and enclosure conditions (direct steam heating)

Energy consumption can be reduced from about 20.9 MJ/kg of dyed fabric for winch dyeing to under 4.6 MJ/kg of dyed fabric for cold pad-batch dyeing with beam washing (a reduction of over 350%). [ 152, Hasanbeigi 2010 ]

Concerning cold pad-batch, because processing occurs at room temperature, the reaction takes longer than at the higher temperatures used in jet processing. Although the dwell time for the cold pad-batch process is extended, staging of batching rolls in a separate area frees the pad for additional applications. [ 162, Cotton Incorporated 2009 ]

**Cross-media effects**
None identified.

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of this technique.

**Economics**
Table 4.65 shows the capital cost and annual operating savings of cold pad-batch dyeing, which vary depending on the size of the plant.
Table 4.65: Capital cost and annual operating savings of cold pad-batch dyeing

<table>
<thead>
<tr>
<th>Capital cost</th>
<th>USD 1 215 000 (¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net annual operating savings</td>
<td>USD 329 000 to USD 878 000 (¹)</td>
</tr>
<tr>
<td>Payback period</td>
<td>1.4 to 3.7 years</td>
</tr>
</tbody>
</table>

(¹) 2001 value.
NB: Costs and savings are associated with the amount of production and not just for one machine.
Source: based on [ 152, Hasanbeigi 2010 ]

Driving force for implementation
Savings in energy consumption.

Example plants
Plants from the data collection using cold pad-batch dyeing are DE026, IT059, IT064, IT065, IT068, IT094 and PT114.

Reference literature
[ 152, Hasanbeigi 2010 ] [ 33, CITEVE 2014 ] [ 162, Cotton Incorporated 2009 ]

4.5.2 Dyeing of cellulose (cotton) fibres

4.5.2.1 [Dyeing with sulphur dyes] Minimised use of sulphur-based reducing agents

Ex-Section 4.6.6

Description
Dyeing is carried out without using sodium sulphide or hydrosulphite as reducing agents. Where this is not possible, partially chemically prereduced dyes (e.g. indigo dyes) and used so that less sodium sulphide or hydrosulphite is added for dyeing.

Technical description
Sulphur dyestuffs are of great importance worldwide in dyeing cotton in medium to dark shades (especially black) with a high fastness to light and washing. Sulphur dyes are insoluble in water and they need to be converted to the water-soluble ‘leuco-form’ at some stage during the dyeing process (see also Section 9.9).

Conventional sulphur dyes are available in powder form. Before dyeing, they have to be reduced with sodium sulphide in alkaline conditions. Other typical sulphur dyes are the ‘pre-reduced’/‘ready-for-use’ dyes. They are supplied in liquid form and already contain the reducing agent in their formulation (the sulphide content may be higher than 5 % [179, UBA, 2001]).

This technique is especially adopted for indigo dyeing of denim fabrics. [ 162, Cotton Incorporated 2009 ]

Excess of sulphide (from the dyestuff and reducing agent) is responsible for aquatic toxicity and odour nuisances in the (workplace atmosphere) (see also Section 0—‘Sulphur-containing reducing agents’ in Section 2.7.8.1).

The ecological profile of sulphur dyeing has decisively improved thanks to the introduction of new sulphur dyes and alternative reducing agents.

The classic powder and liquid sulphur dyes can be successfully replaced by [179, UBA, 2001]:
Chapter 4

- pre-reduced dyestuffs (liquid formulations with a sulphide content < 1 %); (with reference to “DyStar, 2001”)
- non-pre-reduced sulphide-free dyestuffs (water-soluble in the oxidised form); (with reference to “DyStar, 2001”)
- non-pre-reduced sulphide-free stabilised dispersed dyestuffs (in powder or liquid form); (with reference to “DyStar, 2001”)
- non-pre-reduced sulphide-free dyestuffs (stable suspension) (with reference to “Clariant, 2001”).

Unlike the old sulphur dyes with low reduction potential, all these types of dyestuffs can be used without any sodium sulphide (in the pre-reduced liquid formulations a low amount of sodium sulphide is still present in the formulation). The following binary systems are in use (“DyStar, 2001”):

- combination of dithionite and glucose;
- combination of hydroxyacetone and glucose (seldom);
- combination of formamidine sulphinic acid and glucose (seldom).

Glucose is added to sodium dithionite to prevent over-reduction. Looking at the first list of bullet points, the addition of glucose can be omitted when using stabilised sulphide-free dyestuff formulations (3rd bullet point). With the non-pre-reduced sulphur dyestuffs mentioned at the last bullet point, the reduction step can be carried out with glucose alone (“Clariant 2001”).

Glucose is added to sodium dithionite to prevent over-reduction. Looking at the first list of bullet points, the addition of glucose can be omitted when using stabilised sulphide-free dyestuff formulations (3rd bullet point). With the non-pre-reduced sulphur dyestuffs mentioned at the last bullet point, the reduction step can be carried out with glucose alone (“Clariant 2001”).

In the past, an additional concern associated with sulphur dyeing was raised by the use of sodium dichromate as an oxidising agent (applied to reconvert the dye to the original oxidised insoluble form, after adsorption into the fibre). Sodium dichromate has now been fully replaced by hydrogen peroxide, bromate, iodate and chlorite.

Hydrogen peroxide is the preferred oxidising agent. Bromate, iodate and chlorite are detected as AOX. Nevertheless, they are not organohalogen compounds and they are not likely to give rise to hazardous organohalogen products (only certain chlorite products that contain Cl\textsubscript{2} or use chlorine as an activator are likely to give rise to hazardous AOX).

Main-Achieved environmental benefits
Main environmental benefit resulting from the application of sulphide-low or sulphide-free sulphur dyes in combination with sulphide-free reducing agents is that the sulphide content in waste water is minimised.
Reduced emissions to water.

Environmental performance and operational data
In order to derive the maximum environmental and economic benefit from the proposed technique, it is of primary importance that only the strict amount of reducing agent needed to reduce the dyestuff should be added consumed. Consumption of the reducing agent by the oxygen in the machine is therefore avoided as much as possible. One effective technique to ensure this is to use nitrogen to remove oxygen from the liquor and the air in the machine [183, VITO, 2001].

Operational data
A typical recipe for cotton dyeing on a jet machine (liquor ratio 1:6 to 1:8; dyeing for 45 minutes at 95 °C) is given below [179, UBA, 2001] (with reference to “DyStar, 2001”):

- non-pre-reduced sulphur dye: 10 %;
- wetting agent: 1 g/l;
- caustic soda solution (38 °Bé): 15-20 ml/l;
- soda ash: 8-10 g/l;
salt: 20 g/l;  
glucose: 10-12 g/l;  
sodium dithionite: 8-10 g/l or hydroxyacetone: 4-5 g/l or formamidine sulphinic acid: 4-5 g/l.

The dyestuffs and reducing agents described in this section can be used in existing and new dyeing machines (exhaust dyeing as well as continuous techniques).

Cross-media effects

When using sodium dithionite as a reducing agent leads to the sulphite content in waste water has to be taken into account (see Section 2.7.8.1).

Technical considerations relevant to applicability

The applicability may be restricted by the product requirements as the use of alternative reducing agents may lead to possible differences of shade compared to common sulphur dyeing should be taken into consideration [179, UBA, 2001].

Economics

Stabilised non-pre-reduced sulphide-free dyestuffs are more expensive than sulphur dyes. Detailed information is not available [179, UBA, 2001].

Driving force for implementation

Workers health & safety, odour nuisance and waste water problems related to the presence of sulphides.

Example Reference plants

Many plants in Europe and worldwide. Plants from the data collection: DE022, DE030, DE034, DE045, FR134, IT059, IT064, IT065, IT068, IT094, IT096, PT105, PT108, PT109, PT117 and UK126.

Reference literature


4.5.2.2 Use of concentrated alkali solution [Silicate-free fixation method for] in cold pad-batch reactive dyeing

Description

Concentrated aqueous alkali solutions without sodium silicate are used for fixation of dyestuff.

Technical description

Sodium silicate is often used in cold pad-batch dyeing, mainly to increase the pad liquor stability and to avoid selvage carbonisation. On the other hand, sodium silicate gives rise to a number of problems such as the formation of silicate deposits on the textile surface and on the equipment, increased salt in the effluent, etc.

Silicate-free highly concentrated aqueous alkali solutions have been developed and are now available on the market. They are ready-made products (carefully adjusted mixture of alkali in aqueous solution), which can be easily applied with modern dosing systems. They are particularly suitable for the cold pad-batch process.

Main-Achieved environmental benefits

Reduced emissions to water.
Environmental performance and operational data

The following advantages are achievable:

- no residues of alkali in the preparation tank because, unlike with sodium silicate, the alkali can be added as ready-made solution and does not need to be prepared;
- no formation of difficult-to-wash-off deposits on the substrate and on the equipment;
- no need for additional auxiliaries in the padding liquor to avoid the formation of deposits;
- lower electrolyte content in the effluent;
- possibility of using membrane techniques in waste water treatment (no crystallisation in filters, pipes and valves and no membrane blocking, which is the case with sodium silicate).

Operational data

Membrane pumps such as the sera-pumps with a 4:1 ratio between the alkali solution to and the dyestuffs solution are suitable for the application of the product [179, UBA, 2001].

Figure 4.51 shows a typical dosing curve. Using a curve instead of the conventional alkali addition steps brings additional advantages in terms of increased reproducibility [179, UBA, 2001].

![Dosing curve for ready-made alkali solution](image)

Source: [179, UBA, 2001]

Figure 4.51: Dosing curve for ready-made alkali solution

The ready-made alkali solutions are designed for modern minimum-volume troughs (see Section 4.5.1.1), where the pad liquor exchange time is very short and where extremely long pad liquor stability is not needed. Nevertheless, the absence of sodium silicate affects the stability of the pad liquor. More efficient process control (e.g. temperature control of the dyeing liquor) is therefore required and the corresponding investment costs have to be taken into account.

Cross-media effects

None believed likely.
None identified.
Technical considerations relevant to applicability
The technique is applicable to both existing and new installations. However, for existing installations, additional measures for process optimisation and control may be needed in order to guarantee constant conditions [179, UBA, 2001]. May not be applicable for dyeing with dark shades, where an add-on of silicate to the formulation is needed. [ 36, ÖKOPOL 2011]

Economics
The ready-made alkali solutions are more expensive than the conventional fixation methods and additional process control implies investment costs.

However, the following economic benefits are induced have to be considered [179, UBA, 2001]:
- The investment in advanced dosing systems is lower for the silicate-free method because only two dosing units are needed (one for the dyestuff solution and one for the ready-made alkali solution), while with the conventional fixation methods based on silicate, three dosing units are required (one for the dyestuff solution, one for the silicate and one for the alkali). The investment cost for one dosing unit is around EUR 12 000 euros.
- There is no need to change the rubbers of the padder at short time intervals because of silicate deposit formation. The cost for removing the rubber of a padder is estimated at around EUR 7 000-10 000 euros.
- The lower electrolyte content of the liquor reduces the substantivity of the hydrolysed dyestuffs, which is therefore easier to wash off. This results in lower energy and water consumption in the washing-off step of the process.
- higher The productivity of the padders and washing ranges is higher.
- There is a better reproducibility of the process thanks to monitored process conditions.

In conclusion, a reduction of the total process costs is achieved, compared to the conventional fixation methods.

Driving force for implementation
Among the main driving forces it is worth highlighting [179, UBA, 2001]:
- better reproducibility
- reduction of total process costs
- easy handling of the product (possibility of having the alkali in liquid form and dosable in the required concentration without crystallisation problems)
- no deposits and better washing-off behaviour
- possibility of using membrane techniques for waste water treatment.

Product quality and reproducibility of the process.

Example Reference plants
In Europe there are many finishing mills applying ready-made alkali solutions. Some example plants are Miroglio in Italy, T.I.L., F Lyon in France, Riedel & Tietz Textil GmbH, DE 09242 Limbach Oberfrohna in Germany and Fussenegger, A-Dornbirn in Austria.

Plants from the data collection: FR131, IT059, IT070, IT094 and PT114.

Reference literature
[179, UBA, 2001] [36, ÖKOPOL 2011]
4.5.2.3 Use of high-fixation polyfunctional reactive dyestuffs

Ex-Section 4.6.10

Description
Use of polyfunctional reactive dyes with more than one reactive functional group. These dyes require a lower salt concentration.

Technical description
One of the main objectives of research & development studies is the development of reactive dyes with the greatest possible degree of fixation (see also Sections 9.8 and 0 – “Dyes”). Bifunctional (polyfunctional) reactive dyes, containing two similar or dissimilar reactive systems, offer very high levels of fixation in exhaust dyeing. Because of their two reactive groups, bifunctional reactive dyes have an increased probability of chemical reaction with cellulose fibres compared to monofunctional dyes with one reactive group. If one of the reactive groups hydrolyses during the dyeing process, the other one can still chemically react with the hydroxyl groups of cellulose. Moreover, combining two reactive systems in the same dye delivers the advantages of the two individual groups (e.g. high degree of fixation with high fastness levels and wash-off). However, polyfunctional dyes are not necessarily better. Only the right combination of reactive groups makes them superior to conventional monoreactive dyes.

Examples of these high-fixation dye ranges are [179, UBA, 2001]:
• Cibacron FN (exhaust warm) (Ciba)
• Cibacron H (exhaust hot) (Ciba)
• Drimarene HF (Clariant)
• Levafix CA (Dystar)
• Procion H EXL/XL+ (Dystar)
• Sumifix HF (Sumitomo).

Figure 4.52 illustrates two examples. The first has two monofluoro-triazine reactive groups bridging the chromophore; the second (reactive black 5) has two vinyl sulphone reactive groups. There are also reactive dyestuffs with two different reactive groups.
Main-Achieved environmental benefits
The immediate consequence is a significant Reduction of unused dyestuff ending up in the waste water stream (reduced colour and organic load).

Environmental performance and operational data
The fixation of a reactive dye with cellulose can be expressed either as a percentage of the total dye applied (fixation rate, sometimes also called ‘absolute fixation’) or as a percentage of the dye exhausted (exhaustion rate, sometimes also called fixation efficiency). In the case of monofunctional dyes, the fixation rate is approximately 60 % (with an exhaustion rate of about 70 %), so which means that 40 % of the dye applied is lost in the effluent. In the case of bifunctional reactive dyes, an 80 % fixation rate and over 90 % exhaustion rate is achieved.

This is particularly advantageous when advanced oxidation techniques are applied to treat the dye in the effluent (see Section 4.1.7.3.4.1). It has to be noted, however, that a lower amount of dye in the effluent does not necessarily produce a reduction in visual colour. The tinctorial strength of new reactive dyes has significantly improved. This means that deeper and more intense shades are possible with less dye than necessary with other dyes or dye classes. Less dye is therefore left in the effluent, but visual colour may be still high [190, VITO, 2001].

With new those dyes, (and processes) there is also potential for water, energy and chemicals savings. For example, the recently introduced Levafix CA dyes (Dystar) reach more than 90 % fixation with moderate salt quantities.

Post-rinsing to obtain the required level of wet-fastness can be performed quickly and with relatively little energy and water. This is partly a consequence of the high fixation yield of the new bifunctional dyes (only a small amount of unfixed dye needs to be washed off). More important, however, is the fact that some new reactive dyes have molecules especially designed to show reduced affinity when they are in the hydrolys ed form, which means that they have excellent wash-off properties.

An recent innovation from Dystar (Procion XL+ dyes) allows much A shorter processing time may be obtained on certain substrates by combining the pretreatment and dyeing steps using polyfunctional dyes that fix at 90 °C. Savings of up to 40 % in water and energy consumption and more than 30 % of salt are claimed.

Operational data
To facilitate selection and application, dye manufacturers introduced small dye ranges each comprising highly compatible dyes with virtually identical behaviour in the dye bath. Each of these compact ranges is geared to specific application segments. Also, dyeing compatibility matrixes are provided. This is important in order to obtain high reproducibility, low dependency on dyeing conditions (e.g. liquor ratio, dyeing temperature, salt concentration) and therefore ‘right-first-time’ dyeing.

High-fixation reactive dyes can be applied in all types of dyeing machines, but offer a particular advantage on the most modern low-liquor-ratio dyeing machines fitted with multi-task controllers where additional advantages in terms of reduced energy and water consumption can be exploited [179, UBA, 2001]. In particular, new reactive dyes with very good solubility can be applied at ultra-low liquor ratios [190, VITO, 2001].

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.
Economics
Compared to conventional reactive dyes, polyfunctional reactive dyestuffs are more expensive per kilogram, but the higher fixation efficiency, the savings on salt usage and the reduced water and energy consumption lead to a significant reduction of the total cost.

Cost savings are achieved by the application of the new dyes, especially for dark, problematic dyes, e.g. royal blue, with regard to the following parameters:

- salt content: - 20 %
- amount of alkali: - 20 %
- fixation temperature: - 5 %
- low liquor ratio: 1:8
- exhaust and fixation time: - 15 minutes.

[36, ÖKOPOL 2011]

Driving force for implementation
Environmental legislation.
The introduction of legislation restricting colour in the discharged effluent has been the main driving force for the development of high fixation dyes. Another important drive is the Reduction of total processing costs achievable thanks to high dye fixation [179, UBA, 2001].

Example Reference plants
Many plants in Europe.
Plants from the data collection: CZ019, DE051, FR133, IT059, IT064, IT065, IT067, IT068, IT070, IT077, IT078, IT087, IT094, IT096, IT097, PT099, PT114, PT115 and UK124.

Reference literature
[179, UBA, 2001], [190, VITO, 2001], [180, Spain, 2001], [36, ÖKOPOL 2011].

4.5.2.4 Exhaust dyeing with low-salt reactive dyes

Ex-Section 4.6.11

Description
Use of reactive dyes with a reduced concentration of salt.

Technical description
Traditionally, exhaust dyeing of cellulosic fibres with reactive dyestuffs required high amounts of salt to improve exhaustion (usually 50-60 g/l, but also up to 100 g/l for dark shades - see also Sections 2.7.3 and Section 2.7.8.1 — “Salt”). Several dye manufacturers have developed innovative dye ranges and application processes that only need about two thirds of this quantity. Examples are:

- Cibacron LS (Ciba)
- Levafix OS (Dystar)
- Procion XL+ (Dystar)
- Sumifix HF (Sumitomo).

Most of these dyes are polyfunctional dyes and offer a very high level of fixation (see Section 4.5.2.2), thus bringing the added benefit of a reduced amount of unfixed dye in the effluent.

Because of the reduced amount of salt needed for their exhaustion, low-salt dyes are more soluble and can be kept in solution at a higher concentration than necessary for low-liquor-ratio dyeing machines. This offers further possibilities for reducing the overall salt quantity, as illustrated in the following Table 4.66 below.
Table 4.66: Quantities of salt required for dyeing 1 000 kg of fabric to a medium depth of shade

<table>
<thead>
<tr>
<th></th>
<th>Winch (L/R liquor ratio 1:20)</th>
<th>Jet (L/R liquor ratio 1:10)</th>
<th>Low L/R liquor ratio jet (L/R liquor ratio 1:5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional reactive dyes (salt 60 g/l)</td>
<td>1 200 kg</td>
<td>600 kg</td>
<td>300 kg</td>
</tr>
<tr>
<td>Low-salt reactive dyes (salt 40 g/l)</td>
<td>800 kg</td>
<td>400 kg</td>
<td>200 kg</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Main-Achieved environmental benefits

Lower salinity of emissions to water and reduction of chemical consumption.

Environmental performance and operational data

Salt consumption for exhaust dyeing of cellulose fibres is reduced by about one third of the quantity needed for conventional reactive dyestuffs, with positive effects on effluent salinity and smooth running of waste water treatment units [179, UBA, 2001].

Low-salt reactive dyes are high-affinity dyes, which makes them less easy to wash off than low- or medium-affinity types. However, dyes with low affinity in the hydrolysed (unfixed) form are increasingly available, making post-rinsing operations much easier.

Operational data

The lower the salt concentration, the more sensitive the system becomes to any change in parameters that influence exhaustion. To give the dyer the high flexibility needed, dye manufacturers have developed trichromatic combination dyes with high mutual compatibility (by matching the affinity and reactivity of each dye and minimising interactions among components). Products with very similar application properties are now available, which makes them little affected by (or virtually insensitive to) changes in dyeing conditions. Right-first-time production is claimed (for example, with Cibacron LS) even when batch sizes and liquor ratio vary widely, as for example when dyeing blends such as polyester/cotton [190, VITO, 2001].

Individual manufacturers provide comprehensive technical information for their low-salt dye ranges, including detailed salt recommendations according to depth of shade, type of substrate, equipment in use, etc.

The most impressive main feature of advanced reactive dyes is the mutual compatibility of the dyes included in each dye range (matching the affinity and reactivity of each dye and minimising interactions among components). Thanks to sophisticated molecular engineering techniques, it has been possible to design reactive dyes which have the optimum profile required to maximise the right-first-time production. They exhaust at very similar rates. Curves plotted for each dye colour by temperature and time can be laid over one another with practically no variation. This is important in order to obtain high reproducibility, low dependency on dyeing conditions (e.g. liquor ratio, dyeing temperature, salt concentration) and therefore right-first-time dyeing.

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability

Generally, there are no technical restrictions to the applicability of this technique.
Low-salt reactive dyestuffs are applicable to both existing and new dyeing equipment, but offer particular advantage in the most modern low liquor ratio dyeing machines where additional advantages of reduced energy and water consumption can be exploited [179, UBA, 2001].

Economics

Low-salt reactive dyes are significantly more expensive than conventional reactive dyes (mainly because of the sophisticated molecular engineering techniques applied in their manufacture). However, depending on the special circumstances of each dyehouse, the application of low-salt dyes can be of economic benefit.

Driving force for implementation

- Water scarcity.
- Environmental legislation.
- Salt-induced corrosion.

Low-salt reactive dyes were introduced first in areas having arid climate conditions and negative water balance (e.g. North Carolina in the US and Tirupur, Tamil Nadu in India). They have also been successful in regions where dyehouses discharge directly to fresh water and there is a need to minimise salination effects.

Moreover, it should not be forgotten that corrosion caused by the presence of salt is the main cause of failure in water recycling.

Example Reference plants

Many plants in Europe.

Plants from the data collection: IT059, IT064, IT065, IT067, IT068, IT070, IT078, IT082, IT085, IT087, IT092, IT094, IT096, IT097, PT099, PT114 and PT115.

Reference literature

[179, UBA, 2001], [190, VITO, 2001], [180, Spain, 2001], [61, L. Bettens, 1999], [36, ÖKOPOL 2011].

4.5.2.5 Omitting the use of detergents in Optimised rinsing [afterwashing] of cotton dyed with reactive dyes

Ex-Section 4.6.12

Description

Rinsing after dyeing with reactive dyes is carried out at a high temperature (e.g. up to 95 °C) and without using detergents. The heat of the rinsing water is recovered.

Technical description

Both international literature and practical experience in textile mills show that detergents do not improve removal of hydrolysed reactive dyestuffs from the fabric.

On the contrary, high temperatures do have an affect impact on rinsing effectiveness. Tests carried out with rinsing at 90-95 °C have shown that rinsing is more effective and faster at high temperatures. About 30 % more unfixed hydrolysed reactive dyestuff is rinsed out after 10 minutes of rinsing at 95 °C than at 75 °C.

The high degree of fixation and good wash-off properties typical of some new low-salt, polyfunctional reactive dyes (see Sections 4.5.2.2 and 4.5.2.4) are important factors that help to obtain sufficient wash fastness with hot rinsing without the need for detergents.

Many dyehouses already carry out hot rinsing and omit the use of detergents in rinsing after reactive dyeing. The product quality is not negatively affected. On the contrary, most
usually the fastness of the goods is better after the hot rinsing than after the traditional rinsing with detergents, complexing agents and neutralisation in the first rinse.

Energy should be recovered when using large volumes of hot process water. Energy reclamation can be recovered done either by heat exchange between the hot outgoing process water and the cold incoming clean fresh water or by reclamation of the hot water and reuse of both energy and water.

Chemicals to decompose reactive dyes are not used in the washing process, because they destroy the dye. If degradation is intended, surfactants are needed to transport the hardly soluble dye fragments off the fibre and out of the washing bath. This is especially the case for discontinuous processes like jet or jig processes.

For continuous and semi-continuous processes, surfactants are not commonly used, because the dye formulations already contain tenside components (in this case the use of hard water influences the washing process positively). [ 36, ÖKOPOL 2011 ]

**Main-Achieved environmental benefits**
The main benefit is the reduction in consumption of detergents and pollutant load discharged to the waste water. Obviously, the potential for reduction will vary according to the existing dyeing procedure at the company.

**Environmental performance and operational data**
The experience of two dyehouses (one mainly dyeing knitted fabrics and the other dyeing garments) shows that the average potential load reduction can be in the order of 1 kg detergent, 1 kg complexing agent and 1 kg acetic acid per 100 kg of textile.

However, acetic acid is still used if the following finishing step is softening or adding crease resistance. [ 36, ÖKOPOL 2011 ]

Additional advantages are the savings achievable in the amount of chemicals consumed to destroy reactive dyes by free radical treatment processes. In the Fenton reaction for example, since the OH radicals react very fast not only with the dyestuffs but also with many detergents, a large amount of expensive $\text{H}_2\text{O}_2$ can be saved by omitting avoiding the use of detergents.

**Operational data**
It has been reported that difficulties might arise with accidental stops of the machinery. In such conditions, the high temperature of the rinsing water could cause irreversible cleavage of the bond between the reactive groups of the dye and the hydroxyl groups of cotton or viscose [297, Germany, 2002].

**Cross-media effects**
Substituting cold rinsing with hot rinsing leads to higher energy consumption, unless thermal energy from the rinsing effluent is recovered.

**Technical considerations relevant to applicability**
The application of this technique may involve a change in the type of dyes employed. Generally, there are no technical restrictions to the applicability of this technique.

**Economics**
The only change in operating procedures is to omit avoid the addition of detergents. Savings will depend on the number of reactive dyeings carried out at the company.

**Driving force for implementation**
- Savings in chemicals consumption.
- Environmental legislation.
High costs for chemicals and waste water treatment.

Example Reference plants
A Danish textile mill has during the last 5 years totally omitted the use of detergents in the rinsing process after reactive dyeing. The company treats knitted and woven goods made of cotton or cotton/PES and dyes them in all colours and shades. The referenced company works with bifunctional reactive dyes as Cibachron C or Bezaktiv S. Soft water is used.

Another textile mill dyeing garments of knitted and woven fabric has not used detergents during the last 5–6 years, apart from a few exceptions (i.e. red, dark red or bordeaux colours).

Many plants in Europe. In particular, a few examples of plants applying this technique in Denmark are: Kemotextil A/S, Sunesens Textilforædling ApS, Martensen A/S.

Plants from the data collection: FR131, IT064, IT068, IT077, IT078, IT089, IT090, IT091, PT099 and PT111.

Reference literature
[78, Danish EPA, 1999], [7, UBA, 1994], [36, ÖKOPOL 2011].


“Reclamation and reuse of process water from reactive dyeing of cotton”. Desalination 106 (1996) 195-20

4.5.2.6 [Alternative process for continuous (and semicontinuous) dyeing of cellulosic fabric with reactive dyes] Steam fixation

Ex-Section 4.6.13

Description
The reactive dyes are fixed with steam, which avoids the use of chemicals for fixation.

Technical description
The technique consists of referenced is a continuous dyeing process for cellulose fibres that uses selected reactive dyestuffs and which requires no additional substances such as urea, sodium silicate and salt, or long dwell time to fix the dyes, unlike the conventional pad/continuous dyeing systems, it requires no additional substances such as urea, sodium silicate and salt, or long dwell time to fix the dyes. The recipe includes: x g/l dye 1, y g/l dye 2, z g/l dye 3, 1-2 g/l wetting agents and alkali but the other auxiliaries normally used in a conventional process are replaced here by ensuring operating with a controlled steam content during drying.

The dye liquor is applied to the textile using a padder (cotton is squeezed to about 70 % pick-up and viscose to about 80 %) and, after a short passage through air, the fabric is fed directly to the dryer (hot-flue), where it remains for 2 minutes.

In the conventional process, urea is used as solvent for the dye in the dryer heat. Urea melts at 115 °C and binds water above 100 °C, thus allowing penetration of the dyestuff in the fabric during fixation in the steamer. With the referenced alternative process, this is not needed because the conditions in the dryer are set (120 °C and 25 vol-% steam content) so that the fabric remains at a specific temperature of 68 °C as long as it is damp.

Since highly reactive dyes are used, only a low fabric temperature (68 °C), a weak alkali and a short time (2 minutes) are needed for fixation.
Main-Achieved environmental benefits
Reduction in chemicals consumption and reduction of the pollutant load in the waste water.

Environmental performance and operational data
A significant reduction in chemicals consumption is possible, as shown in Figure 4.53.

Source: [180, Spain, 2001]

Figure 4.53: Basic chemicals consumption per 10 million metres with pad-dry-pad-steam, pad-batch, pad-dry-thermofix and the reference technique-steam fixation

No urea, salt (chloride/sulphate), or sodium silicate is consumed and the alkalinity is often lower (less NaOH, due to substitution with Na$_2$CO$_3$ depending on the selected dyes).

One company operating a three-shift system for dyeing continuously by the pad-dry-thermofix process or the pad-dry-pad-steam process, at a rate of 40 m/min, would consume approximately 423 t/yr of urea or 540 t/yr of NaCl. On the other hand, a company operating the referenced alternative technique on a three-shift basis would consume only 22 t/yr of sodium bicarbonate, which ends up in the effluent. In conclusion, the waste water from washing contains only 4-5 % of the chemical load produced by other dyeing processes carried out in accordance with the latest technology [190, VITO, 2001].

The elimination of urea, in particular, results in a lower amount of nitrogen-containing compounds in the waste water and avoids the presence of urea breakdown products in the exhaust air, typically found in pad-thermofix processes.

The absence of salt is advantageous not only because it results in a lower salt load in the final effluent, but also because without salt the unfixed dye is easier to wash off (less water and energy consumption in post-rinsing operations). In addition, dyes that have low substantivity in the hydrolysed form are now employed, which show very good washing-off properties.
Due to less add-on of chemicals and salts, water recycling is easier. [36, ÖKOPOL 2011]

In addition, energy consumption is minimised through control of the exhaust air.

**Operational data**

The temperature and humidity profile during the fixation process is illustrated in Figure 4.54 below.

![Figure 4.54: Fabric temperature and humidity during the dyeing process using the referenced technique steam fixation](image)

Source: [180, Spain, 2001]

A dampening unit is used during start-up of the machine in order to ensure that ambient conditions in the chamber of the dryer are set at 25 vol-% steam content.

Sometimes, the amount of water released from very lightweight fabrics is not enough to keep the chamber at 25 vol-%. In this case, the steam injector is used to spray in the required amount of steam.

It has to be stressed that maximum performance is obtained only with the right choice of fabric pretreatment and well-engineered selected dye formulations.

In addition to high versatility and applicability to a wide variety of fabrics, a number of benefits are achieved in terms of fabric quality compared with other dyeing techniques. These include for example [180, Spain, 2001]:

- soft handle due to mild fixing conditions;
- migration minimised by rapid fixation and humidity control (especially important on pile fabrics, where rub fastness is improved due to less dye migration to the tips);
- improved penetration of in difficult fabrics (compared to pad-thermofix) due to the presence of humidity at high fabric temperatures;
- improved coverage of ‘dead cotton’ compared to pad-batch or exhaust dyeing;
- dyeing PES/viscose and PES/CO blends in a single bath with excellent results.

**Cross-media effects**

None believed likely.

None identified.
Technical considerations relevant to applicability
The process itself is simple and ideal for both small and large batches. It is an economically viable option for dyehouses that are reinvesting.
This process is limited to dyeing processes with defined reactive dyes and defined textures of the fabrics, not, for example, for high-grade dyeing of PES/CO working clothes. [36, ÖKOPOL 2011]

Economics
No IR pre-dyer is needed, unless heavy fabric is being dyed. Nevertheless, the initial investment cost for new hot-flue is around EUR 0.75 million, excluding the cost of an automatic dye kitchen [190, VITO, 2001]. This investment cost, however, is compensated by huge savings in chemicals, energy, flexibility, higher productivity and environmental improvement (less emissions to air or waste water pollution to treat).

The lower chemicals costs arise from the avoidance of sodium silicate, sodium chloride and urea in the dyeing recipe. In many cases, the dye consumption is also reduced compared with the other processes such as pad-batch. This is illustrated in the example reported in Table 4.67 below.

Table 4.67: Comparison between a conventional pad-batch process and the referenced alternative technique applied to mercerised 100 % cotton twill, 300 g/m, 75 % pick-up

<table>
<thead>
<tr>
<th></th>
<th>Pad-batch/sodium silicate method</th>
<th>Referenced Alternative technique</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levafix Yellow CA</td>
<td>15.0 g/l</td>
<td>13.7 g/l</td>
<td>-8.7</td>
</tr>
<tr>
<td>Levafix Red CA</td>
<td>12.0 g/l</td>
<td>11.6 g/l</td>
<td>-3.3</td>
</tr>
<tr>
<td>Levafix Navy CA</td>
<td>10.4 g/l</td>
<td>10.1 g/l</td>
<td>-2.9</td>
</tr>
<tr>
<td>Total dye</td>
<td>37.4 g/l</td>
<td>35.4 g/l</td>
<td>-5.3</td>
</tr>
<tr>
<td>Urea</td>
<td>100 g/l</td>
<td>0 g/l</td>
<td>-100</td>
</tr>
<tr>
<td>Wetting agent</td>
<td>2 g/l</td>
<td>2 g/l</td>
<td>0</td>
</tr>
<tr>
<td>Sodium silicate 38 °Bè</td>
<td>50 ml/l</td>
<td>0 g/l</td>
<td>-100</td>
</tr>
<tr>
<td>Caustic soda 50 % (')</td>
<td>14 ml/l</td>
<td>6 ml/l</td>
<td>-57</td>
</tr>
<tr>
<td>Sodium carbonate (')</td>
<td>0 g/l</td>
<td>10 g/l</td>
<td>+100</td>
</tr>
<tr>
<td>Total chemicals</td>
<td>166 g/l</td>
<td>18 g/l</td>
<td>-89</td>
</tr>
<tr>
<td>Dwell time</td>
<td>12 hours</td>
<td>2 minutes</td>
<td>-99.7</td>
</tr>
</tbody>
</table>

(') Differences in operation (depending on the selected dyes) may allow full substitution of caustic soda and sodium carbonate with sodium bicarbonate (lower alkalinity).
Source: [180, Spain, 2001]

The increased productivity obtained by the elimination of long batching times produces significant savings in comparison to the traditional pad-batch process. Despite the much lower machinery costs for pad-batch equipment, this alternative process has shown to be more cost-effective in terms of total processing costs. Moreover, the demand for rapid response by the industry can be met more easily. Not having to wait until the next day to view shades means a much improved service and a faster delivery to the customer.

However, in Europe, this process has only been established where at the time of investment the size of orders justify a new large-scale plant investment. [36, ÖKOPOL 2011]

Driving force for implementation
Minimised chemicals consumption, sustainable clean technology, market share, growth.

Example Reference plants
The referenced technique is available commercially under the name of Econtrol®, which is a registered trademark of DyStar.
Plants in Spain, Belgium (UCO Sportswear), Italy, Portugal, China, Turkey, India, Pakistan and Korea are operating with the Econtrol® process, are using this technique.

Reference literature
[180, Spain, 2001], [190, VITO, 2001], [36, ÖKOPOL 2011].

4.5.3 Dyeing of keratine (wool) fibres

4.5.3.1 Chromium-free dyeing of wool

Description
Chrome dyes are substituted by reactive or acid dyes.

Technical description
Concerns associated with the use of sodium (or potassium) dichromate as mordant in wool dyeing with chrome dyes are already discussed in ‘oxidising agents’ in Section 2.7.8.1 (‘oxidising agents’). Low-chrome dyeing techniques (see Section 4.5.3.1) allow a considerable improvement in the efficiency of this process, but they cannot avoid the presence of free chromium in the water effluent and in the sludge.

Furthermore, many initiatives discourage the use of chrome mordant dyes (e.g. OSPAR, GuT, EU Ecolabel).

Furthermore, sodium and potassium dichromate are listed in Annex XIV to the REACH Regulation and the use of these substances is therefore subject to authorisation (see Section 2.7.4.2).

Until recently, the use of chrome dyes was considered unavoidable for certain types of wool articles, in particular for dark shades, due to the excellent wet-fastness of these dyes. However, reactive dyestuffs have been put on the market that can provide levels of fastness comparable with those achievable with chrome dyes, even for dark shades.

These new colourants are bifunctional reactive dyestuffs generally containing bromo-acrylamide or vinylsulphone reactive groups. The structure of a typical bifunctional reactive dyestuff of the bromo-acrylamide type is shown in Figure 4.55. The dye range is based on a trichromatic system, where Yellow CE (or Golden Yellow CE), Red CE and Blue CE can be used as the basis for the coloured shade area, and Navy CE and Black CE as the basis for highly fast navies and blacks.
Figure 4.55: Structure of a typical bifunctional reactive dyestuff for wool of the bromoacrylamide type

Six different reactive colours available on the market and the related auxiliaries are shown in the next two tables, together with available details on composition and ecological features.

<table>
<thead>
<tr>
<th>Trade name</th>
<th>Chemical characterisation (all dyestuff products are powder formulations)</th>
<th>Danger symbol</th>
<th>Biodegradation/ bioelimination (%), testing method</th>
<th>spe. COD (mg O₂/g)</th>
<th>spe. BOD₅ (mg O₂/g)</th>
<th>Heavy metals (mg/g)</th>
<th>Organo-halogens (mg/g)</th>
<th>Nitrogen (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lanasol Yellow CE</td>
<td>mixture of azo dyestuffs</td>
<td>Xn</td>
<td>40–50, OECD 303A</td>
<td>700</td>
<td>55</td>
<td>65</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Lanasol Golden Yellow CE</td>
<td>azo-dyestuff</td>
<td>Xn</td>
<td>&lt;10, OECD 302B</td>
<td>669</td>
<td>0</td>
<td>24</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Lanasol Red CE</td>
<td>mixture of azo &amp; anthraquinone dyestuffs (contains reactive black 5)</td>
<td>Xn</td>
<td>40–50, OECD 303A</td>
<td>700</td>
<td>0</td>
<td>24</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Lanasol Blue CE</td>
<td>mixture of azo &amp; anthraquinone dyestuffs (contains reactive black 5)</td>
<td>Xn</td>
<td>40–50, OECD 303A</td>
<td>428</td>
<td>120</td>
<td>24</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Lanasol Navy CE</td>
<td>mixture of azo &amp; anthraquinone dyestuffs (contains reactive black 5)</td>
<td>Xn</td>
<td>20–30, OECD 302B</td>
<td>1032</td>
<td>57</td>
<td>24</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Lanasol Black CE</td>
<td>mixture of azo &amp; anthraquinone dyestuffs (contains reactive black 5)</td>
<td>Xn</td>
<td>20–30, OECD 303A</td>
<td>ca. 500</td>
<td>0</td>
<td>24</td>
<td>96</td>
<td></td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Figure 4.56: Composition and ecological information of six commercial reactive dyestuffs for wool

<table>
<thead>
<tr>
<th>Trade name</th>
<th>Chemical characterisation</th>
<th>Danger symbol</th>
<th>Biodegradation/ bioelimination (%), testing method</th>
<th>spe. COD (mg O₂/g)</th>
<th>spe. BOD₅ (mg O₂/g)</th>
<th>Heavy metals (mg/g)</th>
<th>Organo-halogens (mg/g)</th>
<th>Nitrogen (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cibaflow CIR</td>
<td>anionic de-acrating agent containing alkylpolyalkylene glycol ethers and sodium</td>
<td>Xn</td>
<td>80–90, OECD 302B</td>
<td>418</td>
<td>115</td>
<td>24</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Albegal B</td>
<td>amphoteric hydroxyethylated fatty-acid-amine derivative</td>
<td>Xn</td>
<td>60–70, OECD 302B</td>
<td>1025</td>
<td>0</td>
<td>24</td>
<td>33</td>
<td></td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Figure 4.57: Composition and ecological information of two auxiliaries to be applied with “Lanasol Dyes”

It has to be noted that the formulated products also contain a variable amount of auxiliaries (e.g. anti-dusting agents) that are completely discharged with the exhausted liquor.

Thanks to the high fixation rate now achieved, the released dye only accounts for a minor amount of the total COD from dyeing, whereas the real contribution comes from the other constituents of the dye formulation and from the auxiliaries used in the process (e.g. levelling agents).

The general features of these new reactive dyes, in comparison with chrome dyes, are reported in the following Table 4.68.
### Table 4.68: Comparative analysis of the features of chrome dyes and reactive dyes for wool dyeing

<table>
<thead>
<tr>
<th></th>
<th>Chrome dyestuffs</th>
<th>Reactive dyestuffs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixation mechanism</td>
<td>Small acid dye molecule, which is complexed with chromium</td>
<td>Covalent chemical bond</td>
</tr>
<tr>
<td></td>
<td>• Optimised chrome dyes: &lt; 99%</td>
<td></td>
</tr>
<tr>
<td>Formulation</td>
<td>Only one chromophore to yield black colour</td>
<td>Dye combination necessary to yield black colour</td>
</tr>
<tr>
<td>Levelling properties</td>
<td>Good levelling properties</td>
<td>Levelling properties depend on dyeing auxiliaries and combination reagents (levelling is difficult without assistance of auxiliaries)</td>
</tr>
<tr>
<td>Fastness properties</td>
<td>High standards of fastness</td>
<td>Fastness performance comparable with chrome dyes</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>Shade matching difficult</td>
<td>Very good</td>
</tr>
<tr>
<td>Dyeing process</td>
<td>Two-step dyeing process (dyeing and chroming)</td>
<td>One-step dyeing process (but for dark shades an after-treatment is required)</td>
</tr>
</tbody>
</table>

**Notes:**

**Source:** [179, UBA, 2001], [191, VITO, 2001]

---

**Main-Achieved environmental benefits**

Reduction of emissions of Cr(VI) to water.

By changing over to reactive dyestuffs, the handling of hexavalent chromium, which requires special safety precautions, due to its chronic toxicity and carcinogenic effects, can be avoided.

**Environmental performance and operational data**

As concerns waste water, the presence of chromium, not only in the chelated form, but more importantly as free metal, is avoided. In this respect, it has to be taken into account that dyehouses that accept dyeing without do not use chrome dyes may still use the metal-complex dyes. Nevertheless, in metal-complex dyes the metal is present in the chelated form, which has less impact on the environment brings about less risk than the same amount of chromium released from afterchroming (see Section 0 – ‘Heavy metals emissions’ in Section 2.7.8.1).

**Operational data**

Dyeing cycles are reported to be longer when dyeing with reactive dyes, due to rinsing and clearing (approximately one hour more than a standard cycle of 2.5 h with chrome dyes) [163, Comm., 2001]. However, this technique is improving very rapidly and industrial experience shows that in most cases it is possible to dye at 105 °C and carry out the after-clearing process in the dye bath, without lowering the wet-fastness (see the dyeing curve in Figure 4.58) [280, Germany, 2002]. As a result, the water and energy consumption can be reduced.
Reactive dyestuffs described in this section are suitable for wool and polyamide in all make-ups and can be applied in all types of dyeing machines.

**Cross-media effects**

Attention should be paid to colour, AOX and organic load from non-biodegradable levelling agents.

**Emission of colour to water**

Reactive dyestuffs produce more highly coloured effluents than chrome dyes. This is attributable to the higher colour strength typical of these colourants. In quantitative terms, however, for the same level of colour the amount of dyestuff discharged may be comparable or even less than traditional dyes [61, L. Bettens, 1999]. EU research shows that effective and economically viable routes (Enhanced Thermal Fenton ETF & Enhanced Photo Fenton reaction EPF) are available for destruction of the residual dyestuff [191, VITO, 2001].

**Emission of COD to water**

For an objective assessment of the organic load produced by the dyeing process, the composition of the dye and the COD values of the other constituents of the dye formulation, along with the auxiliaries used in the process, should be considered. The dyestuff itself, thanks to its relatively high fixation rate, makes only a minor contribution to the organic load in the final effluent. On the other hand, the organic load produced by the levelling agents added to the dye liquor is significant in the overall balance. These are fatty amine ethoxylates, which are hardly biodegradable and only 60-70% bioeliminable. Since these compounds have affinity for the wool, it is estimated that 50% of the amount applied will remain on the fibre, while the remaining 50% will end up in the waste water or in the sludge (i.e. transferred to other media). Nevertheless, at a minimum application level of 1% o.w.f. (10 g/kg fibre), 1.5 g/kg of COD
from the levelling agent would still be released into the waste water \((10 \text{ g/kg} \times 0.5 \times 0.3 \times 1025 \text{ mg COD/g})\), unless free-radical destruction methods are applied.

Dyeing with a pH-controlled profile (starting in acidic conditions when reduced reaction occurs and shifting to alkaline pH as soon as the boiling temperature is reached, see Section 4.5.1.5) would allow optimum dye exhaustion with a lower environmental impact (no need for levelling agent). A pH buffer can be used as alkali spender, instead of neutralising the acid bath with alkali (which would give uneven results). However, these compounds also need to be assessed for their hazardousness and the possible formation of harmful products.

**Emission of AOX to water**

The fact that reactive dyestuffs may contain organically bound halogens is regarded as an environmental issue, especially in countries where AOX is a parameter regulated by the environmental legislation. However, In the case of reactive dyes, the AOX found in the waste water is not the result of a haloform reaction and therefore it represents a much lower level of risk for the environment. Furthermore, AOX originating from reactive dyes is not persistent in the environment because of hydrolysis (see also Section 2.7.8.1, "AOX").

Note also that most navy and black dyestuffs (shade range in which chrome dyes are most used) do not contain any AOX at all [280, Germany, 2002].

**Water and energy consumption**

Finally, water and energy consumption. When dyeing with reactive dyes, two rinsing steps at about 80 °C are normally carried out after dyeing, in order to remove the unfixed dye. This leads to higher consumption of water (approximately 30% more [163, Comm., 2001]) and energy.

However, as already mentioned earlier, recent industrial experience shows that in most cases the after-clearing process can be carried out directly in the exhausted dye bath, thus saving water and energy (specific water consumption figures of about 25 l/kg are reported) [280, Germany, 2002].
Technical considerations relevant to applicability

The applicability may be restricted by product specifications. Fastness properties can be very good and even comparable/equivalent to those obtained with chrome dyes. However, the importance of reactive dyes in substitution of chrome dyes is increasing only slowly. The applicability may be limited for a number of reasons:

- Not all operators agree that wool articles treated with the two different classes of dyestuffs both meet the final quality standards, especially for fastness levels. Some finishers still consider that chrome dyes are the only dyes that can guarantee the level of fastness required for overdyeing.
- It is not possible to match the same shade (metamerism) and thus a slightly different product is obtained by substitution.
- It is difficult, especially for commission dyehouses, to change over to reactive dyestuffs because customers often expressly require the use of a specific class of dyestuffs.
- Operators find it difficult to adapt to new techniques because this requires radical changes to a well-established procedure.
- Dyeing with reactive dyes is claimed to be more expensive than with chrome dyes.

Economics

UBA states that costs are comparable with the chroming method when taking into account the overall process costs [179, UBA, 2001].

According to CRAB, Italy, on the other hand, dyeing with reactive dyes is more expensive than with chrome dyes [163, Comm., 2001]. The economic aspects involved with changing over from chrome to reactive dyes are summarised in the following table.

<table>
<thead>
<tr>
<th>Item</th>
<th>Additional costs</th>
<th>Avoided costs</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dyestuff and auxiliaries</td>
<td>CRAB Italy states that 30 % increase in recipe costs (0.25 EURO/kg) is observed, due to the higher cost and the higher consumption levels of reactive dyes [163, Comm., 2001]</td>
<td>A full cost comparison is needed to support this statement</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Increase in water costs due to higher consumption in rinsing steps (30 % more than to chrome dyes) [163, Comm., 2001]</td>
<td>Water use for chroming is up to 25 – 35 l/kg (knitted fabric), but lower for loose fibre, tops, yarn. Metal complex dyeing of semi-worsted wool yarn is ca. 25 l/kg. Reactive dyeing probably needs more water when aftertreatment is carried out in a separate bath.</td>
<td></td>
</tr>
<tr>
<td>Thermal energy</td>
<td>Increase in energy costs due to higher consumption in rinsing steps (estimated 3 – 5 MJ/kg more than with chrome dyes) [163, Comm., 2001]</td>
<td>Estimate has been made based on the following assumptions: two rinsing steps, 1:10 liquor ratio, the water has to be heated from 20 to 80 °C (4.2 kJ/l °C)</td>
<td></td>
</tr>
<tr>
<td>Waste water treatment</td>
<td>Higher energy costs in the ozonisation treatment of the final mixed effluent due to increased colour level [163, Comm., 2001]</td>
<td>EU research showed that more effective and less expensive routes (ETF &amp; EPF) are available for destruction of the residual dyestuff in the segregated waste water stream [191, VITO, 2001]</td>
<td></td>
</tr>
<tr>
<td>Waste disposal</td>
<td></td>
<td>Savings thanks to the absence of</td>
<td></td>
</tr>
</tbody>
</table>
Driving force for implementation

- REACH Regulation.
- Environmental legislation.

Economic reasons are not considered to be the driving force. Pressure and safety requirements set by legislation play a more important role in the ongoing process of substitution for chrome dyes.

As mentioned at the beginning, the use of chrome dyes is also discouraged by various initiatives at European level (e.g. GuT label for carpets, Eco-label for textile products, etc.). GuT members, for example, have agreed to no longer use chrome dyes for carpet wool and the European Eco-label Criteria are taking the same direction for textiles.

GuT and EU labelling do not exclude metal complex dyes. OSPAR recognises the need for chrome dyes, but strict limits are recommended in order to minimise the amount of chrome discharged.

Example Reference plants

Reactive dyes have been on the market for about 15 years and are now successfully applied in many finishing mills in Europe and worldwide.

Plants from the data collection: CZ017, CZ020, IT070, IT071, IT072, IT078, IT082, IT089, IT090, IT092, IT096, IT097, PT098 and PT111.

Reference literature

[179, UBA, 2001], [163, Comm., 2001], [61, L. Bettens, 1999], [59, L. Bettens, 2000], [51, OSPAR, 1994].

4.5.3.2 [Emission reduction in] Optimised metal-complex dyeing of wool [with metal-complex dyestuffs]

Ex-Section 4.6.17

Description

Dyeing is carried out with metal-complex dyes under optimised conditions in terms of pH, auxiliaries and acid used, in order to increase the exhaustion of the dyeing liquor and the fixation of the dyes.

Technical description

Dyeing of loose wool fibre and combed tops is still often carried out using afterchrome or metal-complex dyestuffs. Afterchrome dyestuffs can be substituted by metal-free reactive dyestuffs in many cases. However, when substitution is not possible, another alternative is using metal-complex dyes under optimised conditions (especially pH control).

In the case of 1:2 metal complex dyestuffs (see Section 2.7.4), the dyeing process can be improved by:

- using a special auxiliary (mixture of different fatty alcohol ethoxylates with high affinity for the fibre and the dyestuff);
- replacing acetic acid by with formic acid.
The optimised process is the well-known ‘Lanaset TOP process’, launched by a dyestuffs and textile auxiliaries supplier in 1992. The control of the pH and the application of a mixture of different fatty alcohol ethoxylates shorten the dyeing time drastically compared to the conventional process. In addition, the exhaustion rate is almost 100%, which makes dyeing in a standing bath easier [179, UBA, 2001].

In addition to environmental advantages, the process enables reproducible dyeings with very high fastness properties.

**Main-Achieved environmental benefits**
Reduced emissions to water.
Because of the higher exhaustion and fixation rate, the amount of dye in the exhausted liquor is reduced, which directly correlates with the lower chromium content of the effluent.

**Environmental performance and operational data**
Residual chromium levels down to 0.1 mg/l have been reached in the exhausted dye bath in a laboratory test for a marine shade (i.e. a dark shade). Such low values were confirmed as achievable. However, concerning daily practice in companies, higher values of 1 mg/l are considered more realistic. Emission factors of 10-20 mg/kg of treated wool can therefore be achieved, which correspond to 1-2 mg/l of chromium in the spent dye bath when a 1:10 liquor ratio is used [320, Comm., 2002].

Such low concentration levels open the way for dyeing in a standing bath without the negative effects/limitations arising from build-up of chromium.

The substitution of acetic acid (which has a specific COD of 1 067 O₂ mg/g) by formic acid (which has a specific COD of only 235 O₂ mg/g and is a stronger acid than acetic acid) contributes to lowering the COD load in the effluent.

An additional benefit is achieved due to the reduction of the dyeing cycle time. When applying this technique, the boiling time can be shortened to one third that of the conventional process, which saves energy as well as time.

**Operational data**
Figure 4.59 shows the dyeing curve for the conventional process and the optimised process (Lanaset TOP process).
The technique is applicable in new and existing installations. It is mainly applied for dyeing loose wool fibre and combed tops, which still represent about half of the wool fibre processed annually.

**Cross-media effects**
None believed likely.
None identified.

**Technical considerations relevant to applicability**
The applicability may be restricted by product specifications.

**Economics**
Savings are achieved due to the shorter process time and less lower amount of rinsing water.

**Driving force for implementation**
- Environmental legislation.
- Productivity gains.
The requirements set by environmental legislation to reduce the chromium content in waste water and the desire to increase productivity have been the main driving forces for the implementation of this technique.

**Example-Reference plants**
The process has been successfully put into practice in many dyehouses worldwide. Plants from the data collection: AT005, BE011, CZ020, IT064, IT067, IT068, IT071, IT072, IT077, IT078, IT082, IT085, IT089, IT090, IT097 and UK121.

**Reference literature**
[179, UBA, 2001] [320, Comm., 2002].

### 4.5.3.3 Minimised used of chromates (Low-chrome and ultra-low-chrome afterchroming methods for wool)

#### Ex-Section 4.6.15

**Description**
If chromium-free dyeing and metal-complex dyeing are not applicable, the chromium dyeing can be used, when the use of chromates is authorised and chromates are dosed as a function of the amount of dye taken up by the wool. Dyeing parameters (e.g. pH and temperature of the dyeing liquor) are optimised to ensure that the dyeing liquor is exhausted as much as possible.

**Technical description**
Chrome dyeing of wool is may be still an extremely important process used to obtain deep full shades at an economical price and with excellent fastness properties but in the EU the use of sodium or potassium dichromate for dyeing is subject to authorisation according to the REACH Regulation (see Section 2.7.4.2). At the time of writing this document (in 2019), only two applications for authorisations had been made. [219, ECHA 2019]

In 1995, the world market for wool dyestuffs was about 24000 t, with a higher percentage in Asia, especially China and Japan, than in Europe. Chrome dyes represent about 30% of the global market. They are used for dark shades specifically, 50–60% for black shades, 25–30% for navy and the remaining 10–25% for specific colours, such as brown, bordeaux or green [179, UBA, 2001].

The afterchrome method (see also Sections 2.7.4 and Section 9.6) is now the most widely adopted technique used for the application of chrome dyes, and chromium (as sodium or potassium dichromate) is the metal used almost universally as mordant. In the application of chrome dyes, inefficient chroming methods can lead to the discharge of chromium in spent dye liquors (see also Section 0‘oxidising agents’ in Section 2.7.8.1).

In order to minimise the amount of residual chromium in the final effluent, much attention has recently been given to the low-chrome (stoichiometric) and ultra-low- (substoichiometric) chrome dyeing techniques, where only the minimum amount of dichromate required to form the dye complex in the fibre is dosed.

During the last 10–15 years, the so-called low-chrome dyeing technology has been increasingly used. The method consists in of the stoichiometric dosage of chrome (up to a maximum of 1.5 % o.w.f.) together with careful pH control (3.5–3.8) and optional addition of a reducing agent, which assists in the conversion of Cr(VI) to Cr(III) and promotes its exhaustion onto the fibre [191, VITO, 2001]. Every major chrome dye manufacturer has published data relating to chrome additions and dyeing techniques which are widely adopted (e.g. Bayer, Ciba-Geigy, Sandoz).

By the use of low-chrome techniques it is possible to reduce residual Cr(III) in the spent chroming bath from about 200 mg/l (typical of the conventional process) to about 5 mg/l in...
practical mill conditions. Residual Cr(VI) is almost eliminated. In the laboratory, lower residual Cr(III) concentrations (about 1 mg/l) can be achieved but, although such results are reported in the literature, they are not regularly achievable in practice [191, VITO, 2001].

*Ultra-low chroming* techniques are applied to achieve even lower residual chromium levels or in particular cases when low-chroming techniques cannot guarantee residual chromium levels below 5 mg/l in the spent chroming bath (e.g. wool that has to be dyed in deep shades). Chrome is dosed stoichiometrically, based on the dye uptake of the fibre.

With ultra-low chroming techniques additional measures are applied, compared to the low-chrome process, in order to ensure maximum exhaustion of the dye bath. If the dye bath exhaustion is incomplete before chroming, the residual dye in the liquor will be chromed and remain in the liquor, adding to the discharged chromium. By ensuring maximum dye exhaustion, contamination from this source can be reduced and this will also give maximum fastness performance. Dye bath exhaustion can be improved by ensuring that the dye bath pH is sufficiently low or as Bayer have shown, by allowing the dye bath to cool to 80-90 °C at the end of the dyeing stage. Optimum results will be obtained by draining the dye liquor and setting a fresh bath for chroming [191, VITO, 2001].

**Main Achieved environmental benefits**

Reduction of chromium emissions to water, in comparison with the normal afterchroming method.

Methods using exactly calculated quantities of dichromate and special process conditions result in minimisation of chromium in the waste water.

**Environmental performance and operational data**

First of all, as mentioned above, the use of sodium or potassium dichromate for dyeing is subject to authorisation according to the REACH Regulation.

An emission factor of 50 mg chromium per kg of wool treated is achieved, which corresponds to a chromium concentration of 5 mg/l in the spent chroming bath when a 1:10 liquor ratio is used [191, VITO, 2001].

**Operational data**

In order to ensure accurate dosing and minimum handling of hazardous chemicals by the operator, the application of the low-chroming or ultra-low chroming techniques requires the use of an automated dosing and dispensing system for dichromate and dyes and for pH control. The required amount of dichromate is fed directly to the dyeing machine through pipework (no manual transfer, no human contact, no losses). The system is fitted with control devices for the volumetric control of the delivered quantities, which switch the entire system into emergency mode if normal operating parameters are breached [161, Comm., 2001].

In addition, special safety precautions are recommended for the storage of dichromate. The containers for the solution of sodium dichromate must be stored within isolated bunded areas in order to contain potential spillage and avoid interaction with other chemicals (in case of spillage).

For maximum chroming efficiency, it is essential to eliminate from the chroming bath any chemicals that will inhibit the chromium/dye interaction. Two main classes of chemicals can have this effect. The first class includes all chemicals that can form soluble complexes with chromium, thereby holding the metal in solution in the bath and adding to the effluent load. Examples of such products are sequestering agents and polycarboxylic acids, such as citric acid.

The second class of compounds are those that inhibit the exhaustion of the dichromate anion; the most common example is the sulphate anion. The use of sodium sulphate and sulphuric acid
Chapter 4

are should therefore generally be avoided, except in the manner indicated in the specific Bayer method [191, VITO, 2001].

Note that, even without added reducing agent, reducing species released from the wool into the dye bath will convert Cr(VI) almost quantitatively to Cr(III). An exception is represented, for example, by wool that has been submitted to oxidising shrink-resist treatments, because in this case wool molecules will already be oxidised and the reduction potential will be lower.

However, it has to be taken into account that Too low amounts of dichromate may adversely affect the required reproducibility of shades [280, Germany, 2002].

Cross-media effects
Taking the conventional method as a reference, there are no cross-media effects to be mentioned.

It has to be taken into account that even when: 1) special application methods are employed, which involve reduction of Cr(VI) to Cr(III); 2) the chrome is encouraged to complex with the carboxyl groups within the fibre; 3) a further effluent dilution from rinsing is incorporated, it is still a huge challenge to reduce the chromium level in the total chrome dyeing effluent (spent dye bath + rinsing water) from over 300 mg/l to just 1 mg/l. It is for this reason that the future of afterchrome dyestuffs has been questioned [188, VITO, 2001].

If a fresh bath is set for chroming, as required with the ultra-low chroming technique, the additional water consumption has to be taken into account [280, Germany, 2002].

In addition, this technique will still generate chromium emissions to water, even if lower than the normal afterchroming method.

Technical considerations relevant to applicability
Low-chroming methods are cheap and easy to apply and are already widely used.

The optimised levels of dichromate additions give complete and level chroming of the dye, under specified chroming conditions. This minimises oxidation and cross-linking of the fibre, and therefore also reduces fibre damage.
Generally, there are no technical restrictions to the applicability of this technique.

Economics
It is commonly accepted that in the long term, the introduction of automated dosing/dispensing systems brings about savings in chemicals thanks to improved dosing accuracy, but no quantitative data were made available to this respect [161, Comm., 2001].

The addition of reducing agents increases costs because of the longer dyeing cycles and the resulting reduced productivity [161, Comm., 2001]. The same is valid for the setting of a fresh bath for the chroming step, as required by the ultra-low chroming techniques [280, Germany, 2002].

Driving force for implementation
Environmental legislation.

Pressure and safety requirements set by the legislation are probably the main driving forces for the application of this technique. It should be noted, however, that many initiatives discourage the use of chrome mordant dyes (OSPAR, GuT, EU-Ecolabel, etc.). Chromium-free dying is therefore becoming more and more attractive for companies that are not obliged to use chromium dyes.

Example Reference plants
Many plants in Europe.
Plants from the data collection: IT067, IT071, IT072, IT085, IT089 and IT090.

Reference literature

4.5.3.4 Use of liposomes [as auxiliaries] in acid dyeing of wool [dyeing]

Ex-Section 4.6.18

Description
Dyeing with acid dyes is carried out using liposomes as auxiliaries, which increases the exhaustion rate.

Technical description
The use of liposomes as auxiliary products in wool dyeing with acid dyestuffs allows good dye bath exhaustion at 80 °C and in 40 minutes. The advantages are:

- lower superficial damage of the wool fibre (due to the lower operating temperature the hand-feel of the fabric is softer);
- energy savings;
- no electrolyte use;
- lower COD load in the waste water.

With wool/polyester mixtures, in order to allow the diffusion of disperse dye into the polyester fibre, it is necessary to operate at higher temperatures (100 °C), and to add a low concentration of carriers. Liposomes have the effect of increasing the diffusion of disperse dyestuffs into the wool fibre (see Section 2.7.7—“Polyester-wool blends”). It is therefore important to carry out selection essay tests of the suitable disperse dyestuffs in order to avoid negative effects on the fastness properties of the dyed product.

Main-Achieved environmental benefits
The main environmental benefits associated with the use of liposomes include:

- Energy savings.
- Lower COD load in the waste water.
- Lower conductivity of the waste water.

Environmental performance and operational data
Wool dyeing with acid dyes in the presence of liposomes is carried out at 80 °C for 40 minutes, in a bath containing [308, Spain, 2002]:

- liposome 0.1-0.2 % o.f.w.;
- formic acid;
- acid dyestuff.

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Liposomes based auxiliaries have general applicability in wool dyeing mills [308, Spain, 2002].
Economics
Energy savings and better quality of the fabric compensate for the cost of the liposomes [308, Spain, 2002].

Driving force for implementation
The improved product quality is the main driving force for the implementation of this technique.

Example: Reference plants
Two plants in the Barcelona region are reported to have implemented this technique [308, Spain, 2002].

Reference literature
[308, Spain, 2002], [180, Spain, 2001].

4.5.4 Dyeing of synthetic fibres

4.5.4.1 Batch exhaust dyeing of polyester and polyester blends without dyestuff carriers-free dyeing techniques or with use of environmentally optimised carriers

Ex-Section 4.6.1

Description
Batch dyeing of polyester and wool-free polyester blends is carried out at high temperature (e.g. 130 °C) without the use of dyestuff carriers.

Batch dyeing of wool-polyester blends is carried out with chlorine-free readily biodegradable and bioeliminable carriers.

Technical description
Due to the high glass transition point of polyethylenterephthalate, which is in the range of 80-100 °C, the diffusion rate of disperse dyestuff molecules into the standard PES fibres (PET based) at normal dyeing temperatures is very low. As a result, dyeing conditions typically used for other types of substrates are not applicable. Exhaust dyeing of single polyester and polyester blends can be carried out either in autoclaves at high temperature (HT dyeing at 130 °C, which is usually applied for pure PES and wool-free PES blends) or at normal dyeing temperatures (95-100 °C, which is applied for PES/WO blends) with the help of so-called carriers (see also Sections 2.1.1.1, 2.7.6.2, 2.7.7 and 8.6.7).

Carriers are absorbed to a great extent onto the PES fibre. They improve fibre swelling and encourage colourant migration. In dyeing and rinsing, a significant amount of carriers is emitted to waste water. The fraction that remains on the fibre may be emitted to air during subsequent drying, heat-setting and ironing.

Active substances used in carrier formulations include:

- chlorinated aromatic compounds (mono-chlorobenzene, trichlorobenzenes, etc.);
- o-phenylphenol;
- biphenyl and other aromatic hydrocarbons (trimethylbenzene, 1-methylnaphtalene, etc.);
- phthalates (diethylhexylphthalate, dibutylphthalate, dimethyl phthalate).

Human and aquatic toxicity, high volatility and high odour intensity are the main concerns associated with the use of the above-mentioned substances (see also Section 2.7.8.1) and some phthalates are listed in Annex XIV and/or Annex XVII to the REACH Regulation. [79, EU 2006]
Not only do water and air become contaminated by the emissions, but it is increasingly suspected that consumer health problems can be caused by remobilisation of halogenated carriers (e.g. 1,2,4-trichlorobenzene which is listed in Annex XVII to the REACH Regulation) in the treated textiles [18, VITO, 1998]. [ 79, EU 2006 ]

The application of HT dyeing processes avoids the use of carriers. This technique is currently widely applied when dyeing pure polyester and wool-free PES blends. However, due to the sensitivity of the wool substrate to high temperatures, it is still necessary to use carriers when dyeing polyester blends and, in particular, polyester/wool blends. In these cases, hazardous carriers can be replaced by chlorine-free substances with improved toxicological and environmental characteristics. New carriers are based on:

- benzylbenzoate;
- aromatic carboxylic acid esters; [ 36, ÖKOPOL 2011 ]
- and N-alkylphthalimide.

**Main-Achieved environmental benefits**
Reduced emissions to water.
In the case of HT dyeing processes, waste water and off-gas are carrier-free. The quantity of environmentally problematic substances is reduced.

In the case of chlorine-free carriers, the emissions to air and to water are reduced.

**Environmental performance and operational data**
PES/WO blends may be dyed with benzylbenzoate- and N-alkylphthalimide-based carriers; benzylbenzoate is a readily biodegradable substance (the degree of mineralisation for the benzylbenzoate is 79 % [179, UBA, 2001]), while N-alkylphthalimide is bioeliminable (the \( \text{BOD}_3/\text{COD}\times100 \) is 50 – 100 %) with a fish toxicity between 10 and 100 mg/l. Moreover, because of their low volatility, odour nuisance (especially in the workplace) is negligible.

Both substances show great affinity for the aqueous medium, which makes them easy to prepare (without the need for emulsifying and dispersing agents) and easy to remove at the end of the dyeing process (with lower water consumption).

**Operational data**
In the case of benzylbenzoate carriers, applied concentrations range between 2.0 g/l and 4.50 g/l (dyeing at boiling temperature; average liquor ratio). [179, UBA, 2001] [ 36, ÖKOPOL 2011 ].

N-alkylphthalimide carriers are applied in the range of 2 % (liquor ratio 1:10) to 1 % (liquor ratio 1:20) for dyeing of light shades. For dark shades, the amount of carrier varies between 6 5 % (\( \text{L.R.} \) liquor ratio 1:10) and 3 % (\( \text{L.R.} \) liquor ratio 1:20) [179, UBA, 2001]. [ 36, ÖKOPOL 2011 ].

Carrier-free dyeing at high temperature can be applied to all PES qualities, provided that HT-dyeing equipment is used. Application of HT dyeing to PES blends depends on the sensitivity to high temperature of the fibres in the blend, being particularly critical for PES/WO blends.

**Cross-media effects**
When dyeing in HT conditions a higher quantity of oligomers tends to migrate to the surface of the fibre.

Dyeing at high temperature also requires higher energy consumption. The balance between the different effects involved (the effects of the hazardous carriers on the environment and the effects of higher energy consumption) is, however, still largely in favour of the application of this technique [179, UBA, 2001].
Benzylbenzoate- and N-alkylphthalimide-based carriers are less effective than conventional carriers. They have a reduced penetrating and swelling effect. As a result, a longer residence time and higher amounts (about three times as much as conventional carriers) are needed to achieve the same effect.

**Technical considerations relevant to applicability**

Dyeing with optimised carriers is applicable to all PES blends. Generally, there are no technical restrictions to the applicability of this technique.

**Economics**

Optimised carriers described in this section cost approximately the same as common carriers [179, UBA, 2001].

**Driving force for implementation**

- Environmental legislation.
- REACH Regulation.
- Workers’ health and safety.

Limit values enforced by environmental legislation on workplace safety have been one of the main driving forces in the process of elimination/substitution of halogenated and other hazardous carriers.

In 1994, OSPAR recommended cessation of use of organohalogen carriers ([51, OSPAR, 1994]). Moreover, a number of eco-label schemes for textile products include, among their requirements, prescriptions regarding dye carriers. The European Ecolabel, for example, requires that halogenated carriers should not be used. GuT label requirements (for carpets) state that dye carriers must not be used in manufacture or be detectable in the product.

**Example Reference plants**

Carrier free HT-dyeing processes and the above-mentioned optimised carriers are applied across Europe and the world. A total of 47 plants from the data collection apply this technique.

**Reference literature**

[179, UBA, 2001], [18, VITO, 1998], [61, L. Bettens, 1999], [52, European Commission, 1999], [59, L. Bettens, 2000], [79, EU 2006 ], [36, ÖKOPOL 2011 ].

### 4.5.4.2 Optimised desorption of unfixed dye in batch dyeing

**Description**

Optimised desorption of unfixed dye in batch dyeing of PES and its blends with cellulosic fibres (PES/CO) is achieved by:

- using a desorption accelerator based on carboxylic acid derivatives;
- using a reducing agent that can be used in the acidic conditions of the spent dyeing liquor;
- using disperse dyes that can be desorbed in alkaline conditions by hydrolysis instead of reduction.

**Technical description**

Conventional discontinuous dyeing processes for PES/CO blends with disperse and reactive dyestuffs are carried out in two baths. Optimised auxiliaries based on carboxylic acid derivatives are used as desorption accelerator for clearing. The fastness of the PES fraction and its blends will be optimised effectively by the withdrawal of unfixed dyestuff.

The use of these new auxiliaries allows some processing steps to be avoided as shown in Table 4.70 below.
### Table 4.70: Comparison of dyeing sequences with and without optimised desorption accelerator

<table>
<thead>
<tr>
<th>Conventional two-bath treatment</th>
<th>Two-bath treatment with the optimised desorption accelerator, without intermediate clearing for dark shades</th>
<th>One-bath treatment with the optimised desorption accelerator (for medium and dark shades)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disperse dyeing of PES</td>
<td>Disperse dyeing of PES</td>
<td>High-temperature dyeing of PES and CO in one bath</td>
</tr>
<tr>
<td>Intermediate clearing,</td>
<td>Reactive dyeing of CO (¹)</td>
<td>Rinsing</td>
</tr>
<tr>
<td>often alkaline reduction</td>
<td>Rinsing and neutralisation if needed</td>
<td>Soaping with optimised desorption accelerator</td>
</tr>
<tr>
<td>Rinsing and neutralisation</td>
<td>Soaping with optimised desorption accelerator</td>
<td>Rinsing</td>
</tr>
<tr>
<td>Reactive dyeing of CO</td>
<td>Rinsing</td>
<td></td>
</tr>
<tr>
<td>Rinsing/soaping process</td>
<td>Optional: cationic after-treatment of CO</td>
<td></td>
</tr>
<tr>
<td>Optional: cationic after-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treatment of CO</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(¹) Recommendation for reactive dyeings: 40 °C or 60 °C.

*Source:* [36, ÖKOPOL 2011]

---

### After-treatment in PES dyeing

#### Ex-Section 4.6.5

**Description**

A major problem in the dyeing of PES fibres and PES blends using disperse dyestuffs is wash fastness. In order to meet washing fastness requirements, an after-treatment step is carried out, which removes the non-fixed disperse dyes from the fibre. Reductive after-clearing is normally preferred over simple washing with surfactants because disperse dyestuff molecules absorbed on the surface are broken down into smaller, often colourless and more readily water-soluble fragments (see Section 2.7.6.2). The precondition is that no dyestuffs susceptible to reduction have been used for dyeing.

In the conventional process, after dyeing the polyester at 130 °C, the dye bath (acidic) needs to be cooled down to 70 °C before draining, in order to bring the fibre below its glass transition temperature. The reductive after-treatment is carried out in a new bath using hydrosulphite and a dispersing agent in alkaline conditions (the temperature is raised again to 80 °C during the process). Afterwards, the bath is drained and one or two more rinsing steps are needed in order to remove the remaining alkali and reducing agent. The pH of the textile before entering the steamer needs to be between 4 and 7 in order to avoid yellowing. Rinsing is therefore carried out in acidic conditions.

Besides the environmental concerns involved with the use of hydrosulphite as a reducing agent (see Section 2.7.8.1), this process entails three bath changes (including temperature raising/cooling cycles) and two changes in the pH of the treatment baths: from the acidic pH of the dyeing liquor to the high alkalinity of the after-treatment bath and back again to acidic levels in the rinsing baths. The double change produces higher consumption of water, energy and chemicals, greater demands on time and increased levels of salt in the effluent.

Two different approaches are possible:

**Approach a)** consists of Using a reducing agent based on a special short-chain sulphinic acid derivative that can be added directly in the exhausted acidic dye bath. This reducing agent is liquid and can therefore be metered automatically. Moreover, it has very low toxicity and is readily biodegradable [179, UBA, 2001], [181, VITO, 2001].
Approach \(b\) consists of using disperse dyes that can be cleared in alkaline medium by hydrolytic solubilisation instead of reduction. These are azo disperse dyes containing phthalimide groups [182, VITO, 2001]. However, phthalimide groups are not stable to hydrolysis and are not the preferred solution. [ 36, ÖKOPOL 2011 ]

Main-Achieved environmental benefits
- Reduction of water and energy consumption.
- Reduction of emissions to water.
- Reduction of the amount of waste water generated.

Environmental performance and operational data
The reduction of processing steps results in savings of three to five baths, which correspond to water savings of approximately 45-75 l water/kg fabric. [ 36, ÖKOPOL 2011 ] This technique is used in discontinuous HT processes.

Approach Option \(a\)
First of all, because this reducing agent can be applied in the acidic pH range, significant water and energy savings can be achieved. Compared to the conventional process, water savings of up to 40 % of water can be achieved.

Moreover, these aliphatic short-chain sulphinic acid derivatives are readily biodegradable (the product is non-volatile and water-soluble, with more than 70 % DOC reduction within 28 days, under the OECD test 302B). The sulphur content of the product is approximately 14 %, compared to 34 % with sodium dithionite and the amount of by-products (sulphites and sulphates) can be reduced by half relative to in comparison with the conventional process (see Table 4.71 below).

It is also worth noting that, unlike sodium dithionite, the product is non-corrosive, non-irritant, non-flammable and does not have an unpleasant odour. As a result, workplace safety compared to with sodium dithionite is improved and odour nuisances minimised.

Table 4.71: Sulphur and sulphite concentration and load in the mixed effluent from typical processes using sodium dithionite- or sulphinic-acid-based reducing agents

<table>
<thead>
<tr>
<th>Recipe</th>
<th>Sulphur concentration in mixed effluent (^{(1)}) (mg/l)</th>
<th>Specific sulphur load (^{(2)}) (mg/kg PES)</th>
<th>Maximal sulphite concentration in mixed effluent (^{(1)}) (mg/l)</th>
<th>Maximal specific sulphite load (^{(2)}) (mg/kg PES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium dithionite</td>
<td>260</td>
<td>4 100</td>
<td>640</td>
<td>10 300</td>
</tr>
<tr>
<td>(3 g/l) 2 rinsing baths</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphinic acid</td>
<td>100</td>
<td>1 700</td>
<td>130</td>
<td>2 000</td>
</tr>
<tr>
<td>(3 g/l) 2 rinsing baths</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphinic acid</td>
<td>200</td>
<td>1 700</td>
<td>260</td>
<td>2 000</td>
</tr>
<tr>
<td>(3 g/l) 1 rinsing bath</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{(1)}\) Mixed effluent: sum of the exhausted dye bath, the clearing bath and the number of rinsing baths.
\(^{(2)}\) Data are calculated assuming a liquor ratio of 1:4.


In most cases, concentrated hydrosulphite can be replaced by the same quantity of the referenced optimised reducing agent product. In a typical process, 1.0-1.5 ml/l reducing agent (for medium shades) and 1.5-2.5 ml/l (for dark shades) are added to the exhausted dye bath. The
process is carried out for 10-20 minutes at 70-80 °C. Hot and cold rinsing follow [179, UBA, 2001].

In order to derive the maximum environmental and economic benefit from the proposed technique, it is important that only the strict amount of reducing agent needed to reduce the dyestuff is used. Consumption of the reducing agent by the oxygen in the machine should therefore be avoided as much as possible. One effective technique to ensure this is to use nitrogen to remove oxygen from the liquor and the air in the machine [182, VITO, 2001].

For some types of polyesters that show a higher percentage of oligomer migrating to the surface during the dyeing process, it is advantageous to carry out the after-treatment in a fresh bath.

The technique can be used in all types of dyeing machines, not only for polyester fibres, but also for PAC, CA and their blends.

**Approach Option b)**

With alkali-dischargeable dyes the use of hydrosulphite or other reducing agents can be avoided, which means a lower oxygen demand in the final effluent. There is the possibility of dyeing PES/CO blends using a one-bath two-step dyeing method, as alkali-clearable dyes can be applied in the same bath with cotton-reactive dyes. This brings about additional environmental benefits in terms of water and energy consumption.

Table 4.72 below gives a comparison between two equivalent recipes, one with alkali-clearable dyes and the other with standard disperse dyes.

**Table 4.72: Recipes with alkali-clearable dyes and recipe with standard dyes**

<table>
<thead>
<tr>
<th>Recipe with alkali-clearable dyes</th>
<th>Recipe with standard dyes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dye 40 g/kg</td>
<td>Dye 55 g/kg</td>
</tr>
<tr>
<td>pH stabiliser 25 g/kg</td>
<td>Acetic acid 25 g/kg</td>
</tr>
<tr>
<td>Equalisation agent 10 g/kg</td>
<td>Equalisation agent 10 g/kg</td>
</tr>
<tr>
<td>Levelling agent 5 g/kg</td>
<td>Levelling agent 5 g/kg</td>
</tr>
<tr>
<td>Dispersing agent 12 g/kg</td>
<td>Dispersing agent 12 g/kg</td>
</tr>
<tr>
<td>Detergent 12 g/kg</td>
<td>Detergent 12 g/kg</td>
</tr>
</tbody>
</table>

*Source: [182, VITO, 2001]*

With alkali-clearable disperse dyes there is no need for levelling agents, dispersing agents or detergent. Moreover the amount of dye used is reduced. The resulting environmental benefits are evident.

Alkali-clearable dyes are currently applied for both for PES and PES/CO blends, with greater environmental and economic advantages being achieved with PES/CO blends.

**Operational data**

**Approach A)**

**Approach B)**

**Cross-media effects**

**Approach Option a)**

When the product is used in the dye bath, the unfixed dispersed dye particles are destroyed by reduction so that the effluent is largely free of colour. On the other hand, the by-products of the reductive reaction may be more hazardous than the original dyestuff (e.g. aromatic amines...
originating from reduction of azo dyes). The effluent therefore needs to be treated before being discharged (for polyester oligomers and aromatic amines).

Moreover, low temperatures and acidic conditions result in oligomer deposition on the fabric, batching tanks, and parts of the machines. [36, ÖKOPOL 2011]

**Approach** Option b)

None believed likely.

None identified.

**Technical considerations relevant to applicability**

**Approach** Option a)

The only limitation on applicability is with blends with elastane fibres. The use of reducing agent in acidic conditions may not be applicable to polyester-elastane blends.

Application of sulphinic acid in the case of PAN is difficult because the operational temperature is close to the glass transition point. [36, ÖKOPOL 2011]

Furthermore, complete substitution of sodium dithionite is technically not possible. For aftercleaning of PES, precleaning with sodium dithionite or a mixture of sodium dithionite with substitutes is essential. [36, ÖKOPOL 2011]

**Approach** Option b)

The use of dyes desorbable in alkaline conditions may be restricted by product specifications. The dyes do not cover all shades.

In addition, the technique may not be applicable for disperse dyes with very high fastness requirements. In this case (e.g. for dyes especially developed for the automotive industry), the application is carried out in the conventional acidic medium. [36, ÖKOPOL 2011]

**Economics**

Shorter processing time and savings in water and energy consumption are the main economic advantages achieved.

**Approach** Option a)

Products based on sulphinic acid are considerably more expensive. However, significant savings can be achieved as a result of higher productivity, reduced consumption of energy, water and chemicals and the lower burden in the waste water. [179, UBA, 2001] [36, ÖKOPOL 2011]

**Approach** Option b)

The use of alkali-clearable dyes implies higher recipe costs compared to conventional disperse dyestuffs (about twice as much: the total cost of a recipe with alkali-clearable dye is about EUR 0.5/kg, whereas with standard disperse dyes this is in the order of EUR 0.2/kg). However, **Approach** option b is expected to bring savings in time (higher productivity) and to reduce water, energy and chemical costs (particularly when these dyes are applied for PES/CO blends).

**Driving force for implementation**

- Savings in energy and water consumption.
- Higher productivity and product quality.
- Environmental legislation.

Cost savings (higher productivity) and improvement of the environmental performance (especially with regard to sulphite content in the waste water) are the main reason for application of both these techniques.

**Example Reference plants**

Multiple plants in Germany use desorption accelerator based on carboxylic acid derivatives.
Approach Option a)
The proposed technique is applied in at least five finishing mills in Germany and worldwide as well [179, UBA, 2001].
It is also applied in Plant IT091.

Approach Option b)
Many plants in Europe.
A total of 19 plants from the data collection reported using one of the two options mentioned above.

Reference literature

4.5.4.3 Supercritical CO\textsubscript{2} disperse dyeing of synthetic fibre

Description
Supercritical CO\textsubscript{2} is used as a dyeing medium instead of water in a closed loop process to transport disperse dye into the polyester fibres

Technical description
The technique uses pressurised CO\textsubscript{2} in a supercritical (SC-CO\textsubscript{2}) fluid stage, a phase with characteristics between a liquid and a gas. In this state CO\textsubscript{2} has a very high solvent power, allowing the dye to dissolve easily. The dyes are transported easily and deeply into fibres thanks to the high permeability of CO\textsubscript{2}.

The CO\textsubscript{2}, which takes on liquid-like properties, is contained in stainless steel chambers. After the dyeing cycle, the CO\textsubscript{2} becomes gasified and dye within the cotton fibres condenses as it separates from the gas. The CO\textsubscript{2} is then recycled, pressurised and pumped back into the dyeing vessel.

Achieved environmental benefits
No water or chemicals are required; therefore no water effluents are generated. The CO\textsubscript{2} used can be a by-product (waste gas) reclaimed from existing industrial processes; it is used in a closed-loop system with a 95% recycling rate.
Reduced emissions to water.

Environmental performance and operational data
Lower loads of auxiliary chemicals and additives: SC-CO\textsubscript{2} dyeing does not need aditional chemicals to dissolve dyes. This technology uses pure dyes (preparations with 100 % dye) and with more than 98 % uptake. Energy consumption is 20-50 % lower compared to other water-based dyeing. Dyeing times are shortened due to the high dye diffusivity resulting in high extraction rates.

Dyeing of polyester and polypropylene fibres with SC-CO\textsubscript{2} is performed under isothermal and isobaric conditions.

Cross-media effects
None identified.

Technical considerations relevant to applicability
The technique is generally applicable to synthetic fibres, currently used mainly for polyester fibres (e.g. PET, PTT) and its blends with synthetic fibres (e.g. polypropylene). Only applicable to new plants or major plant upgrades.
SC-CO₂ dyeing on a laboratory scale has been successfully applied to polypropylene and polyamide fibres.

Natural fibres such as cotton and wool can be damaged undergoing a similar process. SC-CO₂ dyeing of polar fibres like cotton and wool are problematic due to the polarity of the dyestuff used in the dyeing of these fibres.

**Economics**

Investment in such equipment is costly (high investment but relatively low operating costs). SC-CO₂ dyeing reduces operational costs to 20% in comparison with water-based dyeing. SC-CO₂ dyeing utilises pure dyes and their cost ranges from USD 0.76 to USD 1.37 per kg of dyed PES fabric, lower than the costs of dyes for traditional, water-based dyeing. Other reasons for the lower costs per kg of dyed fabric include the shorter dyeing time (almost halved in comparison with water-based dyeing technologies) and the absence of chemicals, for instance dispersing agents, levelling agents, and carrier agents.

**Driving force for implementation**

SC-CO₂ dyeing eliminates the need for water, reduces the energy demand and reduces CO₂ emissions. Short batch cycles, efficient dye use and no waste water treatment all contribute to significantly reduced operating costs.

**Example plants**

An Adidas supplier in Thailand (Yeh Group) applies this technique.

**Reference literature**

4.6 Printing

4.6.1 General techniques

4.6.1.1 Reduction of water consumption in cleaning of printing equipment

Description

The equipment used around the printing machine (e.g. screens, buckets and the print paste feed system) needs careful cleaning before it can be used for new colours. In connection with cleaning operations, there are several ways of reducing water consumption when cleaning the equipment used with the printing machine (e.g. screens, buckets and the print paste feed system):

- a) Automatic start/stop control of cleaning water supply (for cleaning the printing belt);
- b) mechanical removal of printing paste;
- c) reuse and recycling of the cleanest part of the rinsing water from the cleaning of the squeegees, screens and buckets;
- d) reuse and recycling of the rinsing water from the cleaning of the printing belt.

Technical description

a) Start/stop control of cleaning of the printing belt

In many cases, water dosage for the cleaning of the printing belt continues when the fabric and therefore the printing belt are stopped for whatever reason. Start/stop control of the water dosage can be automatically connected to the start/stop control of the printing belt.

b) Mechanical removal of printing paste

Large amounts of water for cleaning of squeegees, screens and buckets are used within the print house. Improved printing paste removal before flushing this equipment reduces the amount of water needed for flushing. Physical devices for removal of dye from buckets are available (e.g. scrapers). Modern printing machines have a built-in system for mechanical removal of residual printing paste from pipes and hoses with compressed air. [36, ÖKOPOL 2011]

c) Reuse of the cleanest part of the rinsing water from the cleaning of the squeegees, screens and buckets

Typically, the first half of the effluent from the washing equipment is heavily loaded with printing paste and will have to be discharged as waste water. The water used for this first stage does not, however, need to be of a high quality, which means that recycled water can be used. In the second half of the washing process, clean water must be used, but the effluent can be collected for reuse, potentially as first-rinsing water in the next cycle.

d) Reuse of the rinsing water from the cleaning of the printing belt

The rinsing water from the cleaning of the printing belt is only slightly coloured and contains small amounts of fibres (depending on the fabric) and very small amounts of glue. The rinsing water can be mechanically filtered, collected in an overflow vessel and reused for the same purpose if minor amounts of fresh water are added to the recycling system.

Main-Achieved environmental benefits

The environmental benefit is a reduction in water consumption and waste water generation.

Environmental performance and operational data

In a Danish pigment print house, the implementation of all the above options has reduced the annual consumption of water by approximately 25 000 m³ (55% reduction). For option A alone, the savings are estimated at approximately 2 m³ for every hour the printing machine is stopped.
and the water dosage for cleaning of the printing belt is still running for whatever reason. For option C, 50% of the water can be reused. For option D, approximately 70% of the water can be recycled [192, Danish EPA, 2001].

**Operational data**

No information was made available.

**Cross-media effects**

None believed likely.

None identified.

**Technical considerations relevant to applicability**

Options A–D. All of the above options can be implemented in all types of textile companies involving a printing section: new or existing, large or small. Space availability is a minor factor: the company only needs space for collection tanks (options C and D). However, older printing machines can probably not be retrofitted with a device for mechanical removal of the residual printing paste from pipes and hoses in the printing machine as suggested in option B [192, Danish EPA, 2001] (see Section 4.6.1.6).

**Economics**

In the Danish case mentioned above, the total capital costs (tanks, mechanical filters, pumps and pipes) for all options are estimated at approximately DKK 100 000 DKK (EUR 13 500 euros). Options C and D together amount to approximately DKK 95 000 DKK (EUR 12 825 euros). Option A costs approximately DKK 5 000 DKK (EUR 675 euros) and the cost of option B is negligible. Changes in operating costs (before and after implementation) for all options are negligible. The costs for fresh water and waste water discharge are DKK 9 and DKK 18 DKK per m³ respectively (EUR 1.2 and EUR 2.43 euros per m³). Hence the total annual savings are approximately DKK 67 500 DKK (EUR 90 000 euros). For the case study considered here, the payback time for all options together is estimated at about 2 months [192, Danish EPA, 2001].

**Driving force for implementation**

The high costs of waste water discharge and, in some countries, of fresh water are the main driving forces for implementing the measures described.

**Example Reference plants**

Many plants in Europe. One example plant is mentioned by [192, Danish EPA, 2001]: Danish Colour Design Textile Print A/S

Plants from the data collection: BE009, DE032, IT063, PT099 and UK127.

**Reference literature**

[192, Danish EPA, 2001]

**4.6.1.2 Digital jet printing of carpet and bulky fabric**

**Description**

Computer-controlled contact-free injection of dye into carpet and bulky fabric.

**Technical description**

The principles of jet printing and the latest development in this technique are described in Section 2.8.2.

Jet printing is today a fully digital technique (right from the design stage to industrial production). The designer makes the sample on the computer and from this digital information
the sample can be exactly reproduced on an industrial scale without the need for corrective
adaptation/measure.

**Main Achieved environmental benefits**
Resource efficiency.

**Environmental performance and operational data**
In digital jet printing, selected trichromatic dyes are dosed on-line, based on computed
requirements. The colour is applied on demand. This avoids dye losses or printing paste
residues at the end of the process, which represents a revolutionary significant change from
conventional printing methods (flat-screen and rotary screen).

Another big advantage of this technique is that the amount of thickeners can be reduced
depending on the type of substrate because the dye is shot directly deep into the face of the
fabric.

Further environmental advantages are [171, GuT, 2001]:

- reduced water consumption (only 20% compared with conventional printing);
- less trial-and-error sampling (one of the most important sources of pollution, often forgotten
  in evaluations);
- the printing process can be carried out in the final stage of the manufacturing chain
  (reduction of material losses, particularly of coloured fabric).

**Operational data**
No information made available.

**Cross-media effects**
Compared to analogue printing techniques, no negative cross-media effects have been identified
needs to be mentioned.

However, it is important to point out that the substrate must still undergo fixation and
afterwashing. Therefore water emissions to water cannot be completely avoided.

**Technical considerations relevant to applicability**
Only applicable to new plants or major plant upgrades.
Digital jet printing can be applied to carpet and bulky fabrics. It is also applicable for patterning
runners, mats and tiles, in which case the operation is done very conveniently at the end of the
process on the ready-made product (which does not need to be washed afterwards).

The investment cost is still significant, which means that this technique is applied only in large
companies.

There is still room for developments in [171, GuT, 2001]:

- increasing productivity;
- wider application (uneven pile density, and un-level pile height, blends, unfixed structure);
- reducing investment costs;
- expanding the dye range to cover more, if not all, shades and depths.

**Economics**
The relatively high investment cost (no precise information given) of this sophisticated
equipment makes this technique more appropriate for large-volume print houses. Nevertheless,
digitally controlled printing and processing offers several economic advantages. First of all, this
technique allows the flexibility necessary to satisfy customer and retailer demands with just-in-
time delivery (quick reaction to customers’ orders, alterations easily made). Equally, the
stocking storage of finished goods becomes unnecessary as goods are produced to order. As
designs are stored in an electronic format there is no need for a large screen storage facility [171, GuT, 2001].

**Example Reference plants**
Many plants already use digital jet printing machines.
Plant BE009.
As already stated in Section 2.8.2, the latest developments of this technique are already applied on commercially available machines, such as the Zimmer’s Chromojet and the latest Milliken’s Millitron machine.

**Reference literature**
[171, GuT, 2001].

### 4.6.1.3 Ink-jet digital printing for flat fabric

#### Ex-Section 4.7.9

**Description**
Computer-controlled contact-free application of dye on the surface of flat fabric.

**Technical description**
Ink-jet digital printing (see Section 2.8.2) is increasingly used for light fabrics such as those that are typically printed in the textile finishing sector. Ink-jet printing (see also Section 2.8.2) seems to be the most appropriate technique in this case because the colour has to be applied to the surface (similar to paper).

Although great improvements have been made in ink-jet printing, production speeds are still low, which prevents this technique from yet replacing traditional analogue printing techniques. Nevertheless, it can already offer significant advantages in the production of short runs (typically less than 100 m), where the system losses in analogue printing are often comparable with or can even exceed the amount of paste printed on the fabric.

Urea (for dissolving highly concentrated dyes) and a thickening agent are needed. These auxiliaries cannot be injected through the needles, due to viscosity problems and the reduced size of the needles. Therefore, the first operation in the printing process is to cover the substrate (woven or knitted fabric) with the urea and the thickening agent.

After printing, the fabric generally has to be first dried and then fixation takes place. The fabric is then washed and finished.

Production velocities for ink-jet printing of flat fabrics and knitwear increased enormously between the years 2000 and 2010 and fabrics may be printed at a speed of up to 480 m²/h.

Via piezo-printheads a quality corresponding to 720 dpi can be achieved, resulting in the design of realistic photo motives.

Normally, the printing equipment consists of a fabric feeder printer and hot air jet stenter. The process runs automatically. Pretreated standard fabrics are fed to the capped head of the machine via printing blanket. At first, the printed fabric is dried by hot air (80-120 °C). The energy is supplied to the dryers in the form of electricity (for small equipment), steam or gas. Subsequently, the fabric is rolled up for further treatments like the standard processes fixation (PES: superheated steam, temperatures between 170°C and 180°C; CO, CV, SE: saturated steam, 102 °C), washing and finishing. Before refeeding, the printing blanket is cleaned automatically.
Substrate pretreatment is necessary because the printing inks contain only the highly purified dyestuff. For printing of cotton, viscose and silk, the impregnation for reaction as well as for the improvement of colour intensity is based on urea and sodium bicarbonate plus thickeners (e.g. alginate) to improve the contour definition. The corresponding pretreatment for PES fabrics is just performed with additional thickeners for increasing the dye adhesion as well as the contour definition. The fabric surface needs to be very smooth to avoid contact between the fabric and the printhead. [36, ÖKOPOL 2011]

A suitable set of dyes with affinity for the fabric is required. Companies like Ciba, Dyestar and Brookline have developed prints with such as acid, reactive and disperse dyes. Pigment formulations have also recently been made available but their part in classical textile printing is marginal. Pigment inks are mainly used for adjusted printing on T-shirts.

The most important segment for reactive and acid inks is sophisticated articles of cotton, silk, polyamide, and blends with elastane. Disperse inks are mainly used for flags and banners as well as popular promotional items and sophisticated synthetic fibre articles, preferable PES. [36, ÖKOPOL 2011]

The cleaning of the printheads is done automatically with a rubber wiper moistened with distilled water.

**Main-Achieved environmental benefits**

Dye residues are minimised to small amounts of residues in the cartridge. The application of the “colour-on-demand” principle means that the printing paste preparation stage is no longer needed. Therefore, there are no dye printing paste residues and no printing paste preparation tanks to be cleaned at the end of each run. The environmental advantage over conventional analogue printing techniques is particularly noticeable when processing small lots, when the printing paste losses are particularly high for analogue machines.

Water consumption for cleaning the printing blanket is low. Emissions to water are low due to the relatively small amount of dye uptake on the surface.

In pigment printing, the digital technique is even more advantageous because no afterwashing is needed. This means no residues or waste water from the process and also higher productivity. Pigment printing accounts for a large share of printed goods production and the omission of afterwashing makes this technique likely to become rapidly competitive with conventional printing methods.

**Environmental performance and operational data**

This technique is constantly being improved. However, the current speed of commercial ink-jet textile printing machines is in the range of 20 to 40 m² of fabric per hour.

The speed of commercial ink-jet textile printing machines is in the range of 30 m² to 480 m² of fabric per hour, and more specifically:

- 360 x 540 dpi 1-pass, bi-directional 480 m²/h;
- 360 x 360 dpi 2-pass, bi-directional 360 m²/h;
- 360 x 360 dpi 4-pass, bi-directional 160 m²/h;
- 720 x 720 dpi 2-pass, bi-directional 180 m²/h.

The speed is halved by unidirectional printing. Printing widths up to 320 cm are possible.

The energy consumption is around 15-17 kW. Dye uptake depends on the absorptive capacity of the fabric. For instance:

- reactive dyes on CO: 18 g/m²;
Chapter 4

- disperse dyes in sublimation printing: 10-12 g/m² or in direct printing: 14-15 g/m²;
- acid dyes on PA: 10-15 g/m².

It should be emphasised that digital printing machines can work 24 hours a day and, unlike with analogue printing, no extra time needs to be spent on cleaning operations when changing from one product to another.

Injector maintenance is still crucial.
Printhead maintenance is important. Depending on the type of printhead, repetitive contact may destroy the nozzle line.

Figure 4.60 gives an overview of the inks used in digital printing. The majority of digital printing is done by transfer printing on polyester (see Section 4.6.1.4). [133, Swedish EPA 2019]

![Overview of inks used in textile printing](image)

Figure 4.60: Overview of inks used in textile printing

Ink-jet printing cannot replace flat and rotary screen printing completely because printing speeds up to 2 000 m²/h are out of reach. To choose the right printing technology, speed as well as print design are important considerations, e.g. printing of spots and stripes is more cost-effective in flat or rotary screen printing. [36, ÖKOPOL 2011]

Cross-media effects
Ink-jet printing is considered a clean technology, but it cannot be considered as such when ink wasted (continuous ink printing technologies) or when jets are flushed out with solvent to prevent blocking when the printer is not in use.

In contrast to the cleaning and reuse of feeding tanks in analogue printing, in digital printing waste of cartridges can occur especially for small aggregates.

All large-scale plants use cans (101 up to maximum 120 l) which are returned to plastic recycling after cleaning. Some producers offer special recycling for cans.

Technical considerations relevant to applicability
Ink-jet printing is suitable for flat fabrics, woven and knitted. Only applicable to new plants or major plant upgrades.

Ink-jet printing is often considered a technique only applicable to the production of samples. However, using digital printing for sampling and analogue printing (screen printing) for industrial production implies that the sample obtained by digital printing matches the...
characteristics of the product obtained from analogue printing. This is currently very difficult for various reasons. Therefore the future aim of ink-jet printing in the textile sector is industrial scale production. The problem is that at the current performance speed, the process becomes economically attractive only at runs below 100 m (short runs). In conclusion, the ink-jet technique should be considered as BAT for the production of short runs rather than for the production of samples (with the aim of mass customisation where the sampling machine will be the production machine)[281, Belgium, 2002].

Economics
Information on investment cost was not made available.
Investment ranges from EUR 100 000 for smaller equipment with velocities up to 30 m²/h and EUR 300 000 to EUR 800 000 for large-scale plants. It is reported that the higher improved flexibility and promptness in satisfying customer and retailer demands compensate the machine costs [180, Spain, 2001].

Smaller lot size is the most important argument for ink-jet implementation. Creating a master for rotary screen printing, i.e. creating the screen, is time-consuming and costs up to EUR 400 per screen. Additionally, screens are provided in standardised dimensions. In this case digital printing is more flexible, supporting textile designers with new possibilities of design.

Example Reference plants
Many plants.
- Erler+Pless GmbH, DE-22043 Hamburg.
- Fahnen Herold - Wilhelm Frauenhoff GmbH & Co. KG, DE-42398 Wuppertal.
- Textildruck Imst GmbH & Co, AT-6460 Imst.
- WTG Westfälische Textilgesellschaft Klingenthal & Co mbH, DE-46397 Bocholt.
[36, ÖKOPOL 2011]

Plants from the data collection: CZ015, DE042, DE049, FR131, IT063, PT099 and PT108.

Reference literature
[180, Spain, 2001], [204, L. Bettens, 2000] [36, ÖKOPOL 2011] [133, Swedish EPA 2019]

4.6.1.4 Transfer printing
Description
The design (pattern) is first printed on an intermediate substrate (e.g. paper) using selected disperse dyes and is subsequently transferred to the fabric by applying high temperature and pressure (e.g. using a heat press or a calender).

Technical description
When the transfer paper is contacted with the material in a very hot press, the ink embedded within the paper is converted to a gas (sublimation) and penetrates directly into the fibres of the substrate. The ink becomes physically part of the material as the fibres are slightly melted.

Achieved environmental benefit
Reduced water and energy consumption

Environmental performance and operational data:
In transfer printing, there is no need for further treatment such as steaming or washing, which allows savings in energy and water consumption, although some energy is also needed for the heat press or the calender.
At temperatures above 200 °C, the ink on the transfer paper and the polymer fibres within the substrate are heated, enabling the transfer of ink to media. After 1 minute the heat press is removed, and the transfer paper is peeled off, leaving behind a permanent, full-colour graphic on the substrate. To ensure correct ink transfer, smooth saturation, and fine image quality, a coated sublimation transfer paper with excellent ink-absorption and high-ink release is required.

Technology has also been developed for transfer printing on cotton fibres under ambient conditions. [ 163, Cotton Incorporated 2018 ]

Request to TWG: please provide more information about the “cold” transfer printing on cotton.

Cross-media effects
Energy required for the heat press. Used transfer paper as waste.

Technical considerations relevant to applicability
Transfer printing is used only for synthetic fibres. Only applicable to new plants or major plant upgrades.

Economics
For transfer printing, the investments costs are of the order of USD 20 000 per printer. [ 135, RICARDO 2019 ]

Investment costs for double-sided transfer printing at room temperature are over USD 500 000. [ 163, Cotton Incorporated 2018 ]

Example plants
Plants from the data collection: DE042 and FR131.

Reference literature
[ 133, Swedish EPA 2019 ], [ 135, RICARDO 2019 ] [ 147, Sinocolor 2019 ] [ 163, Cotton Incorporated 2018 ]

4.6.1.5 [Volume minimisation of printing paste supply systems in rotary screen printing machines]. Optimised use of printing paste

Ex-Section 4.7.4

Description
Design and operational techniques to minimise the losses of printing paste residues include:

- minimisation of the volume of the printing paste supply system (e.g. minimising pipe lengths and diameters);
- ensuring a uniform paste distribution over the whole width of the printing machine;
- stopping printing paste supply shortly before the end of the printing;
- manual addition of printing paste for small lots.

Technical description
A typical printing paste supply system for textile rotary screen printing machines is illustrated in Figure 2.22. The volume depends on the diameter of the pipes and squeegee as well as on the pump design and the length of the pipes.

Printing paste supply systems, of which there may be up to 20 per printing machine, have to be cleaned at each change of colour or pattern and a considerable amount of printing paste finds its way into the waste water. As, for fashion patterns, a typical number of different colours per
design is 7 to 10. Typical system volumes in conventional and optimised printing paste supply systems for textiles are shown in Figure 4.61. Note that the figures given in this section are not applicable to carpet rotary screen printing (the screens in carpet rotary screen printing are much bigger—5–6 m width—and the the volumes of printing paste to be delivered are much higher than in most textile printing applications).

<table>
<thead>
<tr>
<th>Printing width (cm)</th>
<th>Conventional system (litres)</th>
<th>Optimised system (litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>164</td>
<td>5.1</td>
<td>2.1</td>
</tr>
<tr>
<td>184</td>
<td>5.2</td>
<td>2.2</td>
</tr>
<tr>
<td>220</td>
<td>5.5</td>
<td>2.3</td>
</tr>
<tr>
<td>250</td>
<td>5.8</td>
<td>2.4</td>
</tr>
<tr>
<td>300</td>
<td>6.2</td>
<td>2.6</td>
</tr>
<tr>
<td>320</td>
<td>6.5</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Notes:
\(^{(1)}\) including pipes, pump and squeegee

Figure 4.61: Volume of conventional and optimised printing paste supply systems in rotary screen printing machines for textiles

In addition to this volume, residual printing paste in the rotary screens has to be taken into account, which may be about 1–2 kg. Thus, in conventional systems the loss per supply system is up to 8 kg.

If this quantity is compared with the amount of paste applied on the printed fabric (see table below), it becomes apparent that the volume of the supply system is highly significant and may even exceed the amount of paste printed on the fabric (for pattern/batch lengths of about 120 m). In Europe in recent years, average printing batch lengths have significantly decreased to only 400–800 m.

<table>
<thead>
<tr>
<th>Pattern/batch length (m)</th>
<th>Weight (kg) (^{(1)})</th>
<th>Printing paste required according to the degree of coverage (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>25%</td>
</tr>
<tr>
<td>120</td>
<td>21.6</td>
<td>5.4</td>
</tr>
<tr>
<td>500</td>
<td>90.0</td>
<td>22.5</td>
</tr>
<tr>
<td>1000</td>
<td>180.0</td>
<td>45.0</td>
</tr>
<tr>
<td>1500</td>
<td>270.0</td>
<td>67.5</td>
</tr>
</tbody>
</table>

Source: [7, UBA, 1994]

Notes:
\(^{(1)}\) assuming 180g/running metre

Figure 4.62: Amount of printing paste required for printing various lengths of fabric at different degrees of coverage

minimising the system volume therefore has major effects in reducing printing paste emissions to waste water.

Diameters of pipes and squeegees have been reduced to 20-25 mm, leading to substantial reductions.

Along with minimum-volume supply systems, paste residues can be minimised by improving paste recovery from the supply system itself. New pumps can be operated in both directions. Thus, at the end of each run, the printing paste can be partly pumped back into the drum. The
problem of air being drawn in via the holes in the squeegee can be solved by applying the technique described in Section 4.6.1.6.

Additional measures are as follows:

- Using squeegees with an even paste distribution over the whole width (minimisation of residual printing pastes in the screens). This is combined with an even paste distribution inside the stencil.
- Manual stopping of printing paste supply shortly before finishing a run in order to minimise the residual printing pastes in the rotary screens.

For small short run lengths in particular, the following measures may also be considered:

- not using the supply system, but instead injecting small quantities of printing paste (1-3 kg) directly into the squeegee manually or by manual insertion of small troughs (with a cross-section of 3x3 cm or 5x5 cm);
- minimisation of pipes by supplying the printing pastes through funnels positioned directly above the pumps.

Main Achieved environmental benefits

- Reduced generation of waste and of waste water.
- Resource efficiency.

Environmental performance and operational data

System volumes and consequent losses can be reduced significantly (according to industrial experience, a reduction of up to one third is possible), depending on the age of the equipment [179, UBA, 2001].

Table 4.73 below shows the typical system volumes in conventional and optimised printing paste supply systems as well as the reduction of printing paste losses for textiles are shown in Figure 4.61. Note that the figures given in this section are not applicable to carpet rotary screen printing (the screens in carpet rotary screen printing are much bigger – 5-6 m in width – and the volumes of printing paste to be delivered are much higher than in most textile printing applications).

<table>
<thead>
<tr>
<th>Printing width (cm)</th>
<th>Conventional system (1) (litres)</th>
<th>Optimised system (1) (litres)</th>
<th>Reduction of printing paste losses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>164</td>
<td>5.1</td>
<td>2.1</td>
<td>59</td>
</tr>
<tr>
<td>184</td>
<td>5.2</td>
<td>2.2</td>
<td>58</td>
</tr>
<tr>
<td>220</td>
<td>5.5</td>
<td>2.3</td>
<td>58</td>
</tr>
<tr>
<td>250</td>
<td>5.8</td>
<td>2.4</td>
<td>59</td>
</tr>
<tr>
<td>300</td>
<td>6.2</td>
<td>2.6</td>
<td>58</td>
</tr>
<tr>
<td>320</td>
<td>6.5</td>
<td>2.7</td>
<td>58</td>
</tr>
</tbody>
</table>

(1) Including pipes, pump and squeegee.

Source: [179, UBA, 2001]

Operational data

Measures such as the manual injection or insertion of printing paste and the manual stopping of the printing paste supply system shortly before the end of the run need trained and motivated staff. Meanwhile, some companies have put in practice the manual injection of printing paste,
but others report that, even for small lots (up to 120 m), the technique is difficult to apply. Reproducibility may be affected because the quantity of printing paste to be injected varies according to the pattern, which is difficult for the staff to manage for the staff. Moreover, a constant level of printing paste within the screen cannot be maintained, which may affect the constancy of the printing quality.

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
The described measures described are applicable to both existing and new installations. Generally, there are no technical restrictions to the applicability of this technique.

Economics
The installation of 12 sets of volume-minimised pipes and squeegees requires an investment cost of about EUR 25 000.

Driving force for implementation
- The need to Minimising production costs by minimising printing paste losses and costs associated with waste water treatment. problems with waste water disposal have been the main driving forces.
- Environmental legislation.

Example Reference plants
Many plants in Europe and world-wide have been retrofitted with minimised printing paste supply systems that operate successfully.
Plants from the data collection: BE009, DE025, IT063, PT108 and SE118.

Reference literature
[179, UBA, 2001], [51, OSPAR, 1994] (P100), [36, ÖKOPOL 2011]

4.6.1.6 [Recovery of printing paste from supply system in rotary screen printing machines] Recovery of residual printing paste

Ex-Section 4.7.5

Description
Residual printing paste in the supply system is pumped back or pushed back to its original container (e.g. by a ball controlled by air pressure).

Technical description
This technique allows the recovery of the printing paste remaining in the supply system in rotary screen printing machines at the end of each run. Before filling the system, a ball is inserted in the squeegee and then transported by the incoming paste to its end. After finishing a print run, the ball is pressed back by controlled air pressure, pumping the printing paste in the supply system back into the drum for reuse. Systems available for reusing residual printing paste are described in Section 4.6.1.7.

The technique is illustrated in the figure below, showing the ball during the phase in which the pump is transporting the paste back to the drum.
Main-Achieved environmental benefits
Reduced generation of waste and of waste water.

Environmental performance and operational data
Printing paste losses are reduced dramatically. In textiles, for instance, at a printing width of 162 cm, the loss is reduced from 4.3 kg (in the case of a non-optimised printing paste supply system) to 0.6 kg.

Rotary screen printing machines have up to 20 supply systems, although in practice, for fashion patterns, 7–10 different printing pastes are common. Therefore, the 3.7 kg of printing paste saved per supply system have to be multiplied by 7–10. Water pollution can thus be minimised considerably.

To achieve maximum benefit from this measure, modern printing machines with minimum-volume feed systems are should be used (see Section 4.6.1.5).

Operational data
The described technique is successfully applied in textile finishing mills, especially in combination with recycling of the recovered printing paste.

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
The push-back system is only applicable to rotary screen printing. The technique is applicable to new installations (new rotary screen printing machines). Certain existing machines can be retrofitted. There is only one supplier for this technique (Stork Brabant B.V., NL 5830 AA Boxmeer). All their machines newer than the so-called RD-III (that is RD-IV and all subsequent models) can be retrofitted with the described system.
As mentioned earlier, the technique is applied in textile finishing mills (for flat fabrics). In principle this system can also work for carpets, but it is not applied for various reasons. Probably, the main reason is related to the type of thickeners most commonly used in carpet printing pastes. These are based on guar gum, which is quite relatively inexpensive, but has a limited shelf life and therefore cannot be stored for a long time before reuse (it is biodegradable and the growth of bacteria and other organisms such as yeasts rapidly alters destroy the viscosity).

Economics
The investment for retrofitting this recovery system to a rotary screen printing machine with 12 new squeegees and pipes (for a printing width of 185 cm) is about EUR 42 000. The next table Table 4.74 below shows the savings achievable in the reference a typical mill.

Table 4.74: Calculation of savings achievable in a typical textile mill by installing the referenced printing paste recovery system (the number of changes as well as the number of printing pastes per design may be higher in industrial practice)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of changes of printing pastes per day</td>
<td>8</td>
</tr>
<tr>
<td>Number of working days per year</td>
<td>250</td>
</tr>
<tr>
<td>Average number of printing pastes per design</td>
<td>7</td>
</tr>
<tr>
<td>Saving of printing paste saved per supply system</td>
<td>3.7 kg</td>
</tr>
<tr>
<td>Price of printing paste</td>
<td>EUR 0.6 euros/kg</td>
</tr>
<tr>
<td>Saving per year</td>
<td>EUR 31 080 euros/yr</td>
</tr>
</tbody>
</table>

NB: The number of changes as well as the number of printing pastes per design may be higher in industrial practice.

Source: [179, UBA, 2001]

The example does not include the investment cost of new pumps, so a certain range of viscosity needs to be maintained. When a wide viscosity range is required, the pumps have to be replaced. The total investment cost is then reported to range between about EUR 90 000 and EUR 112 000 euros.

A payback time of about 2 years can therefore be considered realistic, but only when all of the whole amount of recovered printing paste is reused. In practice this does not happen, especially with mills that use several different types of printing pastes. In such mills, due to logistical problems (limited storage and handling capacities), reuse rates of only 50-75 % are reported, which significantly extends the payback period [179, UBA, 2001].

Driving force for implementation
Severe waste water problems and the need to reduce Reduction of printing paste losses for economic and environmental reasons have been the main driving forces.

Example Reference plants
Worldwide, but especially in Europe, there are many rotary screen printing machines in operation, equipped with the described technique.

Plants from the data collection: DE032 and PT108.

Reference literature
[179, UBA, 2001], [180, Spain, 2001].
4.6.1.7 [Recycling] Reuse of residual printing pastes

Ex-Section 4.7.6

**Description**
The residual printing paste is collected, sorted by type, stored and reused. The degree of reuse of printing paste is limited by its perishability.

**Technical description**
Printing pastes are highly concentrated preparations that consist of dyestuff, thickener and various other auxiliaries according to the different types of pastes (e.g. pigment, reactive, vat and disperse printing pastes). Printing paste residues can reach levels as high as 40-60% in non-optimised equipment. A large portion of these residues is still discharged to the effluent, thus causing considerable waste water problems (see Section 2.8.3).

For a long time, printing pastes were prepared manually, which meant that residues were reused, but the extent and manner of that reuse were highly dependent on the staff responsible and on the production schedule. Today, computer-assisted systems offer more opportunities for recycling printing pastes. In most companies, printing pastes are prepared with computerised systems (each printing paste has its specific recipe which is saved electronically). At the end of a run, each residual paste is weighed and sent to a defined location in a storage facility. The composition is saved electronically and computer programs calculate the formulation of new printing pastes, taking account of the amount, composition and durability (which is not normally a problem) of the residues to be reused.

Another option is to empty all drums with residual printing paste and sort it according to its chemical characteristics (i.e. type of dyestuff and thickener). The drum is cleaned with a scraper to minimise the printing paste loss, then is washed and reused for the preparation of new printing pastes.

**Main-Achieved environmental benefits**
The quantity of residual printing pastes to be disposed of is significantly reduced both as waste water and solid waste.
The amount of residual printing paste is reduced by at least 50% and in many cases by about 75% [179, UBA, 2001], [192, Danish EPA, 2001].

**Environmental performance and operational data**
Textile finishing mills that have applied these techniques report that such systems need some time for implementation in daily routine, but that, after managing any teething problems, they work satisfactorily. The recycling systems described here are most efficient in companies having with only one or two kinds of printing pastes (e.g. pigment and reactive printing pastes). In companies using various different types of printing pastes, the management of a large number of different mixtures may be difficult (logistical problems, limited capacity of the storage area, etc.). In these cases, the recycling rate may be in the range of 50-75% only [179, UBA, 2001].

In the example plant A), the amount of paste washed out from the paste containers was reduced by 50%. It was possible to recover more than 90% of the printing paste residues.
In the example plant B), the recovery rate is 75% after 5 years of implementation, applying four pigment types and about 12 different printing paste systems. In the beginning, only one printing paste system was used, leading to a recovery rate of 90%. The remaining waste amount depends significantly on the lot size. [36, ÖKOPOL 2011]

Trained and motivated personnel are needed for manual operations, such as scraping buckets, aimed at increasing the paste recovery rate. Printers claim that specialised personnel are not willing to scrape buckets, especially given the number of buckets a day that need to be scraped for a typical 12-position printer that has to be changed every 600-800 metres on average.
Operating with modern printing machines with a built-in system for mechanical removal of printing paste from the pipes and hoses of the feeding system will increase the amount of printing paste that can be collected and reused (see Section 4.6.1.6).

Cross-media effects
None believed likely.
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique. Systems for recycling of printing pastes are applicable in the textile industry both in existing and new installations. However, for totally computerised systems, the printing section must have a minimum size of three rotary screen and/or flat screen printing machines [179, UBA, 2001]. This technique is not used applicable in the carpet industry for the same reasons explained in Section 4.6.1.6.

Economics
Investment costs are about EUR 0.5-1 million euros, depending on the size and number of different printing pastes to be recycled. Payback periods are reported to vary between 2 and 5 years depending on individual circumstances [179, UBA, 2001].

Driving force for implementation
Economic considerations in terms of savings in printing paste supply and costs related to problems regarding residual printing paste disposal have been the main driving forces [179, UBA, 2001].

Example Reference plants
Many plants in Europe and worldwide.
Example plant A) Plant DE032 of the data collection.
Example plant B) KBC, DE-79540 Lörrach.
[ 36, ÖKOPOL 2011 ]

Plants from the data collection: CZ019, DE025, PT099, SE118 and UK127.

Important suppliers are:
- Stork Brabant B.V., NL - 5830 AA Boxmeer
- GSE Klieverik Dispensing, NL - 6971 GV Brummen

Reference literature
[179, UBA, 2001], [192, Danish EPA, 2001] [ 36, ÖKOPOL 2011 ]

4.6.2 Printing with dyes

4.6.2.1 Urea substitution and/or reduction
Increase of moisture content in reactive printing with reactive dyes

Description
Reactive printing is carried out without urea by controlled addition of water to the textile materials.
**Technical description**

The urea content in reactive printing paste can be up to 150 g/kg paste. Urea is also used in printing pastes for vat dyes, but in much lower concentrations (about 25 g/kg paste). Urea is applied to:

- increase the solubility of dyestuffs with low water solubility;
- increase the formation of condensate, which is necessary for allowing migration of the dyestuff from the paste to the textile fibre;
- form condensates with a higher boiling point (115 °C) which means that requirements for constant operating conditions are lower (non-constant operating conditions can negatively affect reproducibility if urea is not used).

Urea can be substituted by controlled addition of moisture for printing on cotton, viscose or cotton blends (moisture content of 10 wt-% for cotton fabric, 20 wt-% for viscose fabric and 15 wt-% for cotton blends).

Moisture can be applied either as foam or by spraying a defined quantity of water mist.

In many cases, it is possible to reduce the urea content in reactive printing paste by optimised dosing without additional technical equipment when using silk and viscose fabric. [36, OKOPOL 2011]

**Main Achieved environmental benefits**

Reduced emissions to water and air.

In the textile finishing industry, the printing section is the main source of urea and its decomposition products (NH$_3$/NH$_4^+$). During wastewater treatment, the nitrification of the excess ammonia involves high energy consumption. Discharge of urea, ammonia and nitrate contributes to eutrophication and aquatic toxicity.

The presence of urea in the textile substrate leads also to ammonia emissions to air from the thermal treatment which follows printing.

Minimisation/elimination of urea at source significantly reduces these adverse effects.

**Environmental performance and operational data**

In reactive printing, the urea content in the printing paste can be reduced from 150 g/kg paste to zero by application of moisture. In the case of phthalocyanine complex reactive dyes, however, reduction is possible only to 40 g/kg paste because of the bad migration properties typical of these large-molecule dyestuffs [179, UBA, 2001].

By avoiding the use of urea in reactive printing pastes, the ammonia concentration in the mixed effluent of a finishing mill with a significant printing section decreased from about 90-120 mg NH$_4^+$-N/l to about 20 mg NH$_4^+$-N/l [179, UBA, 2001].

Even without using this referenced technique, the amount of urea consumed can be reduced in reactive paste from about 150 g/kg to about 50 g/kg of printing paste for silk and 80 g/kg for viscose, and still maintain the quality standards.

**Cross-media effects**

The application of moisture needs energy, but this consumption is significantly lower than the energy required for the production of urea [179, UBA, 2001].

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique. The foam and the spraying systems are applicable to both new and existing plants performing reactive printing [179, UBA, 2001].
Chapter 4

For silk and viscose articles, however, it is not possible to completely avoid the use of urea with the spraying system. Indeed, the technique is not reliable enough to ensure a uniform dosage of the low moisture add-on required for these fibres and, especially for fine articles, cases have been reported where spraying systems did not meet the quality standards.

On the contrary, in contrast, the foaming system has proven successful for several years for viscose in complete elimination of without the need for urea [179, UBA, 2001]. This technique should in principle be technically viable also for silk, although it has not yet been proven. Silk is known to be less problematic as a fibre than viscose, but it is typically processed in smaller runs.

Moisture application in unfixed printing is technically challenging and requires close quality control. In some installations, in particular in short steamers, the reduction of urea is not possible for quality reasons. [36, ÖKOPOL 2011]

**Economics**

The investment costs for spraying equipment including on-line moisture measurement are about EUR 30 000 euros, but the foam system is significantly more expensive. Approximately EUR 200 000 euros are required for a foaming machine which relates to a production capacity of up to about 80 000 linear metres per day. The foaming technique has been operated under economically viable conditions in plants—of—-with a capacity of about 30 000 linear metres, 50 000 linear metres and 140 000 linear metres per day.

**Driving force for implementation**

Stringent limits applied by local authorities for NH₄⁺-N in waste water, due to eutrophication and aquatic toxicity in surface water, have promoted the introduction of this technique.

The application of this technique is also very attractive for mills discharging to a municipal waste water treatment plant. Because of the high energy consumption for biological nitrification, many municipalities now charge indirect dischargers for nitrogen emissions.

**Example Reference plants**

Many plants in Europe. Example plants where the technique is currently applied are: Ulmia, DE-Ravensburg-Weissenau; KBC, DE-Loerrach; Textilveredlung Wehr, DE-Wehr [179, UBA, 2001]

Plant DE049.

**Reference literature**

[179, UBA, 2001] [36, ÖKOPOL 2011]

### 4.6.2.2 [Reactive] Two-padding step printing with reactive dyes

**Description**

Printing is carried out without urea by two padding steps with intermediate drying and addition of fixation agents (e.g. an alkaline solution).

**Technical description**

As already described in Section 4.6.2.1, in conventional one-step printing with reactive dyes, urea is used to increase solubility of the dyestuffs and to improve dyestuff migration from the printing paste to the textile fibre.

Minimisation or even substitution of urea is possible in the one-step method by controlled addition of moisture.
Another option is the two-step printing method, involving the following steps:

- padding of the printing paste;
- intermediate drying;
- padding with alkaline solution of fixating agents (especially water-glass);
- fixation by means of overheated steam;
- washing steps (to remove thickeners and improve fastness properties).

The process is carried out without urea.

**Main Achieved environmental benefits**
A significant reduction of the ammonia content in waste water and reduced waste off-gas problems are the main environmental benefits. In addition, the lifetime of printing pastes is lengthened, which increases the opportunities to recycle the residual printing pastes [179, UBA, 2001].

**Environmental performance and operational data**
A typical recipe for the printing paste is given below [179, UBA, 2001].

**Thickening stock solution:**
- alginate-based thickening agent: 700 g
- oxidising agent: 50 g
- complexing agent: 1 g
- preserving agent: 0.5–1 g
- water: x g
- Total: 1000 g

**Printing paste:**
- thickener stock solution: 800 g
- reactive dyestuff: x g
- water: y g
- Total: 1000 g

Fixation is carried out by means of overheated steam (90 s at 125 °C).

It should be noted that this technique is more complex and slower than the one-phase process.

**Cross-media effects**
None believed likely. Intermediate drying requires additional energy and is therefore associated with the environmental impacts of energy production. [36, ÖKOPOL 2011]

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of this technique. Two-step reactive printing can be carried out on cotton and viscose substrates. Application of the fixation liquor needs the combination of an impregnation device with a steamer. Overheated steam is necessary. Reactive dyes based on monochlorotriazine and vinylsulphone types can be used [179, UBA, 2001].

**Economics**
No information was made available provided.

**Driving force for implementation**
Environmental legislation and quality aspects are the reasons for implementing a two-step printing method.

**Example Reference plants**
Many plants in Europe and worldwide.
Reference literature
[179, UBA, 2001] with reference to:
“DyStar, 2000”
DyStar, DE Frankfurt/Main
Product information (2000)
[36, ÖKOPOL 2011]

4.6.3 Printing with pigments

4.6.3.1 Pigment printing pastes with improved optimised environmental performance

Ex-Section 4.7.3

Description
Use of printing chemicals with improved environmental performance this includes:

- thickeners with no or low contents of volatile organic compounds;
- fixation agents with low contents of formaldehyde-containing compounds;
- binders with low contents of ammonia and without formaldehyde-containing compounds.

Technical description
The final stages in pigment printing consist of drying and fixing the printed fabric with hot air. In both stages, emissions of volatile organic compounds to air may be significant (see also Sections 2.8.3 and 8.7.2).

White spirit used for emulsion thickeners was a major source of volatile organic compounds in the past. Water-in-oil (full emulsion) thickeners seem no longer to be applied in Europe and half-emulsion printing pastes (oil in water) are only occasionally used. Hydrocarbons (predominantly aliphatic) are still found in exhaust air, however, mainly arising from mineral oil contained in synthetic thickeners. Their emission potential can be up to 10 g $\text{Org.-C}/\text{kg textile}$.

New-generation thickeners contain minimal amounts of volatile organic solvents. They are based on polyacrylic acid or polyethylene glycol compounds instead of mineral oils. Products have also been developed that do not contain any volatile solvent. They are supplied in the form of non-dusting granules or powders.

According to the Ecolabel criteria for textile products, the printing pastes used shall not contain more than 5 % w/w VOCs. [48, COM 2014]

Another potential source of air emissions to air in pigment printing is fixing agents. The cross-linking agents contained in these auxiliaries are largely based on methylol compounds (melamin compounds or urea-formaldehyde pre-condensates) that give rise to formaldehyde and alcohols (mainly methanol) in the exhaust air. New low-formaldehyde products are now available. Acrylate dispersions used as binders and in some cases synthetic thickeners may also be sources of formaldehyde emissions. The development of a formaldehyde-free printing system based on helizarin binders allows the high quality standard of pigment printing to be maintained without the development of formaldehyde emissions [36, ÖKOPOL 2011]

Furthermore, optimised printing pastes are APEO-free (pigment printing auxiliaries may be found in the waste water as a result of cleaning operations, etc.) and have a reduced ammonia content. Ammonia is used as an additive in binders and is also a source of air pollution.

Main-Achieved environmental benefits

- Reduction of emissions of organic compounds, formaldehyde and ammonia to air.
- When using formaldehyde-free pigment printing systems, formaldehyde emissions are completely prevented.
Environmental performance and operational data

Table 4.75 below shows for three typical thickeners the emissions levels of volatile organic compounds (VOCs) that may arise from drying and fixing.

Table 4.75: Volatile organic carbon-compounds emissions in pigment printing

<table>
<thead>
<tr>
<th>Operation</th>
<th>Pigment print recipe I (g Org- C/kg textile)</th>
<th>Pigment print recipe II (g Org- C/kg textile)</th>
<th>Pigment print recipe III (g Org- C/kg textile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drying</td>
<td>2.33</td>
<td>0.46</td>
<td>0.30</td>
</tr>
<tr>
<td>Fixing</td>
<td>0.04</td>
<td>0.73</td>
<td>0.06</td>
</tr>
<tr>
<td>Total</td>
<td>2.37</td>
<td>1.19</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Recipe I is an already optimised thickener, but still containing hydrocarbons. In the optimised recipe II the mineral oil is replaced by polyethylene glycol, while recipe III uses a powder thickener. With recipe III formaldehyde emissions can be kept below 0.4 g CH₂O/kg of textile (assuming 20 m³ air/kg of textile). As a result, the carry-over of volatile substances from printing to finishing processes can also be reduced to < 0.4 g Org- C/kg.

Using optimised printing pastes, ammonia emission can also be reduced below 0.6 g NH₃/kg of textile (assuming an air/textile ratio of 20 m³/kg).

Operational data

There has been no evidence of variations in operating conditions, product quality or process control [180, Spain, 2001].

Cross-media effects

None believed likely.

Thickeners based on powders may generate dust or block the stencils [179, UBA, 2001].

Technical considerations relevant to applicability

The technique is applicable in new and existing installations [179, UBA, 2001], [180, Spain, 2001].

Economics

The higher costs of the printing pastes are offset by the reduced air treatment costs (lower emissions of organic volatile organic compounds) [180, Spain, 2001], [179, UBA, 2001].

Driving force for implementation

Environmental legislation (regarding, in particular, emission limits set for volatile organic carbon-compounds, formaldehyde and ammonia) is the main motivation for the use of optimised printing pastes [179, UBA, 2001].

Example Reference plants

Many plants in Europe and worldwide.

Plants from the data collection: DE049, PT108, PT099 and UK127.

Reference literature

[180, Spain, 2001], [51, OSPAR, 1994] (P096, P106), [61, L. Bettens, 1999], [179, UBA, 2001] [36, ÖKOPOL 2011 ] [48, COM 2014 ]
4.7 Finishing

4.7.1 General techniques

4.7.1.1 Laser and/or plasma surface treatment of fibre

Description
Laser and/or plasma treatments are used to modify the fibre surface by high-energy heat and/or reaction with charged gaseous species (e.g. ions, radicals) to achieve the required functional properties.

Technical description
Surface properties like adhesion, wetting properties (hydrophilicity, hydrophobicity, oleophobicity), fire retardancy and anti-microbial properties of the fibres (fabrics or garment) are improved by modifying their surface with the heat of a laser beam (UV) and/or dielectrical discharge plasma in normal atmosphere (i.e. corona) or inert or reactive gas plasma (e.g. nitrogen, argon and carbon dioxide gas).

Heat provided by a laser beam erodes a pattern on the surface of the textile fibre (fabric, garment). A mechanical frame holds the textile fibre, fabric or product to enable the laser beam perform the heat treatment. The laser beam is manipulated to treat the whole surface or certain focused areas (e.g. to produce a pattern). Intense heat from the laser beam modifies (melts or vapourises) the surface of the fibre in a very short time period.

In plasma treatment, the surface properties (< 0.1 μm of depth) of the textile fibre are enhanced due to the reaction (e.g. oxidation, degradation, cross-linking) with charged particles (for example, ionised gases (e.g. oxygen, nitrogen, argon), free radicals and neutrals) in a controlled environment of selected gases. The plasmas are generated by different types of power supply: low frequency (LF, 50 kHz to 450 kHz), radio frequency (RF, 13.56 MHz to 27.12 MHz) and microwave (MW, 915 MHz to 2.45 GHz). The plasmas used in textile treatment are cold plasmas, which are broadly classified as low-pressure plasmas (LPP) and atmospheric-pressure plasmas (APP). Atmospheric pressure plasmas are further divided into corona discharge, dielectric barrier discharge (DBD) and atmospheric pressure glow discharge (APGD).

Textile fibres, fabric or garments pretreated with laser and/or plasma treatments require less or no finishing treatment and demonstrate improved dyeability (e.g. shorter times, greater exhaustion).

Achieved environmental benefits
- Reduced energy consumption.
- Reduced effluent.
- Reduced chemicals (finishing agents) consumption.

Environmental performance and operational data
The lasers used are CO₂ gas-based (wavelength of 10 nm - ultraviolet). The degree of surface treatment depends upon the wavelength, power density, and pulse width of the laser beam. The productivity of laser technology is up to three times higher than that possible with the conventional machines.

A variety of low-pressure (e.g RF-powered) and atmospheric-pressure plasma machines for batch (off-line) and/or in-line processing of specific textile products are commercially available.

Also, laser and/or plasma technology makes wetting, drying and effluent treatment operations obsolete, and consequently uses less energy and chemicals than conventional wet processing techniques.
Cross-media effects
The laser beam and plasma decompose the fibre surface and may result in some vapours (fumes, waste gases) which need to be exhausted and may require emission abatement.

Technical considerations relevant to applicability
Generally applicable to all fibres (cotton, wool, synthetic).

Economics
Investment costs are estimated to be between USD 200 000 and USD 500 000 for laser equipment [163, Cotton Incorporated 2018]

The operational costs of energy consumption in laser treatment are lower than the operational costs of drying and the water treatment of finishing effluents from conventional finishing.

Driving force for implementation
- Higher productivity.
- Economics (reduced costs for energy, water and chemicals consumption).
- Environmental legislation.

Example plants
Many plants around the world use laser technology to treat denim fabric or garments (e.g. several hundred machines operate in Bangladesh [174, TextileToday 2017]).
Plant DE042 (corona treatment, for PES finishing).

Reference literature
[135, RICARDO 2019], [166, Gashti et al. 2011], [169, Lawrance 2017], [171, Industry Innovation Centre 2015], [174, TextileToday 2017], [163, Cotton Incorporated 2018].

4.7.1.2 Surface treatment of denim with air nano-bubbles

Description
Finishing agents or dyestuffs are transported to the surface of the fibres with the flow of micro- or nano-size air bubbles in a minimal liquid bath.

Technical description
Chemical products for finishing (softeners, easy-care/wrinkle-free resins, resins for 3D effects, liquid-repellents, antimicrobials, dyes, etc.) are brought into contact with the fabric or garments with a minimal amount of water, being transported to the fibres by a flow of micro- or nano-bubbles of air.

Achieved environmental benefits
- Reduced water consumption and effluent.
- Reduced energy consumption.
- Reduced chemicals (finishing agents) consumption.

Environmental performance and operational data
[172, Puchol et al. 2017]
For the softening process for garments (cotton, polyester, synthetic blends), the treatment time is less than 25 minutes (for 50 kg of textile) and the liquor ratio 1:0.3 for lightweight garments and 1:0.5 for heavy clothing (11.5 % better than the traditional process).

For DWOR (Durable Water- and Oil-Repellents) treatment of garments (protective clothing made of cotton and cotton/polyester blends) with C6 fluorocarbon, the treatment time is less than 40 minutes (50 kg of textile) and the liquor ratio 1:0.8. The process consumes 20 % less C6 fluorocarbon than the traditional process.
In exhaustive dyeing with reactive dyes (dyeing technique that produces irregular effects known by the Italian expression *maltinto*), no salt is needed and dyeing proceeds at an ultra-low liquor ratio.

**Cross-media effects**
None identified.

**Technical considerations relevant to applicability**
Generally applicable to denim.

**Economics**
High initial investment costs, but substantial savings on costs for water and chemical consumption and effluent treatment.

**Driving force for implementation**
- Higher productivity.
- Economics (reduced costs for energy, water and chemicals consumption).
- Environmental legislation

**Example plants**
No information provided.

Request to TWG: please provide information about plants applying this technique.

**Reference literature**
[135, RICARDO 2019], [172, Puchol et al. 2017], [173, JEANOLOGIA S.L. 2015].

**4.7.2 Easy-care**

**4.7.2.1 [Formaldehyde-free or low formaldehyde-poor easy-care finishing]**
Cross-linking agents with improved environmental performance

**Ex-Section 4.8.2**

**Description**
The cross-linking agents which are used in easy-care finishing have no or low potential for formaldehyde releases.

**Technical description**
Easy-care finishing is mainly carried out on cellulosic fibres and their blends in order to increase the crease recovery and/or dimensional stability of the fabrics (see Sections 2.9.2.1 and 8.8.1).

Easy-care finishing agents are mainly compounds synthesised from urea, melamine, cyclic urea derivatives, alcohols, glyoxal, and/or formaldehyde. Cross-linking agents (reactive groups) are composed of free or etherificated N-methylol groups (see Figure 4.64 below).
Figure 4.64: Chemical structure of cross-linking agents

Formaldehyde-based cross-linking agents may release free formaldehyde. According to the harmonised classification, formaldehyde is classified as carcinogenic 1B and mutagenic 2 [47, EU 2008] thought to be carcinogenic and can be harmful is a threat to the workforce (formaldehyde can also be released, for example, during cutting operations). The presence of free formaldehyde or partly hydrolysable releasable formaldehyde on the finished fabric also represents a potential risk for the final consumer. The European Ecolabel scheme for textile products [48, COM 2014] sets a threshold of 16–16 ppm for products that come into direct contact with the skin and for products for babies and children under 3 years old and 75 ppm for garments with limited skin contact and interior textiles.

Low-formaldehyde or even formaldehyde-free products are an alternative (see Table 4.76 below). Formaldehyde-free cross-linking agents are based on modified (methylated and glycolated derivatives of) dimethyldihydroxyethylene urea (DMDHEU) (e.g. 1,3-dimethyl 4,5-dihydroxy 2-imidazolidinone (DHDIM)) or polycarboxylic acids (e.g. 1,2,3,4-
butanetetracarboxylic acid (BTCA), citric acid or maleic acid. [197, Saxena et al. 2017] [230, Roy Choudhury 2017]

Low-formaldehyde DMDHEU-based cross-linking agents (with less than 0.1 % residual formaldehyde in the formulation) are also used for reducing formaldehyde emissions in the easy-care treatment.

Table 4.76: Overview of the formaldehyde release potential of the most important cross-linking agents

<table>
<thead>
<tr>
<th>Type of cross-linking agent</th>
<th>Formaldehyde release potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimethylol urea</td>
<td>High</td>
</tr>
<tr>
<td>Melamine formaldehyde condensation products</td>
<td>High</td>
</tr>
<tr>
<td>Dimethylol dihydroxyethylene urea (DMDHEU)</td>
<td>High</td>
</tr>
<tr>
<td>Dimethylol dihydroxyethylene urea (DMDHEU) derivatives (most commonly used)</td>
<td>Low</td>
</tr>
<tr>
<td>Modified dimethyl dihydroxyethylene urea</td>
<td>Formaldehyde-free None</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Main-Achieved environmental benefits
Reduced emissions of formaldehyde to air.

Environmental performance and operational data
Table 4.77 below shows the emission factors related to the use of different cross-linking agents.

Table 4.77: Potential emissions of formaldehyde and methanol caused by the use of different types of cross-linking agents in textile finishing

<table>
<thead>
<tr>
<th>Type of cross-linking agents</th>
<th>Formaldehyde</th>
<th>Methanol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Textile substrate-based emission factor (g/kg textile substrate)</td>
<td>Resulting concentration with regard to an air-to-textile ratio of 20 m³/kg (mg/Nm³)</td>
</tr>
<tr>
<td>DMDHEU low-methanol</td>
<td>0.15-0.24</td>
<td>8-12</td>
</tr>
<tr>
<td>DMDHEU high-methanol</td>
<td>0.10-0.38</td>
<td>5-19</td>
</tr>
<tr>
<td>DMDHEU high-methanol moist cross-linking agent</td>
<td>0.30-0.80</td>
<td>15-40</td>
</tr>
<tr>
<td>Melamine Type I</td>
<td>0.61-1.07</td>
<td>31-54</td>
</tr>
<tr>
<td>Melamine Type II</td>
<td>0.68-0.80</td>
<td>29-40</td>
</tr>
</tbody>
</table>

Source: [36, ÖKOPOL 2011]

With low-formaldehyde or formaldehyde-free products, a reduction of formaldehyde emissions in finishing is achieved. Formaldehyde residues on the textiles can be minimised (< 75 ppm
mg/kg in the textile products, or even lower than 30-16 ppm for low-formaldehyde-content consumer requirements). With optimised catalysts, the curing temperature and therefore the energy consumption can be reduced.

If directly heated stenters are inefficiently maintained, they may also emit formaldehyde in the exhaust air.

**Operational data**

A typical recipe for low-formaldehyde finishing of cotton (woven fabric) is:

- 40-60 g/l cross-linking agent;
- 12-20 g/l catalyst;
- liquor pick-up: 70 %;
- drying and condensation (150 °C, 3 minutes).

A typical recipe for formaldehyde-free finishing of cotton is:

- 80-120 g/l cross-linking agent (integrated catalyst);
- liquor pick-up: 80 %;
- acidifying with possible add-on of acetic acid;
- drying and condensation (130 °C, 1 min), (170 °C, 45 s).

Cross-linking compounds are often applied in combination with wetting agents, softeners, products which increase rip-resistance, etc.

The low-formaldehyde or formaldehyde-free cross-linking agents can be applied similarly to different conventional products. The kind and amount of catalyst are have to be adjusted accordingly, as well as the curing time and temperature.

**Cross-media effects**

Like the conventional cross-linking agents, the formaldehyde-free alternative products mentioned above are hardly biodegradable. However, as a fundamental rule, the amount of concentrated liquor be kept to a minimum by small pad boxes, and residues should be disposed of separately without draining them to the waste water.

Non-optimised formaldehyde-free products can be odour-intensive.

The required quantity of formaldehyde-free products is approximately twice as high as conventional products.

In addition, the use of low-formaldehyde or formaldehyde-free products extends the required curing time and temperature in the stenter, which in turn leads to higher energy consumption. [ 36, ÖKOPOL 2011 ]

**Technical considerations relevant to applicability**

In the carpet sector it is always possible to avoid formaldehyde emissions by using formaldehyde-free easy-care finishing agents, whereas in the textile sector the use of formaldehyde poor agents may be inevitable [281, Belgium, 2002]. Generally, there are no technical restrictions to the applicability of this technique.

**Economics**

Prices for formaldehyde-free products are significantly higher than for low-formaldehyde-low products (20-300 % in relation to chemical consumption). [ 36, ÖKOPOL 2011 ]

**Driving force for implementation**

- health and safety regulations;
environmental regulations;
consumer standards.

Regulations concerning formaldehyde in the off-gas and compliance with various codes of conduct concerning consumer health (e.g. European Eco-label, etc.) are the main motivation for the use of the formaldehyde-free or low-formaldehyde products.

Example Reference plants
Formaldehyde-free and low-formaldehyde easy-care finishing auxiliaries are supplied by various companies and applied worldwide.

In total, 19 plants from the data collection apply this technique.

Reference literature
[179, UBA, 2001], [51, OSPAR, 1994], [ 47, EU 2008 ], [ 48, COM 2014 ], [ 36, ÖKOPOL 2011 ], [ 197, Saxena et al. 2017 ], [ 230, Roy Choudhury 2017 ]

4.7.3 Softening

4.7.3.1 [Avoiding batch softening] Low-volume application of softening agents

Description
Softening agents are not added to the dyeing liquor but applied in a separate process step by padding, spraying or foaming.

Technical description
In batch processing, softening agents are often applied after the dyeing process directly in the dyeing machine (e.g. jet, overflow) using the exhaustion method.

Unfortunately, this limits the choice of softening agents to environmentally harmful cationic agents and gives rise to a 10-20 % loss of the whole volume of the warm softening bath [78, Danish EPA, 1999].

Alternative techniques are the application of softeners by pad mangles or by spraying and foaming application systems (see Sections 2.9.1 and 2.9.3).

The advantages of these techniques are that the use of cationic softening agents can be avoided and any chemical loss can be reduced to a few per cent [78, Danish EPA, 1999].

The amount of residual liquors is also reduced compared with the waste water volume produced by a batch process. In this respect, the best performances are achieved with application techniques such as spraying and foaming, which allow minimum system losses (residual liquor in the chassis, residual liquor in the pipes and leftovers in the batch storage containers).

However, the concentration of the active substance is much higher, which makes these liquors unsuitable for treatment in a biological system.

Another advantage of applying the softeners in separate equipment after the batch dyeing process is that it is then possible to reuse the dyeing or rinse baths as there is no longer a problem with the presence of residual cationic softeners, which would otherwise limit the adsorption of the dye in the subsequent dyeing process.

Main-Achieved environmental benefits
- Savings in water, energy and chemicals.
- Introduction of less environmentally harmful softening agents.
Environmental performance and operational data
No information was made available provided.

Cross-media effects
When softening is done in separate equipment after the dyeing process, the volume of the residual liquor is reduced (limited to system losses), but the concentration of the active substance is higher. Provided that this concentrated stream is not mixed with the other effluents and sent to a biological waste water treatment, no cross-media effects need to be considered.

Technical considerations relevant to applicability
The technique has general applicability in the textile and carpet sectors.
Generally, there are no technical restrictions to the applicability of this technique.

Economics
Economic benefits can be derived from savings in water, energy and chemicals consumption.

The technique consists of an additional process step which results in higher operational costs. [36, ÖKOPOL 2011]

Driving force for implementation
Savings in water, energy and chemicals.

Example Reference plants
Many plants.
Plants from the data collection: IT059, IT064, IT065, IT068, IT070, IT073, IT074, IT077, IT078, IT079, IT094, PT108 and SE119.

Reference literature
[78, Danish EPA, 1999] [36, ÖKOPOL 2011].

4.7.3.2 Softening of cotton with enzymes

Description
Enzymes are used for softening, possibly in combination with washing or dyeing.

Technical description
Cellulase enzymes are widely used in ‘polishing’ (sometimes called bioblasting) of cotton yarns or (knitted) fabric to remove loose fibres adhered to the fabric, thereby replacing the singeing process step. This is a bio-polishing (bioblasting) process which gives cotton a soft feel and reduces the pilling (fuzz, lint) of the cellulosic fibre.

The technique can be combined with after-bleach washing (bleach clean-up) and dyeing in one process. [165, Nagaraju et al. 2013].

Achieved environmental benefits
• No emissions to air (as singeing is obsolete).
• Reduced chemicals consumption (for softening).

Environmental performance and operational data
Biopolishing may reduce fabric strength and weight but will improve the appearance of a garment through repeated home laundering cycles. Bio-polishing may require a separate bath; however, a carefully selected compatible enzyme can be included in the dye bath, saving additional water, time, and energy.

Technical considerations relevant to applicability
Chapter 4

Generally applicable to cotton yarn and fabric.

Cross-media effects
The organic load in the effluent may be increased, demanding an appropriate biological waste water treatment.

Economics
General investment costs are less than USD 200 000 with a typical 2-year payback period [ 163, Cotton Incorporated 2018 ].

Driving force for implementation
Economics.

Example plants
No information provided.

Request to TWG: please provide information about plants applying this technique.

Reference literature
[ 163, Cotton Incorporated 2018 ], [ 165, Nagaraju et al. 2013 ]

4.7.4 Finishing with flame retardants

4.7.4.1 Optimisation or substitution of the flame retardants used for finishing

Description
Textiles are used that do not require finishing with flame retardants. If not possible, flame retardants are selected by considering:

- the risks associated to the substances in particular in terms of persistence and toxicity;
- the composition and form of the textile materials to be treated;
- the product specifications.

Technical description
Some brominated flame retardants are now strictly regulated and alternative substances with improved environmental performance may be used. Such regulated brominated flame retardants are:

- decabromodiphenyl ether (deca-BDE) which is listed in Annex XVII to REACH and cannot be manufactured or placed on the market at concentrations above 0.1 % w/w (with some exemptions possible);
- hexabromocyclododecane (HBCD) which is listed in Annex XIV to REACH and is therefore subject to authorisation.

Due to the complexity and number of possible combinations of textile substrate, finishing treatment and desired product properties, there is no overarching (one-size-fits-all) solution for suitable alternative flame retardants to replace the conventional compounds. There are alternative options available for certain specific textile products, but they are typically not transferrable to other textile products where flame resistance is required. [ 150, EIPPCB 2019 ]

Moreover, the potential hazardousness of the alternatives also needs to be taken into account (see Table 4.78 for an example of hazard assessment of different alternative chemicals). The regulatory context of these possible alternatives needs also to be considered, by using the ECHA search tool. [ 227, ECHA 2019 ]
Intensive technical screening on a case-by-case basis is therefore needed to find alternatives and a number of criteria may be used to carry out this screening:

- the alternative chemical is halogen-free;
- it does not contain other toxic compounds (antimony, formaldehyde, etc.) that may be associated with adverse health effects in animals and humans (workers or end users);
- it does not bioaccumulate in animals and humans;
- it is easily removable from the waste water;
- it does not migrate to the surface of the substrate, via leaching or volatilisation (i.e. it is fixed on the matrix);
- in comparison with the original chemical, it reduces smoke formation and the smoke produced is less harmful;
- it is renewable and bio-based;
- it is recyclable.

[148, VITO 2019]

The certification of the alternative chemical under existing schemes can help ensure that some of these criteria are fulfilled.

Possible alternative fire retardants are distinguished based on their permanence in permanent fire retardants, on the one hand, and in non-permanent fire retardants on the other hand:

- Permanent fire retardance can be achieved by:
  - chemically binding complex organophosphorus compounds to fibres by treatment with an ammoniac or a melamine derivate;
  - mixing a flame retardant in melt spinning or in polymer granulates;
  - mixing fibres with polymers or co-polymers that are fire-retardant (e.g. polyvinyl chloride, polyvinylidene chloride, polymer combinations with antimony trioxide);
  - treating wool with zirconium salts for example.
- Non-permanent (not wash-proof) fire retardants include:
  - aluminium trihydroxide;
  - ammonium salts from phosphate, bromide, chloride, sulphonate;
  - boracic acid, borax.

[27, Derden et al. 2010]

Organophosphorus compounds
Textiles can be made fire-resistant by carbonising the flammable product with organophosphorus compounds. At a particular (fire) temperature, P compounds form a layer of carbon that shuts off the material from air (oxygen).

A few examples, found in existing literature, of organic phosphorus compounds that could be used as alternatives include: triphenylphosphate, tricresylphosphate, resorcinol bis(diphenylphosphate), bisphenol A diphenylphosphate, tetrakis(hydroxymethyl) phosphoniumchloride, diphenylcresylphosphate and polytetrafluoroethylene (PTFE or teflon).

Organic phosphorus compounds are used on the front side of textiles, so that particular textile properties are hereby lost (technical limitation). However, phosphorus compounds offer very little resistance against moisture (for example they are washed out when textile is cleaned). Thus, there are some technical limitations when replacing conventional flame retardants with organophosphorus compounds.
In some cases, organic phosphorous compounds can be used in the production of mattress textiles. [27, Derden et al. 2010]

Products based on a dispersion of phosphorus-containing compounds offer environmental and economic advantages for durable flame-retardant finishing for 100% PES substrates: Condensation temperatures (150-170 °C) are lower compared to the conventional thermosol process (190-200 °C) and no emissions of formaldehyde are induced. Final cleaning is not necessary. The product meets the values of the international standards such as DIN 4102 B1/B2, BS 5867 Part 2 and NFP 92-504 (M1). [36, ÖKOPOL 2011]

Chlorine-based compounds
Chlorinated paraffins (though not of the short-chain type (C10-13) which are prohibited by the POP Regulation and are on the proposed candidate list of SVHC for inclusion in Annex XIV to REACH) are possible alternative chemicals for making textiles fire-retardant. These alternatives only partly replace deca-BDE. As C-Cl compounds are stronger than C-Br compounds, chlorine compounds are less efficient as flame retardants than deca-BDE and HBCD. [27, Derden et al. 2010]

Melamine
Products based on melamine are also possible alternative chemicals for making textiles fire-resistant. Melamine pyrophosphate is an example of a melamine product. In 2010, this product was tested as an alternative fire retardant but insufficient fire-resistant properties were discovered. [27, Derden et al. 2010]

Silane (chemical compounds of silicium, hydrogen and oxygen)
Another possible alternative for making textiles fire-resistant is the silicium compound POSS (polyhedral oligomeric silsequioxane). According to [27, Derden et al. 2010], silane is rarely used in the textile industry.

Zirconium salts
Zirconium salts are a technically feasible alternative fire retardant for wool. According to [27, Derden et al. 2010], zirconium salts have already been in use in the textile sector for decades, for making wool fire-resistant. In this case, the yarn itself is made fire-proof. In an additional step (e.g. if wool is incorporated into a carpet), an extra fireproof coating can be added (e.g. using latex). The latter activity is often carried out in job-processing companies, where deca-BDE is used as a fire retardant. [27, Derden et al. 2010]

Aluminium trihydroxide
Aluminium trihydroxide is a water-soluble compound and is thus not a durable alternative to deca-BDE in all applications.

In the carpet industry, Al(OH)₃ has been used as fire retardant for the past 10-15 years. The formation of hydrates has a cooling effect. Deca-BDE is not used in the carpet industry. [27, Derden et al. 2010]

Zinc borate
According to the sector, zinc borate is only used for specific applications (e.g. heavy-duty tents). This substance is also dangerous for the environment and public health (R-phrases, e.g. R-50, R-52). [27, Derden et al. 2010]

Intumescent systems
Intumescent systems are mainly based on a complex mixture of carbon, gas and acidifier. In the event of a fire they swell, producing barrier layers. However, for most applications this finishing does not have the required durability. [36, ÖKOPOL 2011]

[58, SUBSPORT 2013] identified intumescent systems containing ammonium polyphosphate, pentaerythritol and melamine as possible alternatives for HBCDD for textile coating.
Achieved environmental benefits
Reduction of emissions of hazardous substances to the environment.

Environmental performance and operational data
The application of optimised or new flame-retardant products is not different to that of conventional products.

A technical disadvantage is that substitutes may have different characteristics (e.g. freezing point, water solubility) to the chemicals to be replaced and the use of alternatives may imply process-related modifications (e.g. keeping chemicals with a lower freezing point warm when in storage).

The alternatives used need to comply with the requirements (demanded test standards) and to be compatible with the substrate concerned. For example, the use of alternatives to replace deca-BDE and HBCD is largely determined by the specific application (e.g. the fire-retarding mechanism that is used and the required fire-retarding properties).

Consequently, the use of alternatives for deca-BDE and HBCD may be more technically difficult for job-processing companies due to the higher variety of activities and requirements of clients, the smaller batches that are produced, the higher number of suppliers, etc.

Cross-media effects [27, Derden et al. 2010]
In some cases, alternative substances have an equally negative (or even worse) impact on the environment or no, or very little, research has been done into the environmental effects and health risks. For instance, organic phosphorus compounds are not abated in the WWTP.

Indeed, physico-chemical phosphorus removal is based on the principle of (co-)precipitation of phosphates. However, organic phosphorus compounds are not removed from waste water when this waste water treatment technique is implemented [198, Derden et al. 2008]. There is therefore a possible displacement of the environmental problem and there may be difficulties to comply with the permit limit values for emissions of phosphorus to water.

Chlorinated paraffins often obtain worse environmental scores than deca-BDE or HBCD.

The US EPA has assessed 31 possible alternatives to deca-BDE. The hazard profiles of the alternatives have been identified in terms of human health effects, aquatic toxicity and environmental fate. The hazard profile of a given alternative, compared to the profile of deca-BDE and to the profiles of other potential alternatives, helps the selection of an alternative by pointing out the possible trade-offs (see Table 4.78). [59, US EPA 2014]

According to [58, SUBSPORT 2013], as far as intumescent systems are concerned, melamine causes severe skin burns and eye damage, it may cause allergic skin reactions and damage to organs and is very toxic to aquatic life with long-lasting effects. In addition, ammonium polyphosphate is persistent and inherently toxic to aquatic organisms.
## Chapter 4

### Table 4.78: Hazard profiles of alternatives to decaBDE

<table>
<thead>
<tr>
<th>Chemical</th>
<th>CAS Number</th>
<th>Human health effects</th>
<th>Aquatic toxicity (1)</th>
<th>Environmental fate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Acute toxicity</td>
<td>Cardiogenicity</td>
<td>Genotoxicity</td>
</tr>
<tr>
<td><strong>Halogenated flame-retardant alternatives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bis(hexachlorocyclopentadienio) cyclooctane</td>
<td>13560-89-9</td>
<td>L</td>
<td>M(2)</td>
<td>M(2)</td>
</tr>
<tr>
<td>Brominated poly(phenylether)</td>
<td>Confidential</td>
<td>L</td>
<td>L(3)</td>
<td>L</td>
</tr>
<tr>
<td>Decabromodiphenyl ethane</td>
<td>84852-53-9</td>
<td>L</td>
<td>M(2)</td>
<td>L</td>
</tr>
<tr>
<td>Ethylene bis-tetrabromomethylmethane</td>
<td>32588-76-4</td>
<td>L</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Tetrabromobisphenol A bis (2,3-dibromopropyl) ether</td>
<td>21850-44-2</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Tris(trichloroethyl)phosphate</td>
<td>19186-97-1</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Tris(trichlorophenoxy) triazine</td>
<td>25713-60-4</td>
<td>M</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td><strong>Polymeric halogenated flame-retardant alternatives</strong> (3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brominated epoxy polymers</td>
<td>68928-70-1</td>
<td>L</td>
<td>L(3)</td>
<td>L</td>
</tr>
<tr>
<td>Brominated epoxy polymer(s)</td>
<td>Confidential</td>
<td>L</td>
<td>L(3)</td>
<td>L(3)</td>
</tr>
<tr>
<td>Mixture of brominated epoxy polymer(s) and bromobenzyl acrylate</td>
<td>Confidential</td>
<td>L</td>
<td>L(3)</td>
<td>L(3)</td>
</tr>
<tr>
<td><strong>Organic phosphorus or nitrogen flame-retardant (PFR or NFR) alternatives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substituted amine phosphate Mixture (10)</td>
<td>Confidential</td>
<td>H</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Triphenyl phosphate</td>
<td>115-86-6</td>
<td>L</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td><strong>Polymeric PFR and NFR alternatives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bisphenol A bis-(diphenyl phosphate); BAPP</td>
<td>181028-79-5</td>
<td>M</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Melamine cyanurate (10)</td>
<td>37640-57-6</td>
<td>M</td>
<td>M</td>
<td>M(2)</td>
</tr>
<tr>
<td>Melamine polyphosphate (10)</td>
<td>15541-60-3</td>
<td>M</td>
<td>M</td>
<td>L(2)</td>
</tr>
<tr>
<td>N-alkoxy hindered amine reaction</td>
<td>191680-81-6</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
</tbody>
</table>

Table 4.78: Hazard profiles of alternatives to decaBDE

*Note: (1) The aquatic toxicity values are based on the LC50 (50% lethal concentration) for fish or Daphnia magna. (2) The values in parentheses indicate the level of hazard (0 = Low, 1 = Medium, 2 = High). (3) Polymeric halogenated flame-retardant alternatives are not included in the hazard profile. (4) The values for organic phosphorus or nitrogen flame-retardant alternatives are based on the reported environmental fate classification (VH = Very High, H = High). (5) The values for polymeric PFR and NFR alternatives are based on the reported safety and effectiveness data.*
<table>
<thead>
<tr>
<th>Products</th>
<th>Category</th>
<th>Literature Code</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
<th>Hazard Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphonate oligomer</td>
<td>68664-06-2</td>
<td>L</td>
<td>M</td>
<td>L(1)</td>
<td>L(11)</td>
<td>M(9)</td>
<td>L(2)</td>
</tr>
<tr>
<td>Polyphosphonate</td>
<td>68664-06-2</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Phosphoric acid, mixed esters with [1,1'-bisphenyl-4,4'-diol] and phenol; BPBP</td>
<td>1003300-73-9</td>
<td>M</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Poly[phosphate-co-carbonate]</td>
<td>77226-90-5</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L(0)</td>
</tr>
<tr>
<td>Resorcinol bis-diphenylphosphate; RDP</td>
<td>125997-21-9</td>
<td>L</td>
<td>M(2)</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
</tbody>
</table>

### Inorganic flame-retardant alternatives

<table>
<thead>
<tr>
<th>Substances</th>
<th>Literature Code</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
<th>Hazard Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium diethylphosphate</td>
<td>225789-38-8</td>
<td>L</td>
<td>L</td>
<td>VL</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Aluminium hydroxide</td>
<td>21645-51-2</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>Ammonium polyphosphate</td>
<td>68333-79-9</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Antimony trioxide</td>
<td>1309-64-4</td>
<td>M(1)</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Magnesium hydroxide</td>
<td>1309-42-8</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Red phosphorus</td>
<td>7723-14-0</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Zinc borate</td>
<td>1332-07-6</td>
<td>L</td>
<td>L</td>
<td>H</td>
<td>M</td>
<td>M</td>
</tr>
</tbody>
</table>

NB: VL = Very Low hazard, L = Low hazard, M = Moderate hazard, H = High hazard, VH = Very High hazard.

Endpoints in colored cells (VL, L, M, H, and VH) were assigned based on empirical data.
Endpoints in italics (VL, L, M, H, and VH) were assigned based on values from predictive models and/or professional judgment.
NI: No information.
Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
The potential usage of inherent flame-retardant fibres as well as new developed products for finishing can result in higher costs.

In practice, often larger quantities of chlorine compounds are needed, compared for example to deca-BDE, to realise the same fire-retarding properties. Multiple substitutes are sometimes implemented.

Very little cost price data are available for alternatives of deca-BDE and HBCD. In one confirmed case, the additional costs for alternatives to replace deca-BDE are estimated at a factor of 2 to 2.5. [ 60, UMass Lowell 2005 ]

Driving force for implementation
Some flame-retardants are banned by REACH.

Example plants
Concerning the plants from the data collection, 14 plants out of 28 carrying out finishing treatment for flame retardance do not use brominated flame retardants. In particular:

- Plant BE010 uses ammonium sulphamate;
- Plant BE011 uses aluminium trihydroxide;
- Plant SE118 uses phosphonate.

Reference literature
[ 36, ÖKOPOL 2011 ] [ 27, Derden et al. 2010 ] [ 58, SUBSPORT 2013 ] [ 59, US EPA 2014 ] [ 60, UMass Lowell 2005 ] [ 148, VITO 2019 ] [ 150, EIPPCB 2019 ] [ 198, Derden et al. 2008 ]

4.7.4.2 Ammonia-cured flame retardants

Description
Cotton textile is impregnated with phosphorous compounds and subsequently cured with ammonia.

Technical description
[ 252, UK, EURATEX 2019 ] [ 253, Cotton Incorporated 2003 ]

Flame-retardant finishing of natural fibres is required for applications such as technical textiles or personal protective equipment (PPE). This process often requires the application of organo-halogenated compounds for textiles with the strictest requirements in terms of flame retardance, especially if the textiles are washed frequently during their cycle of use (e.g. in the case of PPE). The aim of this technique is to replace these halogenated substances with less persistent substances.

In the first step, the textile is impregnated by padding with a phosphorous compound (e.g. THPC - tetrakis(hydroxymethyl)phosphonium chloride) and dried, e.g. in a stenter frame. The textile is then chemically cured with ammonia in a closed chamber in order for the nitrogen-phosphorous complex to be fixed to the textile and to reach a high degree of fastness.

The full flame-retardant effect is achieved by oxidation of the phosphorous compound with \( \text{H}_2\text{O}_2 \) and exposition of the treated textile to air for a short time (so-called sky time). Finally, excess chemicals are washed off and the textile is dried.

The process is summarised in Figure 4.67.
Achieved environmental benefit
Reduction of emissions of hazardous substances to the environment.

Environmental performance and operational data
The curing with ammonia is a continuous process. The textile is guided at the inlet and outlet of the fumigation chamber through a water lock, so that no gaseous ammonia from the chamber can escape to atmosphere.

The air extraction system of Plant BE013 is described in Figure 4.66. Air extracted from the impregnation stage is treated by water scrubbing and there are reported to be no NH₃ emissions to air. Air extracted from the hoods is not treated and the NH₃ emissions to air are reported to be up to 56.2 mg/Nm³ (with annual averages between 6 mg/Nm³ and 10.7 mg/Nm³).
Concerning emissions to water, the nitrogen-phosphorous compounds used are difficult to biodegrade and, depending on the capacity of the downstream waste water treatment plant, the retained residues may have to be recycled or disposed of as waste.

Residual ammonia on fabric as it exits the unit is usually minor and should permit handling with only normal ventilation facilities in that area. [253, Cotton Incorporated 2003]

**Cross-media effects**
Emissions of NH$_3$ to air and of nitrogen to water.

**Technical considerations relevant to applicability**
This technique is applicable to cotton fibres.

**Economics**
The technique described is significantly more expensive due to the additional process steps compared to the standard flame-resistant application equipment, e.g. in a stenter frame. [252, UK, EURATEX 2019]

**Driving force for implementation**
Environmental and chemicals legislation.

**Example plants**
Plant from the data collection: BE013.
4.7.5 Finishing with oil, water and soil repellents

4.7.5.1 Oil, water and soil repellents with improved environmental performance

Description
Oil-, water- and soil-repellents are selected by considering:

- the risks associated to the substances in particular in terms of persistence and toxicity;
- the composition and form of the textile materials to be treated;
- the product specifications.

Technical description
For textiles requiring only a water-repellent finish without any soil- and oil-repellent effects, fluorine-free water-repellent agents with a different chemical basis are used depending on the specified finish requirements, e.g. paraffin formulations, polysiloxanes, modified melamine resins or polyurethanes or highly branched fluorine-free polymers. [36, ÖKOPOL 2011]

Dendrimers and hyperbranched polymers

| Request to TWG: please provide more details about the composition of the dendrimers and hyperbranched polymers used. |

The hyperbranched polymers group includes dendrimers, dendrons, dendrigraft polymers and branched polymers. They are all cascade polymers of different sides or branch extensions.

In the case of knitted polyester, this technology has provided very good results for water repellence, achieving the same water repellence grade and washing fastness as that obtained for the PFC C8 and C6 products.

In the case of wool, the product does not meet either water or oil repellence requirements after washing. Indeed, the water repellence achieved is similar to PFC C6, but the washing fastness is lower, because this product is not resistant to dry cleaning.

Silicone-based repellents

| Request to TWG: please provide more details about the composition of the silicone-based compounds used. |

Silicone repellents are also commonly used in the textile industry to give water repellence to fabrics. These finishing agents are generally made of elastomeric polydimethylsiloxanes which can coat the fabric surface after curing. The structure obtained after finishing by padding of the fabric surface is a three-dimensional, flexible and hydrophobic layer bonded to the fabric’s fibres. It should be noted that silicone repellents’ finishing agents have moderate washing fastness due to the hydrolysis of the siloxane during laundry.

The silicone-based repellents have been tested in a non-woven polyester fabric (automotive), obtaining a high level of water repellence.
Achieved environmental benefit
Reduction of emissions of hazardous substances to the environment.

Environmental performance and operational data
The alternative water and oil repellents do not need particular conditions; they can be applied by padding like the conventional finishes or by spraying directly onto fabric surfaces. Chemicals with strong affinities for the surface of fibres can be applied by exhaustion in dyeing machines, usually after completing the dyeing process.

Recipes can be prepared and dosed by an automatized system.

Table 4.79 compares the energy, water and resources consumption of different types of water repellents (the dendrimer and silicone-based repellents versus the long-chain PFC C8).

Table 4.79: Consumption of energy, water and resources for treating 90 m² of textile

<table>
<thead>
<tr>
<th>Padding process</th>
<th>PFC C8-based</th>
<th>Dendrimer</th>
<th>Silicone-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>PFC C8-based 3.5 kg</td>
<td>Dendrimer 7.5 kg</td>
<td>Silicone-based 13.5 kg</td>
</tr>
<tr>
<td></td>
<td>Wetting agent 0.75 kg</td>
<td>Catalyst 6.75 kg</td>
<td></td>
</tr>
<tr>
<td>Water for padding</td>
<td>150 kg</td>
<td>Water for padding 150 kg</td>
<td>Water for padding 300 kg</td>
</tr>
<tr>
<td></td>
<td>Acetic acid 80% 52.5 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>3.5 kWh</td>
<td>3.5 kWh</td>
<td>3.5 kWh</td>
</tr>
<tr>
<td>Waste water</td>
<td>0.15 m³</td>
<td>0.15 m³</td>
<td>0.3 m³</td>
</tr>
<tr>
<td>Drying and curing</td>
<td>800 MJ</td>
<td>800 MJ</td>
<td>800 MJ</td>
</tr>
<tr>
<td>Electricity</td>
<td>23.1 kWh</td>
<td>23.1 kWh</td>
<td>23.1 kWh</td>
</tr>
</tbody>
</table>

Source: [121, Manich et al. 2018]

Cross-media effects
None identified.

Technical considerations relevant to applicability
Provided that oil and soil repellence is not demanded at the same time and the corresponding specification of requirements for the finish allows their use, fluorine-free water-repellent agents are available.

If, however, the specified requirements include:

- combined soil, oil and chemical repellence;
- high effect level in tumbler, or line drying;
- suitability for lamination;

then these requirements can only be achieved at this point in time by using fluorocarbon resins or combinations of these with extenders, e.g. based on polyisocyanates blocked with 2-butanol oxime. [36, ÖKOPOL 2011] [67, Benninger et al. 2016] [124, LEITAT 2018]

Hyperbranched polymers are applicable for knitted polyester and silicone-based repellents for non-woven polyester.

Economics
No specific investment is needed. In general, the price of fluorine-free alternatives is lower than that of fluorinated treatments.
Dendrimer
The purchasing cost of dendrimer is lower than fluorinated treatments: 27% cost decrease compared to PFC C8-based product and 49% cost decrease compared to PFC C6-based product. The treatment cost of textiles with dendrimer is higher (21%) than with PFC C8-based product and slightly higher (8%) than with PFC C6-based product due to a higher dosage of the chemicals.

Silicone-based
The purchasing cost of silicone-based product is lower than fluorinated treatments (e.g. PFC C8- or C6-based product): 32% cost decrease compared to PFC C8-based product and 53% cost decrease compared to PFC C6-based product. The treatment cost of textiles with silicone-based products is lower (44%) than PFC C6-based product due to the higher purchasing cost of the PFC C6 product. Similar chemical dosages are applied for both treatments.

Driving force for implementation
Environmental legislation.

Example plants
Dendrimer
- HIDROCOLOR s.l. (Llinars del Vallès, Barcelona, Spain).
- BIELLA MANIFATTURE TESSILI s.r.l. (Mongrando, Biella, Italy).

Silicone
- Inotex (Czech Republic).

Out of 45 plants from the data collection carrying out finishing treatment for water, oil and soil repellence, 12 plants use polysiloxane compounds and one plant (SE119) uses dendrimers.

Reference literature
[36, ÖKOPOL 2011] [121, Manich et al. 2018] [67, Benninger et al. 2016] [124, LEITAT 2018]

4.7.6 Shrink-proof finishing of wool

4.7.6.1 Chemical chlorine-free anti-felting

Description
Inorganic salts of peroxymonosulphuric acid are used for shrink-proof finishing of wool.

Request to TWG: please give information about the type of salts

Technical description
The process is continuous and comprises the following steps:

- applying a solution containing oxidising agents based on peroxymonosulphuric acid and a surfactant to the wool;
- washing the reaction products out of the wool;
- treating the wool with a reducing agent; and
- rewashing.

An overview of the process is given in Figure 4.67.
Achieved environmental benefit
No AOX emissions to water.

Environmental performance and operational data
Table 4.80 below compares the mechanical properties of wool treated with the conventional chlorine-based Hercosett process and with the chlorine-free anti-felting process.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Diameter (µm)</th>
<th>Fineness (dtex)</th>
<th>Strength (cN/dtex)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine-Hercosett</td>
<td>22</td>
<td>5.17 ± 1.10</td>
<td>11.30 ± 2.12</td>
<td>41.52 ± 7.63</td>
</tr>
<tr>
<td>Chlorine-free anti-felting</td>
<td>21</td>
<td>4.58 ± 1.15</td>
<td>10.91 ± 1.88</td>
<td>43.00 ± 11.23</td>
</tr>
</tbody>
</table>

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Request to TWG: please confirm that this technique is generally applicable. If not, please provide information about the applicability restrictions.

Economics
The costs are comparable to the traditional chlorine-based Hercosett process.

Driving force for implementation
Environmental legislation.
Example plants
Plants from the data collection: AT005, IT087 and IT097.

Reference literature
[ 117, Bechtold et al. 2012 ], [ 67, Benninger et al. 2016 ] [ 132, Austrian UBA 2018 ]

4.7.6.2 Plasma anti-felting

Description
The wool passes through the plasma field where electrons and ions in the plasma alter the friction profile of the fibre surface, removing the normal felting effect of untreated wool.

Technical description
The exposure of the fibres needs to be carefully calibrated - both in intensity and duration. The plasma field oxidises the surface and creates nano-scale holes in the surface of the fibre. These holes increase the surface friction of the whole fibre, without damaging the fibre scales. This added friction stops the fibres from moving, avoiding the ratcheting effect that leads to felting and shrinkage. [ 159, SUEDWOLLEGROUP 2019 ]

Figure 4.68 shows the result of the plasma treatment on wool fibres and Figure 4.69 shows the machine used.

Figure 4.68: Comparison of untreated wool (left) with wool treated with plasma (right)
Figure 4.69: Machine for plasma treatment

Achieved environmental benefit
No emissions to water.

Environmental performance and operational data
Unlike the Hercosett process, the plasma anti-felting process is a physical treatment and it does not use water; there is therefore no generation of waste water.

The plasma process consumes more energy than the Hercossett process but this may not be the case if the drying step following the conventional Hercossett process is also taken into consideration (see Table 4.81 below).

Table 4.81: Water and energy consumption of conventional and plasma anti-felting treatment

<table>
<thead>
<tr>
<th>Process</th>
<th>Water consumption</th>
<th>Energy consumption (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hercosett</td>
<td>6 000 l/h 17 l/kg of wool</td>
<td>Electricity: EUR 0.02/kg of wool Steam generation for drying: EUR 0.06/kg of wool</td>
</tr>
<tr>
<td>Plasma</td>
<td>No water used</td>
<td>Electricity: EUR 0.055/kg of wool</td>
</tr>
</tbody>
</table>

(1) 2009 value.
Source: [160, Superwool 2009]

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
For operational costs (e.g. for electricity), see Table 4.81.

Driving force for implementation
Environmental legislation.
Example plants
No information provided.

Request to TWG: please provide information about plants applying this technique.

Reference literature
[ 159, SUEDWOLLEGROUP 2019 ] [ 160, Superwool 2009 ]

4.7.7 [Minimisation of emissions in the application of Mothproofing agents]

Ex-Section 4.8.4.

The next three figures (Figure 4.71, Figure 4.73, Figure 4.75) illustrate the baseline processes used by the sector to apply insect resist (IR) agents and identifies the point of application in wet processing and potential points of emission of residual active substance to water. The application method(s) adopted by any manufacturer will depend on the specific yarn production/processing sequence used and it is not uncommon to find more than one application procedure in use on one site.

Techniques to minimise the emission of residual insect resist agent may take a number of forms:
- general practices applicable to the majority of processes, for example material handling and storage and selection of the correct application rate
- specific process modifications which include, for example, changes to the chemistry of the process or the substitution of interfering chemicals
- alternative processes such as the use of specialised machinery dedicated to insect resist application. Application at a different point in the carpet manufacturing sequence is also considered under this heading
- on site pretreatment of specific waste water streams — destruction of residual active substance by alkali hydrolysis.

The following discussion first describes general techniques and then specific modifications applicable to each of the three identifiable processing routes for yarn manufacture:
- yarn production by the “dry spinning” route
- yarn production by the “oil spinning” route
- yarn dyed production route.

4.7.7.1 [General techniques to minimise the emission of insect resist agent active substance] Handling of mothproofing agents

Ex-Section 4.8.4.1 has been split into two different techniques

General techniques to minimise the emission of insect resist agent active substance include: appropriate material handling and dyeing auxiliary selection.

Description
Techniques to minimise spillage of mothproofing agents during dispensing and transport within the dyehouse.

Technical description

Material handling
The handling of environmentally sensitive materials such as formulated mothproofing agent requires the use of special techniques to minimise spillage during dispensing and transport.
within the dyehouse. The majority of commercial formulations are supplied as self-emulsifying concentrates, referred to as concentrates, below.

For handling and transfer of concentrates to dyeing machines, the following measures should be adopted:

- concentrates should only be dispensed from bulk containers within the colour store;
- automated dispensing systems should be considered to minimise spillage and improve accuracy;
- concentrates should be transferred from the colour storage to the point of addition to the process in sealed shockproof containers;
- concentrates should be added directly to the process liquor only when the dyeing is under way and the dye bath volume is stable (prevents displacement spillage).

See also Sections 4.1.6.4.1 and 4.1.6.7.

For handling concentrates in relation to semi-continuous application, the following measures should be applied:

- concentrates should be stored in the original containers, within a bund and protected from accidental impact;
- concentrates should be dispensed directly into the process liquor – stock solutions should not be used;
- dispensing should not be done manually but a manual operation, dosing pumps should be used instead.

Main-Achieved environmental benefits
The correct timing of additions to the dye bath has been shown to play an important role in reducing overall emissions of IR agent by minimising the spillage of the concentrated treatment liquor at the start of the dyeing process.
Reduction of emissions of mothproofing agents to soil, groundwater and surface water.

Environmental performance and operational data
Quantification of the impact of the material handling regime described above on overall mill effluent residues is difficult to assess, but measurements on individual dyeing machines suggest that between 10% and 20% of the total emissions can arise from liquor spillage.

Cross-media effects
Cross-media effect are believed to be unlikely as regards the adoption of the proposed material handling regime.
None identified.

Technical considerations relevant to applicability
The above techniques are applicable to all installations.
Generally, there are no technical restrictions to the applicability of this technique.

Economics
Many of the above measures regarding material handling are of low or no cost. Accurate metering and dispensing systems for use in the colour store and as part of a continuous application system are estimated to cost in the range of EUR 8 000-16 000.

Driving force for implementation
Environmental legislation.

Example plants
Plants from the data collection: IT073, SE119, UK124 and UK127.
General techniques to minimise the emission of insect resist agent active substance include:

**Selection of dyeing auxiliaries**

When mothproofing agents are added directly in the dyeing liquor, dyeing auxiliaries (e.g. levelling agents) that do not hinder the uptake of mothproofing agents are selected.

### Technical description

**Dyeing Auxiliary selection**

Some dyeing auxiliaries are known to exert a retarding action on the uptake (exhaustion) of insect resist mothproofing agents in all dyeing processes. The choice of, for example, levelling agent and polyamide blocking agent can significantly affect the final dye bath and rinse residues. These effects are known to depend on both the dye liquor pH and the auxiliary concentration. Dyeing auxiliaries should be screened for retarding action. Products with a significant retarding action should be substituted, if possible.

These dyeing auxiliaries are also selected considering the adverse impacts they may have on the environment (see Section 4.1.6.3).

**Main-Achieved environmental benefits**

A targeted selection of the dyeing auxiliaries allows a reduction of the concentration of mothproofing agent in spent dye bath liquors.

**Environmental performance and operational data**

No information provided.

**Cross-media effects**

The choice of auxiliaries should be made taking into account overall effects on the environment. The chosen dyeing auxiliaries may have adverse impacts on the environment.

**Technical considerations relevant to applicability**

The above technique is applicable to all installations. However, it should be recognised that substitute auxiliaries with equivalent technical performance are not always available.

**Economics**

No information provided.

**Driving force for implementation**

Environmental legislation.

**Example plants**

Plants from the data collection: IT073, SE119, UK124 and UK127.

**Reference literature**

[32, ENco, 2001], [51, OSPAR, 1994], [50, OSPAR, 1997].
4.7.7.3 [Specific process modifications to minimise the emission of insect resist agent active substance during yarn production by “dry-spinning route”]. Minimisation of emissions of mothproofing agents from yarn production when using the ‘dry spinning route’

Ex-Sections 4.8.4.2

Figure 4.70 below illustrates the baseline process used for the application of mothproofing agents to ‘dry spun’ production yarn during fibre wet processing (see also Section 2.13.5.1). Insect resist Mothproofing agent is applied in loose fibre dyeing by addition to the dye bath at the commencement of the dyeing. In the baseline process, the dye bath and the rinse liquor are discharged to the drain and may carry residual agent not taken up by the fibre. Dewatering the dyed fibre using either a centrifuge or with squeeze rollers also generates an additional potential source of residues.

Candidate Process modifications with the potential to reduce mothproofer emissions of mothproofing agents in loose fibre dyeing include:

- acid after-treatment & and reuse of the rinse bath (see Section 4.7.7.3.1);
- proportional overtreatment of loose fibre (see Section 4.7.7.3.2).
4.7.7.3.1 Acid after-treatment and reuse of the rinse bath

**Ex-Section 4.8.4.2.1**

**Description**
An acidification step is added at the end of the dyeing cycle to increase the uptake of mothproofing agents and the rinse bath is reused for the next dyeing cycle.

**Technical description**
The procedure technique illustrated in Figure 4.70 combines the following:

1. Acid after-treatment: dyeing conditions can be modified to incorporate an acidification step at the end of the dyeing cycle, which consists of lowering the dye liquor pH (< 4.0) at the end of the dyeing cycle. This increases the uptake of mothproofing agents active substance at the end of the cycle and reduces overall residues.
2. Reuse of the rinse bath: reusing the liquor for the next dyeing which can eliminate residues from the rinse bath.

Main Achieved environmental benefits
Reduction of residues and emissions to water from the dyeing process.

Environmental performance and operational data
Emissions of IR agent active substance mothproofing agents are reduced by approximately 90% when compared with the baseline process.

The example given in Table 4.82 the table below illustrates the effectiveness of acid after-treatment.

**Table 4.82: Indicative emissions from loose fibre dyeing**

<table>
<thead>
<tr>
<th>Waste water source</th>
<th>Approximate waste water volume (l/kg)</th>
<th>Residual permethrin (mg/kg fibre)</th>
<th>Achieved reduction in residues</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline process</td>
<td>Modified process after-treatment with formic acid</td>
</tr>
<tr>
<td>Dye bath</td>
<td>10</td>
<td>1.5</td>
<td>0.17</td>
</tr>
<tr>
<td>Rinse bath</td>
<td>9</td>
<td>0.38</td>
<td>0.02</td>
</tr>
<tr>
<td>Hydroextractor liquor</td>
<td>0.5</td>
<td>0.6</td>
<td>0.04</td>
</tr>
<tr>
<td>Process total</td>
<td>19.5</td>
<td>2.48</td>
<td>0.23</td>
</tr>
</tbody>
</table>

NB: Indicative results from a single dyeing carried out with premetallised dyes.
Permethrin application rate: 60mg/kg.
*Source: based on [32, ENco, 2001]*

Cross-media effects
None believed likely.
Increased energy consumption to maintain the dye bath at an elevated temperature for longer.

Technical considerations relevant to applicability
The above techniques are applicable to all installations.

This approach is only feasible if the machine can be unloaded without emptying the dye vessel or if the machine is equipped with an external liquor storage tank to which the liquor can be transferred between unloading and loading.

It is reported that this mothproofing technique may affect the quality of the product after dyeing [281, Belgium, 2002].

Economics
The after-treatment process requires additional time to complete, adding an average 30 minutes to a dyeing cycle. Productivity is reduced accordingly. The energy required to maintain the dye bath at elevated temperature increases overall consumption.

Driving force for implementation
Environmental legislation.

Example Reference plants
Acid after-treatment is reported to be used extensively in the UK industry. A number of installations apply this technique in combination with rinse liquor recycling.
4.7.7.3.2 [Proportional overtreatment of loose fibre] Blending of treated and untreated loose fibres

Ex-Section 4.8.4.2.2

Description
A fraction of the fibres (e.g. 5 – 20 % of total blend weight) is treated with an excess amount of mothproofing agents and subsequently blended with untreated fibres.

Technical description
This technique utilises the fact that an intimate blend of treated and untreated fibres will be resistant to insect attack providing that the overall blend treatment level is maintained. In practice only a proportion of the fibre is treated, by adding mothproofing agents at an increased rate to one or more dyeings. The remaining fibre receives no treatment. Mixing of the two fibre types is achieved during mechanical blending.

The technique can be used for the preparation of both solid shades and yarns with mixed colour effects. The ratio of treated to untreated fibre can vary be varied, but normally between 5 % and 20 % of the total blend weight would be treated.

Main Achieved environmental benefits
Reduction of emissions to water.

Environmental performance and operational data
Using a dedicated installation and treating only 5 % of the total fibre blend with insect resist mothproofing agent is an efficient way of providing protection to a large volume of finished carpet. Estimates of the waste water emissions from such an installation show values of less than 0.2 mg active substance/kg of fibre, which at a 5 % blending ratio is equivalent to 0.01 mg active substance/kg of spun yarn.

Cross-media effects
None believed likely when compared with the baseline process. However, as stated above, the application of this measure alone without dedicated dyeing machinery and waste water recycling systems does not provide sufficient reduction of the emissions of IR agent.

Fewer dyeings are carried out in the presence of mothproofing agents, but the higher application rates required would under normal circumstances result in higher emissions from those dyeings, which may exceed the emissions arising from the normal production sequence. In practice, it has been found that plants using this technique for more than a very small proportion of their production must install some form of dedicated dye liquor reuse system to manage waste water concentrations.

Technical considerations relevant to applicability
The technique can only be adopted on a significant scale by using specially constructed equipment, and is not, therefore, applicable to the majority of dyehouses. Moreover, both the spent dye liquor and the rinse liquor may need to be reused, which implies the construction of dedicated machinery, a revised drainage system and the installation of liquor storage tanks. A revision of the dyeing methods and dyestuff and auxiliary selection may be required to minimise colour contamination.

Economics
On a self build basis, The cost of constructing a dedicated installation from available materials is said was reported to be in excess of EUR 130 000.
Driving force for implementation
Environmental legislation.

Example Reference plants
One installation is known to exist in the UK. No design or operational details are available.

Reference literature
[32, ENco, 2001]

Figure 4.71: Process Map for Mothproofing Dry-Spun Production
[32, ENco, 2001]

4.7.7.4 [Specific process modifications to minimise the emission of insect resist agent active substance during the treatment of stock dyed-yarn scoured production] Minimisation of emissions of mothproofing agents from yarn production when using the ‘loose stock dyeing route’

Ex-Section 4.8.4.3

Figure 4.72 below illustrates the baseline process used for the application of mothproofing agents to yarn produced by using the loose fibre dyeing and yarn scouring route (‘loose stock dyeing route’, see also Section 2.13.5.1). In the baseline process, insect resist mothproofing agents are applied during loose fibre dyeing. The fibre is then converted to yarn and scoured to remove mill dirt and spinning lubricant.

Emissions of mothproofing agents arise from the dyeing and rinsing operations and from the yarn scouring operation, as mothproofing agents are removed from the spun yarn during this operation and concentrate in the scouring liquor.

Figure 4.72 indicates that there are three possible alternative processes modifications to the baseline process that may be applied to reduce mothproofing agent emissions:

- **Process A**: Application of mothproofing agents from in the final bowl of the yarn scouring. It uses conventional, existing equipment and eliminates emissions at the dyeing stage. This technique is not considered to be a best available technique for application of mothproofing agents in conjunction with yarn scouring and is therefore not further described in this document.
- **Process B**: Use of dedicated application machinery designed to operate at very low volumes (see Section 4.7.7.4.1). It eliminates emissions from the dyeing process and fugitive emissions from the conventional scouring bowl application.
- **Process C**: Application of the insect resist mothproofing agent directly to the carpet pile using dedicated foam application machinery (see Section 4.7.7.4.2). The equipment is self contained enclosed and can be operated without emissions to water.
Process A: Application of mothproofing agents in the final yarn scouring bowl.
Process B: Use of dedicated application machinery designed to operate at very low volumes.
Process C: Application of the mothproofing agents directly to the carpet pile.

Source: [51, ENco 2001]

Figure 4.72: Traditional and alternative processes for mothproofing in the loose stock dyeing route
[Process A: Application of agent from the final bowl of the yarn scour – uses conventional, existing equipment and eliminates emissions at the dyeing stage]

Ex-Section 4.8.4.3.1 deleted as according to the existing BREF "In light of this experience the above technique can no longer be considered to represent BAT for application in conjunction with yarn scouring".

4.7.7.4.1 [Process B: Mothproofer] Application using dedicated low-volume [application] equipment [, incorporating liquor clean-up and re-cycling]

Ex-Section 4.8.4.3.2

Description
Use of low-volume bowls to apply mothproofing agents.

Technical description
Specialised application equipment has been developed to meet many of the shortcomings encountered in Process A above. Minimal operating volume both limits liquor contamination and permits recycling of the liquor with intermediate cleaning to remove contaminants. Electronic measurement and process control are used to eliminate fugitive emissions and control mothproofing agent application levels and acidification conditions. Machines of this design are variously referred to as mini-bowl, low-volume bowl or EnviroProof installations.

An installation of the type described above is capable of operation in a number of two modes:

- liquor storage between yarn batches and discharge to drain when liquor is contaminated;
- liquor storage between batches with adsorptive renovation of liquor to eliminate discharge.

Further developments of the low-volume application system have taken place in which residual liquor from the hydroextractor is treated with alkali at high temperature. This procedure is applicable to all insect-resist mothproofing agent formulations based on synthetic pyrethroids, which undergo rapid hydrolysis at elevated temperatures. The degradation products from this reaction are several orders of magnitude less toxic to invertebrates than the parent molecule (Hill, I. R. Pesticide Science. 1989, 27, 429-465) and can thus be safely discharged to drain with other waste water streams. [ 55, Hill 1989 ]

The above technique has also been adapted to treat the spent bowl liquor in the cases where heavy contamination cannot be managed with the adsorptive filter system.

A further variant of the system deals with the hydroextractor liquor by segregation from other effluents, followed by addition to a dye bath. Dark shades are usually chosen to accommodate any slight shade change due to contaminants in the hydroextractor liquor and only 10-20% of the dye bath volume is made up using hydroextractor liquor. The active ingredient present in the hydroextractor liquor behaves in a similar manner to that present in the original formulation and is adsorbed by the fibre under the hot acidic dyeing conditions. Overall residues from this process are of a similar magnitude to those encountered when IR mothproofing agent is applied from the dye bath.

Main-Achieved environmental benefits
Dedicated application machinery eliminates emissions from the dyeing process and fugitive emissions from the conventional scouring bowl application.

Environmental performance and operational data
respectively 22 tonnes and 92 tonnes of carpet yarn were quantified. Both operating modes mentioned above were assessed (i.e. discharge to the drain when liquor is contaminated and adsorptive renovation of liquor to eliminate discharge).

Permethrin released from the installation amounted to 0.97 mg/kg in the case of simple multiple batch processing without clean-up and 0.23 mg/kg for the system running with full clean-up and recycling of the process liquor. In both cases, a significant proportion of the emissions arose when the treated yarn was hydroextracted prior to evaporative drying.

[ 54, Allanach et al. 1995 ]

Cross-media effects
None believed likely
None identified.

Technical considerations relevant to applicability
Installations of this type may be retrofitted to any continuous yarn scouring machine. Versions of the technology have been adapted for both hank and continuous end-to-end yarn processing machines.

Economics
Both commercial and self-built versions of the low-volume application system described above are known. A commercial installation (EnviroProof) retrofitted to an existing scouring line normally includes all the control features associated with chemical dosing and liquor management, together with refurbishment of the final squeeze press of the existing scouring line. Installation costs are in the region of EUR 185 000. The chemical dosing system fitted to these installations is capable of closely regulating application levels in proportion to the yarn throughput. As a result, the nominal treatment level can normally be reduced without compromising the insect resistance of the treated yarn. The magnitude of these savings can vary from site to site, but a 50 % reduction is not uncommon, equivalent to a saving of approximately EUR 7.0/tonne of treated yarn.

Equipment for the control and in-plant treatment of hydroextractor residues and highly contaminated liquors using the alkali hydrolysis technique is often assembled on a self-built basis to suit local site conditions and space. Depending on the complexity of the installation, costs are estimated to be upwards of EUR 7 000. Treatment costs, excluding energy, are in the region of EUR 1.4/m³.

Driving force for implementation
Environmental legislation.

Example Reference plants
A significant number of plants in the UK use variations of the low-volume application techniques described above and their associated spent liquor management systems for the insect resist treatment—mothproofing of yarn in both hank and single end form. Further installations operating similar systems are known to be in operation in Europe and New Zealand.

Reference literature
[32, ENco, 2001] [ 54, Allanach et al. 1995 ] [ 55, Hill 1989 ]
4.7.7.4.2 [Process C: Insect resist] Application of mothproofing agents to the carpet pile [using foam technology]

Ex-Section 4.8.4.3.3

**Description**
Application of mothproofing agents directly to the pile of the carpet by using foam.

**Technical description**
Figure 4.73 shows that this candidate technique does not form part of the yarn manufacturing process. In this case IR agents are applied directly to the pile of the carpet during the backcoating or latexing operation. Specialised equipment has been developed in which a high-density foam incorporating the IR mothproofing agents is generated on site and applied to the carpet using a specially profiled application head. This is a continuous process and can be carried out simultaneously with backing/latexing. The use of foam minimises moisture addition. The foam is generated within a contained area on demand and any rinsing water is recycled and used to prepare the next batch of foam.

**Main-Achieved environmental benefits**
When operated with a rinse liquor reuse system, the process is effluent-free and eliminates the emission of the mothproofing agent active substance to the aquatic environment.

**Environmental performance and operational data**
There are no emissions to the mill waste water stream. For the treatment to be fully effective, the active ingredient must penetrate to the base of the carpet pile structure. The density of the pile structure, the foam density and foam blow ratio control penetration. Technical aspects of the technology are described by Allanach and Greenwood (Proceedings of the 9th International wool Textile Research Conference Vol.3,325-332, 1995)

In comparison to yarn application techniques a somewhat higher overall application rate is required to ensure that the base of the pile is adequately protected against insect damage. The foam adds moisture to the carpet which must be removed by evaporation and additional drying capacity may be required over and above that required to cure the latex or backcoat, which implies increased energy consumption.

**Cross-media effects**
None believed likely.
- Increased energy consumption.
- Increased amount of chemicals needed.

**Technical considerations relevant to applicability**
The technique relies on application of the mothproofing finish directly to the pile of the carpet and is, therefore, applicable only on sites where the final carpet manufacturing processes are carried out. Commission dyers and sales yarn spinners are unable to make use of this technique. Practical experience indicates that penetration of the foam to the base of the pile may be difficult to achieve with some densely tufted and woven pile structures. The application of a foam to the surface of some pile structures is also known to cause unacceptable changes in the surface appearance of the finished carpet and these effects have to determined on a case-by-case basis.

**Economics**
Dedicated equipment designed specifically to achieve the level application of foam at a low moisture add-on is required. At the time of writing only one commercially available system has been fully evaluated for insect resist treatment. The equipment can be retrofitted to an existing carpet finishing line if space allows, at a cost of approximately EUR 160 000. Depending on the construction of the carpet, additional drying capacity may need to be installed, or alternatively...
the finishing line may need to be run at a slower speed. Due to the higher required application rate, chemical costs are approximately twice those incurred when a mothproofing finish is applied during yarn wet processing.

Example Reference plants
The technique is employed by a number of UK and European carpet manufacturers.

Reference literature
[32, ENco, 2001] [56, Allanach et al. 1995]

Figure 4.73: Process map for mothproofing stock dyed—yarn scoured production
[32, ENco, 2001]

4.7.7.5 [Specific process modifications to minimise the emission of insect resist agent active substance during the treatment of yarn dyed production] Minimisation of emissions of mothproofing agents from yarn production when using the 'yarn dyeing route'

Ex-Section 4.8.4.4

Figure 4.74 below illustrates the baseline process for the mothproofing of carpet yarn produced via the yarn dyeing route. In this process, mothproofing is carried out simultaneously with colouration, the required quantity of mothproofing agent being added to the dye vessel at the commencement of dyeing.

The active substance is adsorbed by the fibre as the temperature of the dye liquor increases. This adsorptive process reaches equilibrium at the boiling point, with more than 98% of the active substance partitioning towards the fibre. The spent dye liquor contains residual active substance at a concentration that depends on the dyeing conditions. Acidic dyeing conditions (pH < 4) yield the lowest residues. Dyeing carried out under more neutral conditions, for example in the case of dyeing with pre-metalised dyestuffs, generally results in higher residues in liquors.

The dyeing may be followed by a rinsing cycle, which may also contain residual active substance. In the conventional process both these spent liquors are discharged to the mill’s waste water attenuation equalisation tank. The liquor expelled extracted during hydroextraction of the dyed yarn may also contain the active substance at trace levels.

Emissions from the baseline process depend on a large number of interrelated variables as each dyeing is virtually unique. For practical purposes, the pH of the dye liquor can be considered to have the single most important effect and emission values from a large number of dyeings generally fall within the following ranges (Enco Environmental Network, unpublished):

- dyeing at a pH < 4 0.1-0.4 mg/kg yarn;
- dyeing at a pH > 4 2.0-7.0 mg/kg yarn.

Inspection of As shown in Figure 4.74, indicates that there are four alternative processes modifications (numbered 1 to 4) which are capable of minimising the emission of mothproofing agents when compared with the baseline process. Two of these alternatives, continuous low-volume application (Process 2) and foam application (Process 4) have been described above in Sections 4.7.7.4.1 and 4.7.7.4.2 respectively the section on minimising emissions from the stock dye—yarn scour yarn production route. The two candidate techniques which are suitable only for the yarn dye production route (Process 1 and Process 3) are described in Sections 4.7.7.5.1 and 4.7.7.5.2 below.
**Process 1:** After-treatment under acidic conditions.

**Process 2:** Continuous low-volume application.

**Process 3:** Application of mothproofing agents in a modified centrifugal hydroextractor.

**Process 4:** Application of mothproofing agents directly to the pile of the carpet by using foam.

*Source:* [51, ENco 2001]

**Figure 4.74:** Traditional and alternative processes for mothproofing in the yarn dyeing route

### 4.7.7.5.1 [Process 1.] After-treatment under acidic conditions

**Ex-Section 4.8.4.4.1**

**Description**

In this process, Mothproofing is carried out from a separate bath to colouration dyeing as an after-treatment, following rinsing. The after-treatment bath is acidified to provide optimum conditions for mothproofing agent uptake.

**Technical description**

See above.

**Main-Achieved environmental benefits**

Reduced generation of waste water.
Environmental performance and operational data

Treatment is carried out in the absence of any retarding chemicals and at a pH optimal for mothproofing agent adsorption. Residual active substance loads are typically between 0.1 mg/kg and 0.4 mg/kg.

In many dyehouses, wool and wool blend dyeing is carried out using a variety of dyeing conditions, depending on the particular dyestuffs selected to meet end-product requirements. This process is applicable to used for the mothproofing of yarn that would be when yarn is dyed under conditions which are not optimised for mothproofing agent uptake. In practice, the technique is used to mothproof yarn when the dyeing conditions specify a liquor pH greater than approximately 5.0.

Cross-media effects
None believed likely.
- Increased water consumption.
- Increased energy consumption to maintain the dye bath at an elevated temperature for longer.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
The process requires the use of an additional after-treatment bath, equal in volume to the original dye bath. Depending on machine design and yarn load, water consumption will lie between 15 m³/tonne and 25 m³/tonne. Additional energy is required to raise the after-treatment bath to the dyeing temperature, together with additional time to complete the lengthened process.

Example Reference plants
This technique is used in UK dyehouses to minimise emissions from a dyeing that would otherwise yield unacceptably high residues.

Reference literature
[32, ENCo, 2001]

.Process 2. Low volume semi-continuous application]

Ex-Section 4.8.4.4.2 deleted because it is a repetition of ex-Section 4.8.4.3.2

4.7.7.5.2 [Process 3.] Application of mothproofing agent in [from] a modified centrifugal hydroextractor

Ex-Section 4.8.4.4.3

Description
The technique relies on the use of a modified batch hydroextractor. Centrifugal force is used to transport treatment liquor sprayed into the centrifugal hydroextractor from a centrally located spray head through the yarn load as it rotates.

Liquor expelled from the centrifuge is either collected and recycled, or separated from other waste water streams and treated to remove residual active substance.

Technical description
The technique was is fully described by Allanach (Proceedings of the 8th International Wool Textile Research Conference, Vol.4, 568-576,1990), in [ 57, Allanach 1990 ].
The technique requires modification of the centrifuge, the centrifuge drainage system and the provision of spent liquor treatment techniques—facilities. These may consist of either alkali hydrolysis or a physical separation technique. The system as originally envisaged used a heated treatment liquor to encourage mothproofer uptake and re-cycling of the treatment liquor between batches. No such installations were ever operated on a commercial basis, but variants of the system have been used.

**Main-Achieved environmental benefit**
A reduction in mothproofing agents residues discharged to waste water.

**Environmental performance and operational data**
Batch to batch reuse of the liquor can be difficult to implement because of the risk of colour change. The technique is, therefore, not universally applicable and for this reason has not been widely adopted by industry.

**Technical considerations relevant to applicability**
Generally, there are no technical restrictions to the applicability of this technique.

**Economics**
There are no commercially available packages solutions. Modification of an existing centrifugal hydroextractor on a self-built basis and the provision of ancillary equipment is estimated at approximately EUR 30 000.

**Driving force for implementation**
Environmental legislation.

**Example Reference plants**
One plant in the UK is known to operate a variant of the process described above, but no details are available.

**Reference literature**
[32, ENco, 2001] [ 57, Allanach 1990 ].

**Figure 4.75:** Process map for mothproofing yarn dyed production
[32, ENco, 2001]
4.8 Laminating and coating

4.8.1 Hot-melt lamination
[ 36, ÖKOPOL 2011 ]

Description
Hot-melt lamination is used instead of flame lamination.

Technical description
In hot-melt lamination, melted solvent-free polymers are applied to textile fabrics by appropriate aggregates (see Section 2.10.1).

Compared to flame lamination where the substrates to be stuck together are exposed directly to a flame burner leading to emissions of crack products of the polyurethane foams used, in hot-melt lamination the operating temperature is too low to generate crack products. For this reason no air emission abatement techniques are necessary. Thus no additional environmental impacts like energy and water consumption as well as the resulting waste water and operating expenses will occur.

Achieved environmental benefits
Reduction of emissions of organic compounds to air.

Environmental performance and operational data
Emissions of isocyanate during production are low. They depend on the amount of non-bonded isocyanate monomers. The monomer content of the polyurethanes used can be up to 2%. The content in monomer-poor products is less than 0.1%. They will be captured by an exhaust device and discharged to the atmosphere, because they react immediately with humidity to form non-hazardous substances. Working place measurements show concentrations of MDI (methylene diphenyl diisocyanate) of < 0.05 mg/m³ (< 0.005 ml/m³) [ 36, ÖKOPOL 2011 ]

Hot-melt lamination provides high production velocities. Theoretically, in slot die coating the rate rises up to more than 500 m/min. Limits of velocity are defined by the substrate: 30-60 m/min for fine knitted fabrics and 150-200 m/min for tight woven fabrics and non-wovens. In the textile sector the velocity of roller systems is in the range of 40-50 m/minute. Due to short exposure times, the thermal stress for the substrates is low.

The energy consumption of the extruder is approximately 0.3-0.5 kW/kg of adhesive, 0.4-0.6 kW/kg of adhesive for the melting tank [ 36, ÖKOPOL 2011 ]

Normally, the power input of slot die coating systems is lower compared to roller systems (due to the lower mass ratio between slot dies and rollers). The power input also depends on the process parameters (operating temperature, applied quantity, capacity etc.).

Adhesive consumption is between 1 g/m² and 50 g/m² or even higher depending on the type of substrates to be laminated and the laminate performance requirements.

Cross-media effects
None identified.

Technical considerations relevant to applicability
Hot-melt lamination can be performed with a lot of different substrates and foams. Adhesive characteristics and fogging behaviour conform to all requirements of the automotive industry [ 36, ÖKOPOL 2011 ]

Hot-melt lamination may not be applicable to thin textiles.
Compared to flame lamination, hot-melt lamination causes an irregular surface on thin fabrics (‘orange-peel skin’ effect). Additionally, there is the problem of adhesive penetration in thin fabrics.

**Economics**

Investment costs for hot-melt lamination are higher compared to flame lamination equipment, especially with regard to the purchase cost of an extruder for thermoplastics.

Equipment for hot-melt triplex-laminates used for seats in vehicles is more expensive than equipment for hot-melt duplex-laminates.

Generally, investing in equipment for hot-melt lamination will be profitable considering the absence of ‘burnt’ foam and the unneeded exhaustion equipment. According to the data of an operator, the break-even point for flame lamination for conventional foams compared to hot-melt lamination is achieved for a foam density of 55 kg/m$^3$, e.g. used for the ceiling in vehicles. For a foam density of approximately 38 kg/m$^3$ (use for seats in vehicles), the cost advantage is approximately 7% for flame lamination.

**Driving force for implementation**

- Improved environmental performance (emissions to air).
- Economics.

**Example plants**


Plants from the data collection: CZ015, DE026 and FR131.

**Reference literature**

[ 36, ÖKOPOL 2011 ] [ 175, Weydts et al. 2019 ]

**[Final effluent/emission abatement techniques]**

**[Treatment of mixed waste water with about 60% water recycling]**

Ex-Section 4.10.2 deleted as per conclusions of the KoM
5 BEST AVAILABLE TECHNIQUES (BAT) CONCLUSIONS

This chapter has been completely rewritten compared to the original TXT BREF

[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 green italics in square brackets.]

Scope

These BAT conclusions concern the following activities specified in Annex I to Directive 2010/75/EU, namely:

- 6.2. Pre-treatment (operations such as washing, bleaching, mercerisation) or dyeing of textile fibres or textiles where the treatment capacity exceeds 10 tonnes per day.
- 6.11. Independently operated treatment of waste water not covered by Directive 91/271/EEC provided that the main pollutant load originates from activities covered by these BAT conclusions.

These BAT conclusions also cover:

- The following activities when they are directly associated with activities specified in point 6.2 of Annex I to Directive 2010/75/EU:
  - coating;
  - dry cleaning;
  - fabric production;
  - finishing;
  - lamination;
  - printing;
  - singeing;
  - wool carbonising;
  - wool fulling;
  - yarn production.
- The combined treatment of waste water from different origins provided that the main pollutant load originates from activities covered by these BAT conclusions and that the waste water treatment is not covered by Directive 91/271/EEC.
- On-site combustion plants which are directly associated with the activities covered by these BAT conclusions provided that the combustion gases are put into direct contact with the textile fibres or textiles (such as direct heating, drying, heat-setting) or when radiant and/or conductive heat is transferred through a solid wall (indirect heating) without using an intermediary heat transfer fluid.

These BAT conclusions do not cover:

- Coating and lamination where the organic solvent consumption capacity of more than 150 kg per hour or more than 200 tonnes per year. This is covered by the BAT conclusions on surface treatment using organic solvents including preservation of wood and wood products with chemicals (STS).
- Production of man-made fibres and yarns.
- Unhauling of hides and skins. This may be covered by the BAT conclusions for the tanning of hides and skins (TAN).
Other BAT conclusions and reference documents which could be relevant for the activities covered by these BAT conclusions include the following:

- Surface Treatment Using Organic Solvents including Preservation of Wood and Wood Products with Chemicals (STS);
- Tanning of Hides and Skins (TAN);
- Waste Incineration (WI);
- Waste Treatment (WT);
- Emissions from Storage (EFS);
- Energy Efficiency (ENE);
- Industrial Cooling Systems (ICS);
- Monitoring of Emissions to Air and Water from IED Installations (ROM);

These BAT conclusions apply without prejudice to other relevant legislation, e.g. on the registration, evaluation, authorisation and restriction of chemicals (REACH), on the classification, labelling and packaging (CLP) or on biocidal products (BPR).
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>Cellulosic materials</td>
<td>Cellulosic materials include cotton and viscose.</td>
</tr>
<tr>
<td>Channelled emissions</td>
<td>Emissions of pollutants to air through any kind of duct, pipe, stack, etc.</td>
</tr>
<tr>
<td>Continuous measurement</td>
<td>Measurement using an automated measuring system permanently installed on site.</td>
</tr>
<tr>
<td>Desizing</td>
<td>Removal of sizing chemicals.</td>
</tr>
<tr>
<td>Diffuse emissions</td>
<td>Non-channelled emissions to air.</td>
</tr>
<tr>
<td>Direct discharge</td>
<td>Discharge to a receiving water body without further downstream waste water treatment.</td>
</tr>
<tr>
<td>Dry cleaning</td>
<td>Cleaning of textile materials with an organic solvent.</td>
</tr>
<tr>
<td>Existing plant</td>
<td>A plant that is not a new plant.</td>
</tr>
<tr>
<td>Finishing</td>
<td>Physical and/or chemical treatment aiming at giving the textile materials end-use properties such as visual effect, handle characteristics, waterproofing or non-flammability.</td>
</tr>
<tr>
<td>Hazardous waste</td>
<td>Hazardous waste as defined in point 2 of Article 3 of Directive 2008/98/EC.</td>
</tr>
<tr>
<td>Indirect discharge</td>
<td>Discharge which is not a direct discharge.</td>
</tr>
<tr>
<td>Liquor ratio</td>
<td>For a batch process, weight ratio between the dry textile materials and the process liquor used.</td>
</tr>
<tr>
<td>Major plant upgrade</td>
<td>A major change in the design or technology of a plant with major adjustments or replacements of the process and/or abatement technique(s) and associated equipment.</td>
</tr>
<tr>
<td>Mass flow</td>
<td>The mass of a given substance or parameter which is emitted over a defined period of time.</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>Organic solvent</td>
<td>Organic solvent as defined in Article 3(46) of Directive 2010/75/EU.</td>
</tr>
<tr>
<td>Periodic measurement</td>
<td>Measurement at specified time intervals using manual or automated methods.</td>
</tr>
<tr>
<td>Pick-up</td>
<td>For a continuous process, weight ratio between the liquid taken up by the textile materials and the dry textile materials.</td>
</tr>
<tr>
<td>Process chemicals</td>
<td>Substances and/or mixtures as defined in Article 3 of Regulation EC/1907/2006 and used in the process(es), including sizing chemicals, bleaching chemicals, dyes, printing pastes and finishing chemicals.</td>
</tr>
<tr>
<td>Process liquor</td>
<td>Solution and/or suspension containing process chemicals.</td>
</tr>
<tr>
<td>Sizing</td>
<td>Impregnation of yarn with process chemicals aiming to protect the yarn and provide lubrication during weaving.</td>
</tr>
<tr>
<td>Synthetic materials</td>
<td>Synthetic materials include polyester, polyamide and acrylic.</td>
</tr>
<tr>
<td>Textile materials</td>
<td>Textile fibres and/or textiles.</td>
</tr>
<tr>
<td>Thermal treatment</td>
<td>Thermal treatment of textile materials includes drying, curing, fixing or heat-setting which is carried out as a process step of the activities covered by these BAT conclusions.</td>
</tr>
</tbody>
</table>
## Pollutants and parameters

<table>
<thead>
<tr>
<th>Term used</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony</td>
<td>Antimony, expressed as Sb, includes all inorganic and organic antimony compounds, dissolved or bound to particles.</td>
</tr>
<tr>
<td>AOX</td>
<td>Adsorbable organically bound halogens, expressed as Cl, include adsorbable organically bound chlorine, bromine and iodine.</td>
</tr>
<tr>
<td>BOD&lt;sub&gt;n&lt;/sub&gt;</td>
<td>Biochemical oxygen demand. Amount of oxygen needed for the biochemical oxidation of the organic matter to carbon dioxide in n days (n is typically 5 or 7). BOD&lt;sub&gt;n&lt;/sub&gt; is an indicator for the mass concentration of biodegradable organic compounds.</td>
</tr>
<tr>
<td>Chromium</td>
<td>Chromium, expressed as Cr, includes all inorganic and organic chromium compounds, dissolved or bound to particles.</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide.</td>
</tr>
<tr>
<td>COD</td>
<td>Chemical oxygen demand. Amount of oxygen needed for the total chemical oxidation of the organic matter to carbon dioxide using dichromate. COD is an indicator for the mass concentration of organic compounds.</td>
</tr>
<tr>
<td>Copper</td>
<td>Copper, expressed as Cu, includes all inorganic and organic copper compounds, dissolved or bound to particles.</td>
</tr>
<tr>
<td>Dust</td>
<td>Total particulate matter (in air).</td>
</tr>
<tr>
<td>HOI</td>
<td>Hydrocarbon oil index. The sum of compounds extractable with a hydrocarbon solvent (including long-chain or branched aliphatic, alicyclic, aromatic or alkyl-substituted aromatic hydrocarbons).</td>
</tr>
<tr>
<td>NH&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Ammonia.</td>
</tr>
<tr>
<td>Nickel</td>
<td>Nickel, expressed as Ni, includes all inorganic and organic nickel compounds, dissolved or bound to particles.</td>
</tr>
<tr>
<td>NO&lt;sub&gt;x&lt;/sub&gt;</td>
<td>The sum of nitrogen monoxide (NO) and nitrogen dioxide (NO&lt;sub&gt;2&lt;/sub&gt;), expressed as NO&lt;sub&gt;2&lt;/sub&gt;.</td>
</tr>
<tr>
<td>SO&lt;sub&gt;x&lt;/sub&gt;</td>
<td>The sum of sulphur dioxide (SO&lt;sub&gt;2&lt;/sub&gt;), sulphur trioxide (SO&lt;sub&gt;3&lt;/sub&gt;), and sulphuric acid aerosols, expressed as SO&lt;sub&gt;2&lt;/sub&gt;.</td>
</tr>
<tr>
<td>Sulphide, easily released</td>
<td>The sum of dissolved sulphides and of those undissolved sulphides that are easily released upon acidification, expressed as S&lt;sup&gt;2-&lt;/sup&gt;.</td>
</tr>
<tr>
<td>TOC</td>
<td>Total organic carbon, expressed as C (in water), includes all organic compounds.</td>
</tr>
<tr>
<td>TN</td>
<td>Total nitrogen, expressed as N, includes free ammonia and ammonium nitrogen (NH&lt;sub&gt;4&lt;/sub&gt;–N), nitrite nitrogen (NO&lt;sub&gt;2&lt;/sub&gt;–N), nitrate nitrogen (NO&lt;sub&gt;3&lt;/sub&gt;–N) and organically bound nitrogen.</td>
</tr>
<tr>
<td>TP</td>
<td>Total phosphorus, expressed as P, includes all inorganic and organic phosphorus compounds, dissolved or bound to particles.</td>
</tr>
<tr>
<td>TSS</td>
<td>Total suspended solids. Mass concentration of all suspended solids (in water), 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>
<tr>
<td>VOC</td>
<td>Volatile organic compound as defined in Article 3(45) of Directive 2010/75/EU.</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zinc, expressed as Zn, includes all inorganic and organic zinc compounds, dissolved or bound to particles.</td>
</tr>
</tbody>
</table>

For the purposes of these BAT conclusions, the following **acronyms** apply:

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS</td>
<td>Chemicals management system</td>
</tr>
<tr>
<td>DTPA</td>
<td>Diethylenetriaminepentaacetic acid</td>
</tr>
<tr>
<td>EDTA</td>
<td>Ethylenediaminetetraacetic acid</td>
</tr>
<tr>
<td>EMS</td>
<td>Environmental management system</td>
</tr>
<tr>
<td>ESP</td>
<td>Electrostatic precipitator</td>
</tr>
<tr>
<td>NTA</td>
<td>Nitrilotriacetic acid</td>
</tr>
</tbody>
</table>
General considerations

[Note to the TWG: In order to avoid repetition, this section contains general considerations that are essential to the understanding of these 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 environmental performance levels are expressed.]

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.

Emission levels associated with the best available techniques (BAT-AELs) for emissions to air

When a mass flow threshold is indicated, the BAT-AELs only apply if the mass flow of the given substance or parameter emitted from the emission point is above the associated mass flow threshold.

Emission levels associated with the best available techniques (BAT-AELs) for emissions to air given in these BAT conclusions refer to concentrations (mass of emitted substances 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 oxygen content, and expressed in mg/Nm$^3$.

For averaging periods of BAT-AELs for emissions to air, the following definition applies.

<table>
<thead>
<tr>
<th>Type of measurement</th>
<th>Averaging period</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periodic</td>
<td>Average over the sampling period</td>
<td>Average value of three consecutive measurements of at least 30 minutes each. ($^1$)</td>
</tr>
</tbody>
</table>

($^1$) For any parameter where, due to sampling or analytical limitations, a 30-minute sampling/measurement and/or an average of three consecutive measurements is inappropriate, a more representative sampling/measurement procedure may be employed.

Emission levels associated with the best available techniques (BAT-AELs) for emissions to water

Emission levels associated with the best available techniques (BAT-AELs) for emissions to water given in these BAT conclusions refer to concentrations (mass of emitted substances per volume of water), expressed in mg/l.

Averaging periods associated with the BAT-AELs refer to either of the following two cases:

- in the case of continuous discharge, daily average values, i.e. 24-hour flow-proportional composite samples;
in the case of batch discharge, average values over the release duration taken as flow-proportional composite samples, or, provided that the effluent is appropriately mixed and homogeneous, a spot sample taken before discharge.

Time-proportional composite samples can be used provided that sufficient flow stability is demonstrated.

Other environmental performance levels associated with best available techniques (BAT-AEPLs)

Specific energy consumption levels associated with the best available techniques

The environmental performance levels related to specific energy consumption refer to yearly averages calculated using the following equation:

\[
\text{specific energy consumption} = \frac{\text{energy consumption}}{\text{activity rate}}.
\]

where:

energy consumption: the total annual amount of heat and electricity consumed by a given process, minus the heat recovered from the process, expressed in MWh/year;

activity rate: total annual amount of textile materials treated in the process, expressed in t/year.

Specific water consumption levels associated with the best available techniques

The environmental performance levels related to specific water consumption refer to yearly averages calculated using the following equation:

\[
\text{specific water consumption} = \frac{\text{water consumption}}{\text{activity rate}}.
\]

where:

water consumption: the total annual amount of water consumed by a given process including water used for washing and rinsing the textile materials and for cleaning the equipment, minus the water reused or recycled to the process, expressed in m³/year;

activity rate: total annual amount of textile materials treated in the process, expressed in t/year.

Specific wool grease recovery level associated with the best available techniques

The environmental performance level related to specific wool grease recovery refers to a yearly average calculated using the following equation:
specific wool grease recovery = \frac{\text{amount of wool grease recovered}}{\text{activity rate}}

where:

- **amount of wool grease recovered**: the total annual amount of wool grease recovered from the pre-treatment of raw wool fibres by scouring, expressed in kg/year;
- **activity rate**: total annual amount of raw wool pre-treated by scouring, expressed in t/year.

Caustic soda recovery level associated with the best available techniques

The environmental performance level related to caustic soda recovery refers to a yearly average calculated using the following equation:

caustic soda recovery = \frac{\text{amount of caustic soda recovered}}{\text{amount of caustic soda before recovery}}

where:

- **amount of caustic soda recovered**: the total annual amount of caustic soda recovered from spent mercerisation rinsing water, expressed in kg/year;
- **amount of caustic soda before recovery**: total annual amount of caustic soda in the spent mercerisation rinsing water, expressed in kg/year.
5.1 General BAT conclusions

5.1.1 Overall environmental performance

Note to the TWG: the following description of the general EMS features (i. to xx.) is based on standard text agreed at the level of the IED Article 13 Forum and used in recent documents such as the BAT conclusions for FDM, WI and STS. The possibilities for changes are therefore limited to the section dealing specifically with TXT issues (from xxi. onward).

BAT 1. In order to improve the overall environmental performance, BAT is to elaborate and implement an environmental management system (EMS) that incorporates all of the following features:

i. commitment, leadership, and accountability of the management, including senior management, to the implementation of an effective EMS;
ii. an analysis that includes the determination of the organisation’s context, the identification of the needs and expectations of interested parties, the identification of characteristics of the installation that are associated with possible risks for the environment (or human health) as well as of the applicable legal requirements relating to the environment;
iii. development of an environmental policy that includes the continuous improvement of the environmental performance of the installation;
iv. establishing objectives and performance indicators in relation to significant environmental aspects, including safeguarding compliance with applicable legal requirements;
v. planning, and implementing the necessary procedures and actions (including corrective and preventive actions where needed), to achieve the environmental objectives and avoid environmental risks;
vi. determination of structures, roles and responsibilities in relation to environmental aspects and objectives and provision of the financial and human resources needed;
vii. ensuring the necessary competence and awareness of staff whose work may affect the environmental performance of the installation (e.g. by providing information and training);
viii. internal and external communication;
ix. fostering employee involvement in good environmental management practices;
x. establishing and maintaining a management manual and written procedures to control activities with significant environmental impact as well as relevant records;
xi. effective operational planning and process control;
xii. implementation of appropriate maintenance programmes;
xiii. emergency preparedness and response protocols, including the prevention and/or mitigation of the adverse (environmental) impacts of emergency situations;
xiv. when (re)designing a (new) installation or a part thereof, consideration of its environmental impacts throughout its life, which includes construction, maintenance, operation and decommissioning;
xv. implementation of a monitoring and measurement programme; if necessary, information can be found in the Reference Report on Monitoring of Emissions to Air and Water from IED Installations;
xvi. application of sectoral benchmarking on a regular basis;
xvii. periodic independent (as far as practicable), internal auditing and periodic, independent external auditing in order to assess the environmental performance and to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;
xviii. evaluation of causes for nonconformities, implementation of corrective actions in response to nonconformities, review of the effectiveness of corrective actions, and determination of whether similar nonconformities exist or could potentially occur;
xix. periodic review, by senior management, of the EMS and its continuing suitability, adequacy and effectiveness;
xx. following and taking into account the development of cleaner techniques.

Specifically for the textile industry, BAT is also to incorporate the following features in the EMS:

xxi. an inventory of inputs and outputs (see BAT 2);
xxii. a water management plan (see BAT 9);
xxiii. an energy efficiency plan (see BAT 10);
xxiv. a chemicals management system (see BAT 13);
xxv. a waste management plan (see BAT 28).

Note
Regulation (EC) No 1221/2009 establishes the European Union eco-management and audit scheme (EMAS), which is an example of an EMS compliant with this BAT.

Applicability
The level of detail and the degree of formalisation of the EMS will generally 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 4.1.1.1]

BAT 2. In order to improve the overall environmental performance, BAT is to establish, maintain and regularly review (including when a significant change occurs) an inventory of inputs and outputs, as part of the environmental management system (see BAT 1), that incorporates all of the following features:

(i) information about the production process(es), 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 techniques to prevent or reduce emissions, including their performance (e.g. abatement efficiency);
(ii) information about the quantity and characteristics of materials used, including textile materials and process chemicals (see BAT 14);
(iii) information about water consumption;
(iv) information about energy consumption;
(v) information about the quantity and characteristics of the waste water streams, such as:
   (a) average values and variability of flow, pH, temperature, and conductivity;
   (b) average concentration and mass flow values of relevant substances/parameters and their variability (e.g. COD/TOC, nitrogen species, phosphorus, metals, priority substances, microplastics);
   (c) data on toxicity and bioeliminability (e.g. BOD₅, BOD₆ to COD ratio, Zahn-Wellens test, biological inhibition potential (e.g. inhibition of activated sludge));
(vi) information about the characteristics of the waste gas streams, such as:
   (a) average values and variability of flow and temperature;
   (b) average concentration and mass flow values of relevant substances/parameters and their variability (e.g. dust, organic compounds);
   (c) flammability, lower and higher explosive limits, reactivity;
   (d) presence of other substances that may affect the waste gas treatment system or plant safety (e.g. water vapour, dust);
information about the quantity and characteristics of waste generated.

**Applicability**
The scope (e.g. level of detail) and nature of the inventory will generally 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 4.1.1.2*

**BAT 3. In order to improve the overall environmental performance, BAT is to use advanced process monitoring and control systems.**

**Description**
The monitoring and control of processes is carried out with on-line automated systems equipped with sensors and controllers using feedback connections to rapidly analyse and adapt key process parameters to reach optimal process conditions (e.g. optimal uptake of process chemicals).

Key process parameters include:

- level, pH, temperature and conductivity of the process liquor;
- amount of textile materials treated;
- dosage of process chemicals;
- drying parameters (see also BAT 12 e).

*This BAT conclusion is based on information given in Section 4.1.1.3*
BAT 4. In order to improve the overall environmental performance, BAT is to use both of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Use of textile materials with low contents of contaminants</td>
<td>Criteria for the selection of incoming textile materials are defined to minimise the content of contaminants including toxic substances, poorly biodegradable substances and substances of very high concern. These criteria may be based on certification schemes or standards. Controls are carried out to verify that incoming textile materials fulfil the predefined criteria. These controls may consist of measurements and/or verification of information provided by suppliers and/or producers of textile materials. These controls may address the content of:</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>b. Use of textile materials with reduced processing needs</td>
<td>Use of textile materials with inherent characteristics that reduce the need for processing. These materials may include:</td>
<td>The applicability may be restricted by product specifications</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*This BAT conclusion is based on information given in Sections 4.1.5.1, 4.1.5.2 and 4.1.5.3*

5.1.2 Monitoring

BAT 5. BAT is to monitor at least once every year:

- the annual consumption of water, energy and materials used, including textile materials and process chemicals,
- the annual amount of waste water generated,
- the annual amount of materials recovered, of waste generated and of waste sent for disposal.

Description
Monitoring includes direct measurements, calculations or recording, e.g. using suitable meters or invoices. The monitoring is broken down to process level and considers any significant changes in the processes.

[This BAT conclusion is based on information given in Sections 4.1.1.2, 4.1.3.1, 4.1.4.2 and 4.1.9.1]

BAT 6. For waste water streams identified by the inventory of inputs and outputs (see BAT 2), BAT is to monitor key parameters (e.g. continuous monitoring of waste water flow, pH and temperature) at key locations (e.g. at the inlet and/or outlet of the waste water pretreatment, at the inlet to the final waste water treatment, at the point where the emission leaves the installation).

[This BAT conclusion is based on information given in Section 4.1.2.1]

BAT 7. 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(s)/parameter</th>
<th>Standard(s)</th>
<th>Activities / processes</th>
<th>Minimum monitoring frequency</th>
<th>Monitoring associated with</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adsorbable organically bound halogens (AOX) (^{(1)})</td>
<td>EN ISO 9562</td>
<td>All activities / processes</td>
<td>Once every month</td>
<td>BAT 19</td>
</tr>
<tr>
<td>Alkylphenols and alkylphenol ethoxylates (^{(1)})</td>
<td>EN standards available for some alkylphenols and alkylphenol ethoxylates (i.e. EN ISO 18857-1 and EN ISO 18857-2)</td>
<td>All activities / processes</td>
<td>Once every 3 months</td>
<td></td>
</tr>
<tr>
<td>Biochemical oxygen demand (BOD(_5)) (^{(2)})</td>
<td>EN 1899-1</td>
<td>All activities / processes</td>
<td>To be decided, after effluent characterisation (^{(5)})</td>
<td></td>
</tr>
<tr>
<td>Biodegradability</td>
<td>EN ISO 9888</td>
<td>All activities / processes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brominated flame retardants (^{(1)})</td>
<td>EN standard available for some polybrominated diphenyl ethers (i.e. EN 16694)</td>
<td>Finishing with flame retardants</td>
<td>Once every 3 months</td>
<td></td>
</tr>
<tr>
<td>Chemical oxygen demand (COD) (^{(2)})</td>
<td>No EN standard available</td>
<td>All activities / processes</td>
<td>Once every month</td>
<td></td>
</tr>
<tr>
<td>Colour</td>
<td>EN ISO 7887</td>
<td>Dyeing</td>
<td>Once every month</td>
<td></td>
</tr>
<tr>
<td>Hydrocarbon oil index (HOI)</td>
<td>EN ISO 9377-2</td>
<td>All activities / processes</td>
<td>Once every 3 months</td>
<td></td>
</tr>
<tr>
<td>Metals / metalloids</td>
<td>Antimony (Sb)</td>
<td>Various EN standards available (e.g. EN ISO 11885, Pre-treatment and/or dyeing of polyester</td>
<td>Once every month</td>
<td></td>
</tr>
<tr>
<td>ds</td>
<td>EN standards available for some pesticides (e.g. EN 12918, EN 16693 or EN ISO 27108)</td>
<td>Pre-treatment of raw wool fibres by scouring</td>
<td>Once every 3 months</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>Finishing with flame retardants using antimony trioxide</td>
<td>Dyeing with chromium-containing dyes</td>
<td>Once every month</td>
<td></td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>All activities / processes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>Dyeing with dyes containing hexavalent chromium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hexavalent chromium (Cr(VI))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pesticides (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perfluorinated compounds (1)</td>
<td>No EN standard available</td>
<td>All activities / processes</td>
<td>Once every 3 months</td>
<td></td>
</tr>
<tr>
<td>Sulphide, easily released (S²)</td>
<td>No EN standard available</td>
<td>Dyeing with sulphur dyes</td>
<td>Once every 3 months</td>
<td></td>
</tr>
<tr>
<td>Surfactants</td>
<td>EN standard available for anionic surfactants (i.e. EN 903)</td>
<td></td>
<td>Once every 3 months</td>
<td></td>
</tr>
<tr>
<td>Total nitrogen (TN) (2)</td>
<td>EN 12260 or EN ISO 11905-1</td>
<td></td>
<td>Once every month</td>
<td></td>
</tr>
<tr>
<td>Total organic carbon (TOC) (2)(3)</td>
<td>EN 1484</td>
<td></td>
<td>Once every month</td>
<td></td>
</tr>
<tr>
<td>Total phosphorus (TP)</td>
<td>EN ISO 6878, EN ISO 15681-1, EN ISO 15681-2 or EN ISO 11885</td>
<td></td>
<td>Once every month</td>
<td></td>
</tr>
<tr>
<td>Total suspended solids (TSS) (2)</td>
<td>EN 872</td>
<td></td>
<td>Once every month</td>
<td></td>
</tr>
<tr>
<td>Toxicity (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish eggs (Danio rerio)</td>
<td>EN ISO 15088</td>
<td>All activities / processes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daphnia (Daphnia magna Straus)</td>
<td>EN ISO 6341</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luminescent bacteria (Vibrio fischeri)</td>
<td>EN ISO 11348-1, EN ISO 11348-2 or EN ISO 11348-3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duckweed (Lemna minor)</td>
<td>EN ISO 20079 or EN ISO 20227</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algae</td>
<td>EN ISO 8692, EN ISO 10253 or EN ISO 10710</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>To be decided based on a risk assessment, after effluent characterisation (4)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(1) The monitoring only applies when the substance(s)/parameter, including groups of substances or individual substances in a group of substances, concerned is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.

(2) The monitoring only applies in the case of a direct discharge to a receiving water body.

(3) 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.

(4) An appropriate combination of the toxicity parameters can be used.

(5) The effluent characterisation is carried out before starting operation of the plant or before a permit for the plant is updated for the first time after the publication of these BAT conclusions, and after each significant change in the plant.

[This BAT conclusion is based on information given in Section 4.1.2.2]

BAT 8. BAT is to monitor channelled 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>Substance/parameter</th>
<th>Standard(s)</th>
<th>Activities / processes</th>
<th>Minimum monitoring frequency</th>
<th>Monitoring associated with</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>EN 15058</td>
<td>Singeing</td>
<td>Once every 3 years</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combustion plants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dust</td>
<td>EN 13284-1</td>
<td>Fabric production</td>
<td></td>
<td>BAT 24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Singeing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermal treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>No EN standard available</td>
<td>Coating (1)</td>
<td>Once every year (1) (2)</td>
<td>BAT 23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flame lamination</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Printing (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Singeing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermal treatment after finishing and after printing (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₃</td>
<td>No EN standard available</td>
<td>Coating (1)</td>
<td>Once every year (1) (2)</td>
<td>BAT 25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Printing (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermal treatment after finishing and after printing (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOₓ</td>
<td>EN 14792</td>
<td>Singeing</td>
<td>Once every 3 years</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combustion plants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOₓ (6)</td>
<td>EN 14791</td>
<td>Combustion plants</td>
<td>Once every 3 years</td>
<td>—</td>
</tr>
<tr>
<td>TVOC</td>
<td>EN 12619</td>
<td>Coating</td>
<td>Once every year (1) (2)</td>
<td>BAT 23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lamination</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Printing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Singeing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermal treatment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) The measurements are carried out at the highest expected emission state under normal operating conditions.

(2) In the case of a dust mass flow of less than 50 g/h, the minimum monitoring frequency may be reduced to once every 3 years.

(3) The monitoring only applies when the substance concerned is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.

(4) In the case of a formaldehyde mass flow of less than 2.5 g/h, the minimum monitoring frequency may be reduced to once every 3 years.

(5) In the case of a NH₃ mass flow of less than 50 g/h, the minimum monitoring frequency may be reduced to once every 3 years.

(6) The monitoring does not apply if natural gas only is used as fuel.

(7) In the case of a TVOC mass flow of less than 100 g/h, the minimum monitoring frequency may be reduced to once every 3 years.

[This BAT conclusion is based on information given in Section 4.1.2.3]
## 5.1.3 Water use and waste water generation

**BAT 9.** In order to reduce water consumption and waste water generation, BAT is to use all of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Management techniques</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Water management plan and water audits</td>
<td>A water management plan is part of the EMS (see BAT 1) and includes: • flow diagrams and a water mass balance as part of the inventory of inputs and outputs mentioned in BAT 2; • establishment of water efficiency objectives; • implementation of water optimisation techniques (e.g. control of water usage, reuse/recycling, detection and repair of leaks). Water audits are carried out at least annually to ensure the objectives of the water management plan are met.</td>
<td>The level of detail of the water management plan and water audits will generally be related to the nature, scale and complexity of the plant.</td>
</tr>
<tr>
<td>b. Production optimisation</td>
<td>This includes: • optimised combination of processes (e.g. pretreatment processes are combined, bleaching of textile materials is avoided before dyeing in dark shades); • optimised scheduling of batch processes (e.g. dyeing of the textile materials in dark shades is carried out after dyeing in light shades in the same dyeing equipment).</td>
<td>Generally applicable.</td>
</tr>
<tr>
<td><strong>Design and operation techniques</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Water-free processes</td>
<td>Processes that do not use water include plasma, laser or ozone treatments.</td>
<td>Only applicable to new plants or major plant upgrades. The applicability may be restricted by the characteristics of the textile materials and/or product specifications.</td>
</tr>
<tr>
<td>d. Optimisation of the amount of process liquor used</td>
<td>Batch processes are carried out with low-liquor-ratio systems (see Section 5.9.4). Continuous processes are carried out with low-volume application systems (see Section 5.9.4).</td>
<td></td>
</tr>
<tr>
<td>e. Optimised cleaning of the equipment</td>
<td>This includes: • water-free cleaning (e.g. by wiping or brushing the tanks’ inner surfaces); • multiple cleaning steps with low amounts of water; the water of the last cleaning step may be reused to clean another part of equipment.</td>
<td>Generally applicable.</td>
</tr>
<tr>
<td>f. Optimised batch processing, washing and rinsing of textile materials</td>
<td>This includes: • use of auxiliary tanks for temporary storage of: o spent washing or rinsing water; o fresh or spent process liquor; • multiple drain and fill steps for rinsing and washing with low amounts of water.</td>
<td></td>
</tr>
</tbody>
</table>
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Optimised continuous processing, washing and rinsing of textile materials

This includes:

• timely process liquor preparation based on online pick-up measurements;
• automatic closure of the washing water inflow when the washing machine stops;
• countercurrent rinsing and washing;
• intermediary mechanical dewatering of textile materials (see BAT 12 b) to reduce the carry-over of process chemicals.

Reuse and recycling techniques

Water reuse and/or recycling

Reuse and/or recycling of water streams (preceded or not by water treatment), e.g. for cleaning, rinsing, cooling or in the processing of textile materials. The degree of water reuse/recycling is limited by the content of impurities in the water streams.

Generally applicable

Reuse of process liquor

Process liquor, including the process liquor extracted from textile materials by mechanical dewatering (see BAT 12 b), is reused after analysis and make-up if needed. The degree of reuse of process liquor is limited by the content of impurities.

Table 5.1: BAT-associated environmental performance levels (BAT-AEPLs) for specific water consumption

<table>
<thead>
<tr>
<th>Specific process(es)</th>
<th>BAT-AEPL (Yearly average) (m³/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bleaching (1)</td>
<td>Batch 3–48 (2)</td>
</tr>
<tr>
<td></td>
<td>Continuous 3–8</td>
</tr>
<tr>
<td>Scouring of cellulosic materials (1)</td>
<td>Batch 2–43 (3)</td>
</tr>
<tr>
<td></td>
<td>Continuous 2–20</td>
</tr>
<tr>
<td>Desizing of cellulosic materials (1)</td>
<td>2–20</td>
</tr>
<tr>
<td>Mercerisation</td>
<td>2–13 (4)</td>
</tr>
<tr>
<td>Washing of synthetic material</td>
<td>5–20</td>
</tr>
<tr>
<td>Batch dyeing</td>
<td>Fabric 10–175 (5)</td>
</tr>
<tr>
<td></td>
<td>Yarn 3–140 (6)</td>
</tr>
<tr>
<td></td>
<td>Loose fibre 13–62</td>
</tr>
<tr>
<td>Continuous dyeing</td>
<td>2–16</td>
</tr>
</tbody>
</table>

(1) The BAT-AEPL for the combined pre-treatment of cotton textiles by bleaching, scouring and desizing is 9–20 m³/t. The lower end of the range is typically achieved for continuous treatment.

(2) The lower end of the range is typically achieved with a high level of water recycling (e.g. above XX).

(3) The lower end of the range is typically achieved with a high level of water recycling (e.g. above XX).

(4) The lower end of the range is typically achieved with a high level of water recycling (e.g. above 85 %).

(5) The lower end of the range is typically achieved with a high level of water recycling (e.g. above 85 %).

(6) The lower end of the range is typically achieved with a high level of water recycling (e.g. above 95 %).

Request to TWG: please provide information to complete footnotes (2) and (3).

The associated monitoring is given in BAT 5.

(This BAT conclusion is based on information given in Sections 4.1.3, 4.5.1.3, 4.5.1.6 and 4.5.1.7)
### 5.1.4 Energy efficiency

**BAT 10.** In order to use energy efficiently, BAT is to use all of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Management techniques</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| a. Energy efficiency plan and energy audits | An energy efficiency plan is part of the EMS (see BAT 1) and includes:  
- energy flow diagrams as part of the inventory of inputs and outputs (see BAT 2);  
- setting objectives in terms of energy efficiency (e.g. MWh/t of textile materials processed);  
- implementing actions to achieve these objectives.  
Energy audits are carried out at least annually to ensure that the objectives of energy efficiency plan are met. | The level of detail of the energy efficiency plan will generally be related to the nature, scale and complexity of the plant |
| b. Production optimisation | Optimised scheduling of fabric batches to undergo thermal treatment in order to minimise the idling time of the equipment. | Generally applicable |
| **Common techniques** | | |
| c. Use of common techniques | This includes:  
- burner maintenance and control;  
- cogeneration;  
- energy-efficient motors;  
- energy-efficient lighting;  
- optimising steam distribution systems, e.g. by using point-of-use boilers;  
- regular inspection and maintenance of the steam distribution systems to prevent or reduce steam leaks;  
- process control systems;  
- reducing heat losses by insulating equipment components and by covering tanks or bowls containing warm process liquor;  
- optimising the temperature of the rinsing water;  
- avoiding overheating of the process liquors;  
- variable speed drives;  
- optimising air conditioning and building heating. | Generally applicable |
| **Heat recovery techniques** | | |
| d. Recycling of warm cooling water | See BAT 9 h. This avoids the need for heating cold water. | |
| e. Reuse of warm process liquor | See BAT 9 i. This avoids the need for heating cold process liquor. | Generally applicable |
| f. Heat recovery from waste water | Heat from waste water is recovered by heat exchangers, e.g. to warm up process liquor. | |
| g. Reuse and/or recycling of warm air | Warm cooling air (e.g. from air-cooled air compressors) is reused and/or recycled (e.g. for drying, after dedusting if needed). | |
Heat recovery from waste gases

Heat from waste gases (e.g. from thermal treatment of textile materials, steam boilers) is recovered by heat exchangers and used (e.g. to warm up process water or to preheat combustion air).

Heat recovery from steam use

Heat, e.g. from hot condensate and boiler blowdown, is recovered.

[This BAT conclusion is based on information given in Sections 4.1.4.1 and 4.1.4.3]

**BAT 11. In order to increase energy efficiency when using compressed air, BAT is to use all 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>Optimal design of the compressed air system</td>
<td>Several systems are installed to supply compressed air with different pressure levels. This avoids the unnecessary production of high-pressure air.</td>
</tr>
<tr>
<td>b.</td>
<td>Optimal use of the compressed air system</td>
<td>Compressed air production is stopped during long shutdown or idling times of equipment, and single areas can be isolated from the rest of the system, in particular if they are associated with infrequent uses.</td>
</tr>
<tr>
<td>c.</td>
<td>Control of leakages in the compressed air system</td>
<td>The most common sources of air leakages are regularly checked (e.g. couplings, hoses, tubes, fittings, pressure regulators).</td>
</tr>
<tr>
<td>d.</td>
<td>Reuse and/or recycling of warm cooling water or warm cooling air of air compressors</td>
<td>See BAT 10 d and BAT 10 g.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 4.1.4.4]
BAT 12. In order to increase the energy efficiency of thermal treatment, BAT is to use all of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Techniques for reducing the use of heating</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Wet-on-wet dyeing or finishing of fabric</td>
<td>Dyeing or finishing liquors are applied directly to the wet fabric, thus avoiding an intermediate drying step.</td>
<td></td>
</tr>
<tr>
<td>b. Mechanical dewatering of textile materials</td>
<td>The water content of textile materials is reduced by mechanical techniques (e.g. centrifugal extraction, squeezing and/or vacuum extraction).</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>c. Avoiding overdrying of textile materials</td>
<td>The textile materials are not dried below their natural moisture level.</td>
<td></td>
</tr>
</tbody>
</table>

| **Design and operation techniques** | | |
| d. Optimising air circulation in stenters | This includes: | Only applicable to new plants or major plant upgrades |
| | • the number of air injection nozzles is adapted to the width of the fabric; | |
| | • the distance between the nozzles and the fabric is as short as possible; | |
| | • the pressure drop caused by the stenters’ internal components is as small as possible. | |
| e. Advanced process monitoring and control of drying | The following drying parameters are monitored and controlled (see BAT 3): | Generally applicable |
| | • humidity content and temperature of the inlet air; | |
| | • temperature of textile materials and air within the dryer; | |
| | • humidity content and temperature of the exhaust air; drying efficiency is optimised by a high humidity content (e.g. above 0.1 kg water/kg dry air); | |
| | • residual moisture content of the fabric. | |
| | The exhaust airflow is adjusted to optimise drying efficiency and is reduced during idling time of drying equipment. | |
| f. Microwave or radio-frequency dryers | Drying of textile materials with high-efficiency microwave or radio frequency dryers. | Only applicable to new plants or major plant upgrades |

| **Heat recovery techniques** | | |
| g. Heat recovery from waste gases | See BAT 10 h. | Generally applicable |

[This BAT conclusion is based on information given in Section 4.1.4.5]

Table 5.2: BAT-associated environmental performance levels (BAT-AEPLs) for specific energy consumption

<table>
<thead>
<tr>
<th>Process</th>
<th>Unit</th>
<th>BAT-AEPL (Yearly average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal treatment</td>
<td>MWh/t</td>
<td>0.5–4.4</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.
5.1.5 Chemicals

BAT 13. In order to improve the overall environmental performance, BAT is to elaborate and implement a chemicals management system (CMS) as part of the EMS (see BAT 1) that incorporates all of the following features:

I. process chemicals procurement policy to select process chemicals and their suppliers with the aim to minimise the use of hazardous chemicals such as substances of very high concern and to avoid the procurement of excess amount of process chemicals. In order to reduce emissions to air, the selection of process chemicals may be based on emission factors (see Section 5.9.1);
II. anticipatory monitoring of regulatory changes related to hazardous chemicals and safeguarding compliance with applicable legal requirements;
III. identification of the process chemicals pathways through the plant (from procured process chemicals to products, waste and emissions);
IV. assessment of the risks associated to the chemicals, based on the chemicals’ hazards, concentrations and amounts. This may include an estimation of their emissions to the environment;
V. regular (e.g. annual) check aiming at identifying potentially new available and safer alternatives to the use of hazardous chemicals (e.g. changes of process(es) or use of other chemicals with no or lower environmental impacts such as enzymes);
VI. goals and action plans to avoid or reduce the use of hazardous chemicals;
VII. development and implementation of procedures for the handling, storage, use and return of process chemicals (see BAT 20).

The criteria for selecting process chemicals and their suppliers may be based on certification schemes or standards. In that case, the compliance of the process chemicals and their suppliers with these schemes or standards is regularly verified.

Applicability
The level of detail of the CMS will generally be related to the nature, scale and complexity of the plant.

[This BAT conclusion is based on information given in Section 4.1.6.1]

BAT 14. In order to improve the overall environmental performance, BAT is to elaborate and implement a chemicals inventory and tracking system as part of the CMS (see BAT 13).

Description
The chemicals inventory and tracking system is computer-based and contains information about:

• the identity of the process chemicals;
• the quantities and location of the process chemicals procured, recovered (see BAT 15 f), stored, used and returned to suppliers;
• the characteristics of process chemicals including properties with adverse effects on the environment and/or human health.

[This BAT conclusion is based on information given in Section 4.1.6.2]
BAT 15. In order to reduce the consumption of chemicals, BAT is to use all 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>Reduction of the need for process chemicals</td>
<td>This includes:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• regularly reviewing the formulation of process chemicals and liquors;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• using demineralised water in the processes to reduce the need for complexing agents;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• production optimisation (see BAT 9 b).</td>
</tr>
<tr>
<td>b.</td>
<td>Treatment of textile materials with enzymes</td>
<td>Enzymes are selected (see BAT 13 c) and used to catalyse the reactions with textile materials to lower the consumption of process chemicals (e.g. in desizing, bleaching and/or washing).</td>
</tr>
<tr>
<td>c.</td>
<td>Automatic systems for preparation and dosing of process chemicals and process liquors</td>
<td>Automatic systems for weighing, dosing, dissolving, measuring and dispensing which ensures precise delivery of process chemicals and process liquors to the production machines. See BAT 3.</td>
</tr>
<tr>
<td>d.</td>
<td>Optimisation of the quantity of process chemicals used</td>
<td>See BAT 9 d.</td>
</tr>
<tr>
<td>e.</td>
<td>Reuse of process liquor</td>
<td>See BAT 9 i.</td>
</tr>
<tr>
<td>f.</td>
<td>Recovery and use of leftover process chemicals</td>
<td>Residual process chemicals are recovered (e.g. by thoroughly purging pipes or completely emptying packaging) and used in the process.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Sections 4.1.6.4 and 4.1.6.7]

BAT 16. In order to prevent or reduce emissions to water of poorly biodegradable substances, BAT is to use all 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>Substitution of alkylphenols and alkylphenol ethoxylates (AP/APEO) are substituted by biodegradable surfactants, e.g. alcohol ethoxylates (AE).</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>b.</td>
<td>Substitution of phosphorus- or nitrogen-containing complexing agents</td>
<td>Complexing agents containing phosphorus (e.g. triphosphates) or nitrogen (e.g. polycarboxylic acids such as EDTA, DTPA or NTA) are substituted by biodegradable substances, e.g:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• polycarboxylates (e.g. polycrylates and copolymers of acrylic and maleic acids);</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• hydroxy carboxylic acids (e.g. gluconates, citrates);</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• sugar-based acrylic acid copolymers.</td>
</tr>
<tr>
<td>c.</td>
<td>Substitution of mineral-oil-based antifoaming agents</td>
<td>Mineral-oil-based antifoaming agents are substituted by biodegradable substances, e.g. silicone-based antifoaming agents.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 4.1.6.8]
5.1.6  Emissions to water

BAT 17.  In order to reduce the waste water volume, the pollutant loads discharged to the waste water treatment plant and the emissions to water, BAT is to use an integrated waste water management and treatment strategy that includes an appropriate combination of process-integrated techniques, techniques to recover and reuse process liquors, and treatment techniques (see BAT 18 and BAT 19).

Description
The integrated waste water management and treatment strategy is based on the information provided by the inventory of inputs and outputs (see BAT 2).

[This BAT conclusion is based on information given in Section 4.1.7.1]

BAT 18.  In order to reduce emissions to water, BAT is to (pre)treat waste water containing pollutants that cannot be treated adequately by a biological treatment.

Description
The treatment is carried out as part of an integrated waste water management and treatment strategy (see BAT 17) and is generally necessary to:

- protect the (downstream) biological waste water treatment against inhibitory or toxic compounds;
- remove compounds that are insufficiently abated during biological waste water treatment (e.g. toxic compounds, poorly biodegradable organic compounds, organic compounds that are present in high concentrations, or metals);
- remove compounds that could otherwise be stripped to air from the collection system or during biological waste water treatment (e.g. sulphide);
- remove compounds that have other negative effects (e.g. corrosion of equipment; unwanted reaction with other substances; contamination of waste water sludge).

The treatment is carried out on site or off site. On-site treatment is generally carried out as close as possible to the source in order to avoid dilution.

The techniques used depend on the pollutants targeted and include adsorption, chemical oxidation and chemical reduction (see BAT 19).

Waste water which may contain toxic or poorly biodegradable compounds includes:

- spent liquors from sizing, dyeing and finishing;
- spent printing pastes.

The biodegradability of the COD/TOC content of the waste water sent to biological treatment is at least 80 %, monitored in accordance with the standard EN ISO 9888.

[This BAT conclusion is based on information given in Sections 4.1.7.1 and 4.1.7.2]
BAT 19. In order to reduce emissions to water, BAT is to use an appropriate combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Typical pollutants targeted</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preliminary and primary treatment, e.g.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Equalisation</td>
<td>All pollutants</td>
<td></td>
</tr>
<tr>
<td>b. Neutralisation</td>
<td>Acids, alkalis</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>c. Physical separation (e.g. screens, sieves, grit separators, grease separators, oil-water separation, hydrocyclones or primary settlement tanks)</td>
<td>Gross solids, suspended solids, oil/grease</td>
<td></td>
</tr>
<tr>
<td><strong>Physico-chemical treatment, e.g.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. Adsorption</td>
<td>Adsorbable dissolved non-biodegradable or inhibitory pollutants, e.g. AOX</td>
<td></td>
</tr>
<tr>
<td>e. Precipitation</td>
<td>Precipitable dissolved non-biodegradable or inhibitory pollutants, e.g. metals, phosphorus</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>f. Chemical oxidation</td>
<td>Oxidisable dissolved non-biodegradable or inhibitory pollutants, e.g. AOX, sulphide</td>
<td></td>
</tr>
<tr>
<td>g. Chemical reduction</td>
<td>Reducible dissolved non-biodegradable or inhibitory pollutants, e.g. hexavalent chromium (Cr(VI))</td>
<td></td>
</tr>
<tr>
<td>h. Evaporation</td>
<td>Soluble contaminants</td>
<td></td>
</tr>
<tr>
<td><strong>Biological treatment, e.g.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i. Activated sludge process</td>
<td>Biodegradable organic compounds</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>j. Membrane bioreactor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>k. Anaerobic treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nitrogen removal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l. Nitrification/denitrification (when the treatment includes a biological treatment)</td>
<td>Total nitrogen, ammonia</td>
<td>Nitrification may not be applicable in the case of high chloride concentrations (e.g. above 10 g/l). Nitrification may not be applicable when the temperature of the waste water is low (e.g. below 12 °C).</td>
</tr>
<tr>
<td><strong>Solids removal, e.g.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m. Coagulation and flocculation</td>
<td>Suspended solids and particulate-bound metals</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>n. Sedimentation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o. Filtration (e.g. sand filtration, or membrane filtration)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p. Flotation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) The descriptions of the techniques are given in Section 5.9.3.

[This BAT conclusion is based on information given in Sections 4.1.7.2 and 4.1.7.3]
### Table 5.3: BAT-associated emission levels (BAT-AELs) for direct discharges to a receiving water body

<table>
<thead>
<tr>
<th>Substance/Parameter</th>
<th>Activities / processes</th>
<th>BAT-AEL ((^1)) (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adsorbable organically bound halogens (AOX) ((^2))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical oxygen demand (COD) ((^3))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrocarbon oil index (HOI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metals / metalloids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antimony (Sb)</td>
<td>Pre-treatment and/or dyeing of polyester</td>
<td>0.1–0.4</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>Dyeing with chromium-containing dyes</td>
<td>0.01–0.3</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>All activities / processes</td>
<td>0.03–0.4</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>All activities / processes</td>
<td>0.01–0.5</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>All activities / processes</td>
<td>0.04–0.5</td>
</tr>
<tr>
<td>Sulphide, easily released (S(^2))</td>
<td>Dyeing with sulphur dyes</td>
<td>0.3–1</td>
</tr>
<tr>
<td>Total nitrogen (TN)</td>
<td></td>
<td>5–20 ((^6))</td>
</tr>
<tr>
<td>Total organic carbon (TOC) ((^4))</td>
<td>All activities / processes</td>
<td>13–40 ((^6))</td>
</tr>
<tr>
<td>Total phosphorus (TP)</td>
<td></td>
<td>0.4–5</td>
</tr>
<tr>
<td>Total suspended solids (TSS)</td>
<td></td>
<td>5–45</td>
</tr>
</tbody>
</table>

(\(^1\)) The averaging periods are defined in the general considerations.  
(\(^2\)) The BAT-AELs only apply when the substance/parameter concerned is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.  
(\(^3\)) Either the BAT-AEL for COD or the BAT-AEL for TOC applies. The BAT-AEL for TOC is the preferred option because TOC monitoring does not rely on the use of very toxic compounds.  
(\(^4\)) The upper end of the BAT-AEL range may be up to 150 mg/l when the amount of waste water discharged is less than 25 m\(^3\)/t of treated textile materials.  
(\(^5\)) The BAT-AEL may not apply if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned, provided this does not lead to a higher level of pollution in the environment.  
(\(^6\)) The BAT-AELs may not apply if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned, provided this does not lead to a higher level of pollution in the environment.  

The associated monitoring is given in BAT 7.

### Table 5.4: BAT-associated emission levels (BAT-AELs) for indirect discharges to a receiving water body

<table>
<thead>
<tr>
<th>Substance/Parameter</th>
<th>Activities / processes</th>
<th>BAT-AEL ((^1)) ((^2)) (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adsorbable organically bound halogens (AOX) ((^2))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrocarbon oil index (HOI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metals / metalloids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antimony (Sb)</td>
<td>Pre-treatment and/or dyeing of polyester</td>
<td>0.1–0.4</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>Dyeing with chromium-containing dyes</td>
<td>0.01–0.3</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>All processes</td>
<td>0.03–0.4</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>All processes</td>
<td>0.01–0.5</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>All processes</td>
<td>0.04–0.5</td>
</tr>
<tr>
<td>Sulphide, easily released (S(^2))</td>
<td>Dyeing with sulphur dyes</td>
<td>0.3–1</td>
</tr>
</tbody>
</table>

(\(^1\)) The averaging periods are defined in the general considerations.  
(\(^2\)) The BAT-AELs may not apply if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned, provided this does not lead to a higher level of pollution in the environment.  
(\(^3\)) The BAT-AELs only apply when the substance/parameter concerned is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.

The associated monitoring is given in BAT 7.
5.1.7 Emissions to soil and groundwater

BAT 20. In order to prevent or reduce emissions to soil and groundwater, BAT is to use all 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>Techniques to reduce the likelihood and environmental impact of overflows and failures of process and storage tanks</td>
<td>Generally applicable</td>
</tr>
<tr>
<td></td>
<td>This includes:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• slow immersion into and withdrawal of textile materials from the process liquor to avoid spillages;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• automatic level adjustment of process liquor (see BAT 3);</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• avoiding direct injection of water to heat or cool the process liquor;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• overflow detectors;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• channelling overflows to another tank;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• tanks for liquids are located in a suitable secondary containment; their volume is sized to accommodate at least the complete loss of the liquid of the largest tank that is within the secondary containment;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• isolation of tanks and secondary containment (e.g. by closing valves);</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• the surfaces of the process and storage areas are impermeable to the liquids concerned.</td>
<td></td>
</tr>
<tr>
<td>b.</td>
<td>Regular inspection and maintenance of plant and equipment</td>
<td>The plant and the equipment are regularly inspected and maintained to ensure proper functioning; this includes in particular checking the integrity and/or leak-free status of valves, pumps, pipes, tanks and containments/bunds as well as the proper functioning of warning systems (e.g. overflow detectors).</td>
</tr>
<tr>
<td>c.</td>
<td>Optimised storage location of process chemicals</td>
<td>The storage areas are located in such a way to eliminate or minimise the unnecessary transport of process chemicals within the plant (e.g. the transport distances on site are minimised).</td>
</tr>
<tr>
<td>d.</td>
<td>Dedicated area for unloading hazardous process chemicals</td>
<td>Hazardous process chemicals are unloaded in a bunded area connected to a dedicated drainage system.</td>
</tr>
<tr>
<td>e.</td>
<td>Segregated storage of process chemicals</td>
<td>Incompatible process chemicals are kept separated. This segregation relies on physical separation and on the chemicals inventory and tracking system (see BAT 14).</td>
</tr>
<tr>
<td>f.</td>
<td>Return of unused process chemicals</td>
<td>Unused process chemicals (i.e. which remain in their original containers) are returned to their suppliers.</td>
</tr>
<tr>
<td>g.</td>
<td>Handling and storage of packaging containing process chemicals</td>
<td>Packaging containing liquid process chemicals is completely emptied by gravity or by mechanical means (e.g. brushing, wiping) without the use of water. Packaging containing process chemicals in powder is emptied using suction. Empty packaging is stored in a dedicated area.</td>
</tr>
</tbody>
</table>
5.1.8 Emissions to air

BAT 21. In order to reduce diffuse VOC emissions to air from the use of organic solvents, BAT is to collect diffuse emissions and send the waste gases to treatment.

Applicability
The applicability may be restricted by safety concerns. In the case of existing plants, the applicability may be restricted by operational constraints or by the volume of air to be extracted.

BAT 22. In order to facilitate the recovery of energy and the reduction of channelled emissions to air, BAT is to limit the number of emission points.

Description
The combined treatment of waste gases with similar characteristics ensures more effective and efficient treatment compared to the separate treatment of individual waste gas streams. The extent to which the number of emission points can be limited depends on technical (e.g. compatibility of the individual waste gas streams) and economic factors (e.g. distance between different emission points).

BAT 23. In order to reduce channelled emissions of organic compounds (e.g. formaldehyde) to air, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Condensation</td>
</tr>
<tr>
<td>b.</td>
<td>Ionisation</td>
</tr>
<tr>
<td>c.</td>
<td>Thermal oxidation</td>
</tr>
<tr>
<td>d.</td>
<td>Wet scrubbing</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 4.1.8.14]
Table 5.5: BAT-associated emission levels (BAT-AELs) for channelled emissions of organic compounds (e.g. formaldehyde) to air

<table>
<thead>
<tr>
<th>Substance/Parameter</th>
<th>Activities / Processes</th>
<th>BAT-AEL (Average over the sampling period) (mg/Nm³)</th>
<th>Mass flow threshold (g/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formaldehyde</td>
<td>Coating (^{(1)}) (^{(2)})</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flame lamination (^{(1)})</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Printing (^{(1)}) (^{(4)})</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Singeing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermal treatment in finishing (^{(1)})</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermal treatment in printing (^{(1)}) (^{(4)})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TVOC</td>
<td>Coating</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lamination</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Printing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Singeing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermal treatment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{(1)}\) The BAT-AEL only applies when formaldehyde is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.

\(^{(2)}\) The BAT-AEL does not apply where the organic solvent consumption for coating exceeds 5 tonnes per year.

\(^{(1)}\) The BAT-AEL does not apply where the organic solvent consumption for lamination exceeds 15 tonnes per year.

\(^{(4)}\) The BAT-AEL does not apply where the organic solvent consumption for rotary screen printing exceeds 30 tonnes per year.

\(^{(5)}\) The lower end of the BAT-AEL range is typically achieved when using thermal oxidation.

The associated monitoring is given in BAT 8.

BAT 24. In order to reduce channelled dust emissions to air, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Cyclone</td>
<td>See Section 5.9.2.</td>
</tr>
<tr>
<td>b. Electrostatic precipitator (ESP)</td>
<td></td>
</tr>
<tr>
<td>c. Wet scrubbing</td>
<td></td>
</tr>
</tbody>
</table>

\[This \text{BAT conclusion is based on information given in Section 4.1.8.14}\]

Table 5.6: BAT-associated emission level (BAT-AEL) for channelled dust emissions to air

<table>
<thead>
<tr>
<th>Substance/Parameter</th>
<th>Activities / Processes</th>
<th>BAT-AEL (Average over the sampling period) (mg/Nm³)</th>
<th>Mass flow threshold (g/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>Fabric production</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Singeing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermal treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 1–10</td>
<td>50</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 8.

BAT 25. In order to reduce channelled ammonia emissions to air, BAT is to use wet scrubbing.

Description
See Section 5.9.2.
[This BAT conclusion is based on information given in Section 4.1.8.14]

Table 5.7: BAT-associated emission level (BAT-AEL) for channelled ammonia emissions to air

<table>
<thead>
<tr>
<th>Substance/Parameter</th>
<th>Activities / Processes</th>
<th>BAT-AEL (1) (Average over the sampling period) (mg/Nm³)</th>
<th>Mass flow threshold (g/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₃</td>
<td>Coating</td>
<td>3–10</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Printing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermal treatment in finishing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermal treatment in printing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) The BAT-AEL only applies when NH₃ is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.

The associated monitoring is given in BAT 8.

BAT 26. In order to prevent emissions of organic compounds to air from dry cleaning, BAT is to extract the air from dry cleaning, to treat it using adsorption with activated carbon (see Section 5.9.2) and to fully recirculate it to dry cleaning.

[This BAT conclusion is based on information given in Section 4.4.5]

BAT 27. In order to reduce emissions of organic compounds to air from the thermal treatment of synthetic textile materials, BAT is to wash them.

Description
Synthetic textile materials are washed prior to thermal treatment. If needed, the washing water is sent to treatment (see BAT 19).

[This BAT conclusion is based on information given in Section 4.4.6]
### 5.1.9 Waste

**BAT 28.** In order to prevent or reduce the quantity of waste, in particular of hazardous waste, sent for disposal, BAT is to use all of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Waste management plan</td>
<td>A waste management plan is part of the EMS (see BAT 1) and is a set of features aiming to: 1) minimise the generation of waste, 2) optimise the reuse, regeneration, recycling and/or recovery of waste, and 3) ensure the proper disposal of waste.</td>
<td>The level of detail of the waste management plan will generally be related to the nature, scale and complexity of the plant.</td>
</tr>
<tr>
<td>b. Separate collection and storage of waste contaminated with hazardous chemicals</td>
<td>Waste (e.g. liquid waste, paper, cloths, absorbent material, laboratory waste, sludge from waste water treatment) contaminated with hazardous chemicals (e.g. finishing chemicals such as flame retardants, oil-, water- and soil-repellents) is collected and stored separately.</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>c. Use of process chemicals before their expiry date</td>
<td>The maximum storage time of process chemicals is clearly established and is monitored to avoid the expiry date being exceeded.</td>
<td></td>
</tr>
<tr>
<td>d. Reuse of packaging</td>
<td>Process chemicals packaging is selected to facilitate its complete emptying (e.g. considering the size of the packaging aperture or the nature of the packaging material). After emptying (see BAT 20), the packaging is reused.</td>
<td></td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Sections 4.1.9.1 and 4.1.9.2]
5.2 BAT conclusions for the pre-treatment of raw wool fibres by scouring

The BAT conclusions in this section apply to the pre-treatment of raw wool fibres by scouring and apply in addition to the general BAT conclusions in Section 5.1.

**BAT 29.** In order to use resources efficiently as well as to reduce water consumption and waste water generation, BAT is to recover wool grease and recycle waste water.

**Description**
Waste water from wool scouring is treated (e.g. by a combination of centrifugation and sedimentation) to separate grease, dirt and water. Grease is recovered, water is partially recycled to scouring and dirt is sent to further treatment.

**Table 5.8: BAT-associated environmental performance levels (BAT-AEPLs) for the recovery of wool grease from the pre-treatment of raw wool fibres by scouring**

<table>
<thead>
<tr>
<th>Type of wool</th>
<th>Unit</th>
<th>BAT-AEPL (Yearly average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse wool (i.e. wool fibre diameter typically higher than 35 µm)</td>
<td>kg of recovered grease per tonne of raw wool pre-treated by scouring</td>
<td>11–15</td>
</tr>
<tr>
<td>Extra and super fine wool (i.e. wool fibre diameter typically lower than 20 µm)</td>
<td></td>
<td>50–60</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.

*[This BAT conclusion is based on information given in Section 4.2.2.1]*

**BAT 30.** In order to use energy efficiently, BAT is to use all of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Covered scouring bowls</td>
<td>Scouring bowls are fitted with covers to prevent heat losses by convection or evaporation (see BAT 10 c).</td>
<td>Only applicable to new plants or major plant upgrades</td>
</tr>
<tr>
<td>b. Optimised temperature of the last scouring bowl</td>
<td>The temperature of the last scouring bowl is optimised to increase the efficiency of the subsequent mechanical wool dewatering (see BAT 12 b) and drying.</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>c. Direct heating</td>
<td>Scouring bowls and dryers are directly heated by gas firing in order to avoid the heat losses which occur in the generation and distribution of steam.</td>
<td>Only applicable to new plants or major plant upgrades</td>
</tr>
</tbody>
</table>

*[This BAT conclusion is based on information given in Section 4.2.3]*

**BAT 31.** In order to use resources efficiently and to reduce the amount of waste sent for disposal, BAT is to biologically treat organic residues from the pre-treatment of wool by scouring (e.g. dirt, waste water treatment sludge).

**Description**
The organic residues are treated by composting or anaerobic digestion.
[This BAT conclusion is based on information given in Section 4.2.2.3]
5.3 BAT conclusions for the production of yarn and fabric

The BAT conclusions presented in this section apply to the production of yarn and fabric and apply in addition to the general BAT conclusions in Section 5.1.

BAT 32. In order to reduce emissions to water from the use of sizing chemicals, BAT is to use all of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Selection of sizing chemicals</td>
<td>Sizing chemicals with improved environmental performance in terms of quantity needed, washability, recoverability and/or biodegradability (e.g. modified starches, certain galactomannans, polyvinyl alcohol and certain polyacrylates) are used.</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>b. Pre-wetting of the cotton yarns</td>
<td>The cotton yarns are dipped into hot water prior to sizing. This allows a reduction of the amount of sizing chemicals.</td>
<td></td>
</tr>
<tr>
<td>c. Compact spinning</td>
<td>The fibre strands are compressed by suction or by mechanical or magnetic compacting. This allows a reduction of the amount of sizing chemicals.</td>
<td>The applicability may be restricted by product specifications</td>
</tr>
</tbody>
</table>

This BAT conclusion is based on information given in Section 4.3.1.2

BAT 33. In order to reduce emissions to air and to water from the use of oils, BAT is to avoid the use of mineral oils in spinning and knitting.

Description
Mineral oils are substituted by synthetic oils and/or ester oils, with improved environmental performance in terms of washability and biodegradability.

This BAT conclusion is based on information given in Section 4.3.1.1
### BAT 34. In order to use energy efficiently, BAT is to use technique a and one or both of techniques b and c given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Use of common techniques</td>
<td>This includes:</td>
</tr>
<tr>
<td></td>
<td>- reducing the volume of the production area to reduce the amount of energy</td>
</tr>
<tr>
<td></td>
<td>needed for humidifying the ambient air;</td>
</tr>
<tr>
<td></td>
<td>- using advanced sensors that detect thread breaks to stop the spinning or</td>
</tr>
<tr>
<td></td>
<td>weaving machines.</td>
</tr>
<tr>
<td>b. Use of common techniques in</td>
<td>This includes:</td>
</tr>
<tr>
<td>spinning</td>
<td>- using lighter spindles and bobbins in ring frames;</td>
</tr>
<tr>
<td></td>
<td>- using spindle oil with optimal viscosity;</td>
</tr>
<tr>
<td></td>
<td>- maintaining an optimal oiling level of the yarn;</td>
</tr>
<tr>
<td></td>
<td>- optimising the ring diameter with respect to the yarn diameter in ring</td>
</tr>
<tr>
<td></td>
<td>frames;</td>
</tr>
<tr>
<td></td>
<td>- gradual start-up of the ring spinning machines;</td>
</tr>
<tr>
<td></td>
<td>- using vortex spinning;</td>
</tr>
<tr>
<td></td>
<td>- optimised movement of empty bobbin conveyors in cone winding machines.</td>
</tr>
<tr>
<td>c. Use of common techniques in</td>
<td>This includes:</td>
</tr>
<tr>
<td>weaving</td>
<td>- avoiding excessive air pressure for air-jet weaving;</td>
</tr>
<tr>
<td></td>
<td>- using a double-width loom for large-volume batches.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 4.3.2]
5.4 BAT conclusions for the pre-treatment of textile materials other than raw wool fibres

The BAT conclusions in this section apply to the pre-treatment of textile materials other than raw wool fibres and apply in addition to the general BAT conclusions in Section 5.1.

BAT 35. In order to use energy efficiently as well as to reduce water consumption and waste water generation, BAT is to use both of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Combined pre-treatment of cotton textiles</td>
<td>Various pre-treatment operations of cotton textiles (e.g. desizing, scouring and bleaching) are carried out simultaneously.</td>
<td>Only applicable to new plants or major plant upgrades</td>
</tr>
<tr>
<td>b. Cold pad-batch treatment of cotton textiles</td>
<td>Desizing and/or bleaching are carried out with the cold-pad batch technique (see Section 5.9.4).</td>
<td></td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Sections 4.1.4.1, 4.4.3 and 4.4.4]

BAT 36. In order to use resources and energy efficiently as well as to reduce water consumption and waste water generation, 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. Single desizing liquor</td>
<td>A single desizing liquor is used to remove different types of sizing chemicals. This solution is strongly alkaline (pH higher than 13) and contains hydrogen peroxide.</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>b. Recovery and reuse of water-soluble sizing chemicals</td>
<td>When desizing is carried out by washing with hot water, water-soluble sizing chemicals (e.g. polyvinyl alcohol and polyacrylates) are recovered from the washing water by ultrafiltration. The concentrate is reused for sizing, whereas the permeate is reused for washing.</td>
<td>Only applicable in plants where sizing and desizing are carried out at the same plant</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Sections 4.4.1 and 4.4.8.1]

BAT 37. In order to prevent or reduce emissions to water of chlorine-containing compounds and complexing agents, BAT is to use one or both of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Chlorine-free bleaching</td>
<td>Bleaching is carried out with chlorine-free bleaching chemicals (e.g. hydrogen peroxide, peracetic acid or ozone), possibly catalysed with enzymes.</td>
</tr>
<tr>
<td>b. Optimised hydrogen peroxide bleaching</td>
<td>The use of complexing agents can be completely avoided or minimised by reducing the concentration of hydroxyl radicals during bleaching. This is achieved by: • using demineralised water; • prior removal of metal impurities from textile materials (e.g. by magnetic separation or chemical extraction); • controlling the pH and the peroxide concentration during bleaching.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 4.4.7]
BAT 38. In order to use resources efficiently and to reduce the amount of alkali discharged to waste water treatment, BAT is to recover caustic soda used for mercerisation.

**Description**
Caustic soda is recovered from the rinsing water by evaporation and further purified, if needed.

**Table 5.9:** BAT-associated environmental performance level (BAT-AEPL) for the recovery of caustic soda used for mercerisation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>BAT-AEPL (Yearly average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery of caustic soda used for mercerisation</td>
<td>%</td>
<td>75–95</td>
</tr>
</tbody>
</table>

The associated monitoring is given in BAT 5.

*[This BAT conclusion is based on information given in Section 4.4.8.2]*
5.5 BAT conclusions for dyeing

The BAT conclusions in this section apply to dyeing and apply in addition to the general BAT conclusions in Section 5.1.

BAT 39. In order to use resources efficiently and to reduce emissions to water from dyeing, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique for batch and continuous dyeing</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Selection of dyes</td>
<td>Dyes without dispersing agents are used or, where this is not possible, with dispersing agents that are biodegradable (e.g. based on fatty acid esters).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Techniques for batch dyeing</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>b. pH-controlled dyeing</td>
<td>For textile materials with zwitterionic characteristics, dyeing is carried out at constant temperature and controlled by gradually lowering the pH of the dyeing liquor below the isoelectric point of the textile materials.</td>
</tr>
<tr>
<td>c. Optimised removal of unfixed dyestuff in reactive dyeing</td>
<td>Unfixed dyestuff is removed from the textile materials by using enzymes (see BAT 15 b) and/or vinyl polymers.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Sections 4.5.1.1, 4.5.1.4 and 4.5.1.5]

BAT 40. In order to use resources efficiently and to reduce emissions to water from the dyeing of cellulosic materials, BAT is to use one or a combination of the techniques given below.

<table>
<thead>
<tr>
<th>Technique for dyeing with sulphur dyes</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Minimised use of sulphur-based reducing agents</td>
<td>Dyeing is carried out without sodium sulphide or hydrosulphite as reducing agents. Where this is not possible, partially chemically pre-reduced dyes (e.g. indigo dyes) are used so that less sodium sulphide or hydrosulphite is added for dyeing.</td>
<td>The applicability may be restricted by product specifications</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technique for continuous dyeing with vat dyes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>b. Selection of vat dyes</td>
<td>Vat dyes are selected to enable dyeing without subsequent steaming, oxidising and washing.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Techniques for dyeing with reactive dyes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>c. Use of high-fixation reactive dyes</td>
<td>Use of poly-functional reactive dyes with more than one reactive functional group.</td>
</tr>
<tr>
<td>d. Use of cationic cotton</td>
<td>Dyeing is carried out on cationic cotton, which does not require the use of salts.</td>
</tr>
<tr>
<td>e. Cold pad-batch dyeing</td>
<td>Dyeing is carried out with the cold pad-batch technique (see Section 5.9.4).</td>
</tr>
<tr>
<td>f. Optimised rinsing</td>
<td>Rinsing after dyeing with reactive dyes is carried out at a high temperature (e.g. up to 95 °C) and without using detergents. The heat of the rinsing water is recovered (see BAT 10 f).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Techniques for continuous dyeing with reactive dyes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>g. Use of concentrated alkali solution</td>
<td>In cold pad-batch dyeing (see Section 5.9.4), concentrated aqueous alkali solutions without sodium silicate are used for the fixation of dyes.</td>
</tr>
</tbody>
</table>
h. Steam fixation of reactive dyes

The reactive dyes are fixed with steam, which avoids the use of chemicals for fixation. The applicability may be restricted by the characteristics of the textile materials and by product specifications.

[This BAT conclusion is based on information given in Section 4.1.5.3.2, 4.5.1.2, 4.5.1.3, 4.5.1.8, 4.5.2.1, 4.5.2.2, 4.5.2.3, 4.5.2.5, 4.5.2.6]

**BAT 41.** In order to reduce emissions to water from the dyeing of wool, BAT is to use one of the techniques given below in the following order of priority.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Chromium-free dyeing</td>
<td>Wool dyeing is carried out with reactive or acid dyes.</td>
<td>The applicability may be restricted by product specifications</td>
</tr>
<tr>
<td>b. Optimised metal-complex dyeing</td>
<td>Dyeing is carried out with metal-complex dyes under optimised conditions in terms of pH, auxiliaries and acid used, in order to increase the exhaustion of the dyeing liquor and the fixation of the dyes.</td>
<td>The applicability may be restricted by product specifications</td>
</tr>
<tr>
<td>c. Minimised use of chromates</td>
<td>When the use of chromates is authorised, chromates are dosed as a function of the amount of dye taken up by the wool. Dyeing parameters (e.g. pH and temperature of the dyeing liquor) are optimised to ensure that the dyeing liquor is exhausted as much as possible.</td>
<td>Generally applicable</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 4.5.3]

**BAT 42.** In order to reduce emissions to water from the dyeing of polyester with disperse dyes, 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. Batch dyeing without dyestuff carriers</td>
<td>Batch dyeing of polyester and wool-free polyester blends is carried out at high temperature (e.g. 130 °C) without the use of dyestuff carriers.</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>b. Optimised use of dyestuff carriers in batch dyeing</td>
<td>Batch dyeing of polyester-wool blends is carried out with chlorine-free and biodegradable dyestuff carriers.</td>
<td>The use of a reducing agent that can be used in acidic conditions may not be applicable to polyester-elastane blends. The use of dyes desorbable in alkaline conditions may be restricted by product specifications</td>
</tr>
<tr>
<td>c. Optimised desorption of unfixed dye in batch dyeing</td>
<td>This includes: - using a desorption accelerator based on carboxylic acid derivatives; - using a reducing agent that can be used in the acidic conditions of the spent dyeing liquor; - using disperse dyes that can be desorbed in alkaline conditions by hydrolysis instead of reduction.</td>
<td>Only applicable to new plants or major plant upgrades</td>
</tr>
<tr>
<td>d. Supercritical CO₂ dyeing</td>
<td>Supercritical CO₂ is used as a dyeing medium instead of water in a closed loop process to transport disperse dye into the polyester fibres.</td>
<td>Generally applicable</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 4.5.4]
5.6 BAT conclusions for printing

The BAT conclusions in this section apply to printing and apply in addition to the general BAT conclusions in Section 5.1.

BAT 43. In order to reduce water consumption and waste water generation, BAT is to optimise the cleaning of the printing equipment.

Description
This includes:
- mechanical removal of the printing paste;
- automatic start and stop of the cleaning water supply;
- reuse and/or recycling of cleaning water (see BAT 9 h).

[This BAT conclusion is based on information given in Section 4.6.1.1]

BAT 44. In order to use resources efficiently, 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><strong>Selection of printing technology</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Digital jet printing</td>
<td>Computer-controlled injection of dye onto textile materials.</td>
<td>Only applicable to new plants or major plant upgrades</td>
</tr>
<tr>
<td>b. Transfer printing on synthetic textile materials</td>
<td>The design is first printed on an intermediate substrate (e.g. paper) using selected disperse dyes and is subsequently transferred to the fabric by applying high temperature and pressure.</td>
<td></td>
</tr>
<tr>
<td><strong>Design and operation technique</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| c. Optimised use of printing paste | This includes:  
• minimisation of the volume of the printing paste supply system (e.g. minimising pipe lengths and diameters);  
• ensuring a uniform paste distribution over the whole width of the printing machine;  
• stopping the supply of printing paste shortly before the end of the printing;  
• manual addition of printing paste for small-scale usage. | Generally applicable |
| **Recovery and reuse of printing paste** | | |
| d. Recovery of residual printing paste | Residual printing paste in the supply system is pumped back or pushed back to its original container. | The push-back system is only applicable to rotary screen printing |
| e. Reuse of residual printing paste | The residual printing paste is collected, sorted by type, stored and reused. The degree of reuse of printing paste is limited by its perishability. | Generally applicable |

[This BAT conclusion is based on information given in Sections 4.6.1.2, 4.6.1.3, 4.6.1.4, 4.6.1.5, 4.6.1.6 and 4.6.1.7]
BAT 45. In order to prevent ammonia emissions to air and to prevent the generation of urea-containing waste water from printing with reactive dyes on cellulosic materials, BAT is to use one of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Increase of moisture content</td>
<td>Printing is carried out without urea by controlled addition of water to the textile materials.</td>
</tr>
<tr>
<td>b. Two padding step printing</td>
<td>Printing is carried out without urea by two padding steps with intermediate drying and addition of fixation agents (e.g. an alkaline solution).</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 4.6.2]

BAT 46. In order to reduce emissions of organic compounds (e.g. formaldehyde) as well as of ammonia to air from printing with pigments, BAT is to use printing chemicals with improved environmental performance.

Description
This includes:
- thickeners with no or low contents of volatile organic compounds;
- fixation agents with low contents of formaldehyde-containing compounds;
- binders with low contents of ammonia and without formaldehyde-containing compounds.

[This BAT conclusion is based on information given in Section 4.6.3]
Chapter 5

5.7 BAT conclusions for finishing

The BAT conclusions in this section apply to finishing and apply in addition to the general BAT conclusions in Section 5.1.

5.7.1 Easy-care finishing

BAT 47. In order to reduce emissions of formaldehyde to air from easy-care finishing of cellulosic materials, BAT is to use cross-linking agents with no or low potential for formaldehyde releases.

[This BAT conclusion is based on information given in Sections 4.7.2.1]

5.7.2 Softening

BAT 48. In order to improve the overall environmental performance of softening, BAT is to use one of the techniques given below.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Low-volume application of softening agents</td>
<td>See Section 5.9.4. Softening agents are not added to the dyeing liquor but applied in a separate process step by padding, spraying or foaming.</td>
</tr>
<tr>
<td>b. Softening of cotton with enzymes</td>
<td>See BAT 15 b. Enzymes are used for softening, possibly in combination with washing or dyeing.</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Sections 4.7.3.1 and 4.7.3.2]

5.7.3 Finishing with flame retardants

BAT 49. In order to improve the overall environmental performance of finishing with flame retardants, BAT is to use one or both of the techniques given below, giving priority to technique a.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Use of textiles with inherent flame retardance properties</td>
<td>Textiles are used that do not require finishing with flame retardants.</td>
<td>The applicability may be restricted by product specifications</td>
</tr>
<tr>
<td>b. Selection of flame retardants</td>
<td>Flame retardants are selected by considering: the risks associated with them (see BAT 13 v), in particular in terms of persistence and toxicity; the composition and form of the textile materials to be treated; the product specifications.</td>
<td>Generally applicable</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 4.7.4.1]
5.7.4 Finishing with oil-, water- and soil-repellents

BAT 50. In order to improve the overall environmental performance of finishing with oil-, water- and soil-repellents, BAT is to use oil-, water- and soil-repellents with improved environmental performance.

Description
Oil-, water- and soil-repellents are selected by considering:

- the risks associated with them (see BAT 130), in particular in terms of persistence and toxicity;
- the composition and form of the textile materials to be treated;
- the product specifications.

[This BAT conclusion is based on information given in Section 4.7.5.1]

5.7.5 Shrink-proof finishing of wool

BAT 51. In order to reduce emissions to water from shrink-proof finishing of wool, BAT is to use chlorine-free antifelting.

Description
Inorganic salts of peroxymonosulphuric acid are used for shrink-proof finishing of wool.

[This BAT conclusion is based on information given in Section 4.7.6.1]

5.7.6 Mothproofing

BAT 52. In order to reduce the consumption of mothproofing agents, 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. Selection of dyeing auxiliaries</td>
<td>When mothproofing agents are added directly in the dyeing liquor, dyeing auxiliaries (e.g. levelling agents) that do not hinder the uptake of mothproofing agents are selected.</td>
<td>Generally applicable</td>
</tr>
<tr>
<td>b. Mothproofing in acidic conditions</td>
<td>Mothproofing agents are added in acidic conditions to improve their uptake, either directly in the exhausted dyeing liquor or in a separate step.</td>
<td>The applicability may be restricted by product specifications</td>
</tr>
<tr>
<td>c. Blending of treated and untreated loose fibres</td>
<td>A fraction of the fibres (e.g. 5–20 % of the total blend weight) is treated with an excess amount of mothproofing agents and subsequently blended with untreated fibres.</td>
<td>Only applicable to new plants or major plant upgrades</td>
</tr>
<tr>
<td>d. Low-volume application of mothproofing agents</td>
<td>See Section 5.9.4. In the case of spraying, the excess mothproofing solution is recovered from the textile materials by centrifugation and reused.</td>
<td>Generally applicable</td>
</tr>
</tbody>
</table>

[This BAT conclusion is based on information given in Section 4.7.7]
5.8 BAT conclusions for lamination

The BAT conclusions presented in this section apply to lamination and apply in addition to the general BAT conclusions in Section 5.1.

BAT 53. In order to reduce emissions of organic compounds to air from lamination, BAT is to use hot-melt lamination instead of flame lamination.

**Description**
Molten polymers are applied to textiles without the use of a flame.

**Applicability**
May not be applicable to thin textiles.

*[This BAT conclusion is based on information given in Section 4.8.1]*
## 5.9 Description of techniques

### 5.9.1 Technique to monitor emissions to air

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission factors</td>
<td>Emission factors are representative values that attempt to relate the quantity of a substance emitted to a process associated with the emission of that substance. Emission factors are derived from emission measurements according to a predefined protocol considering the textile materials and the reference processing conditions. They are expressed as the mass of a substance emitted divided by the mass of textile materials treated at the reference gas flow (e.g. grams of organic carbon emitted per kg of textile materials treated at a waste gas flow of 20 m$^3$/h).</td>
</tr>
</tbody>
</table>

### 5.9.2 Techniques to reduce emissions to air

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adsorption</td>
<td>The removal of pollutants from a waste gas stream by retention on a solid surface (activated carbon is typically used as adsorbent). Adsorption may be regenerative or non-regenerative. In non-regenerative adsorption, the spent adsorbent is not regenerated but disposed of. In regenerative adsorption, the adsorbate is subsequently desorbed, e.g. with steam (often on site), for reuse or disposal and the adsorbent is reused. For continuous operation, typically more than two adsorbers are operated in parallel, one of them in desorption mode.</td>
</tr>
<tr>
<td>Condensation</td>
<td>Condensation is a technique that eliminates vapours of organic and inorganic compounds from a waste gas stream by reducing its temperature below its dew point.</td>
</tr>
<tr>
<td>Cyclone</td>
<td>Equipment for the removal of dust from a waste gas stream based on imparting centrifugal forces, usually within a conical chamber.</td>
</tr>
<tr>
<td>Electrostatic precipitator (ESP)</td>
<td>Electrostatic precipitators (ESPs) 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. Abatement efficiency may depend on the number of fields, residence time (size), and upstream particle removal devices. They generally include between two and five fields. Electrostatic precipitators can be of the dry or of the wet type depending on the technique used to collect the dust from the electrodes.</td>
</tr>
<tr>
<td>Ionisation</td>
<td>In ionisation (also referred to as direct cold plasma technique), the air or the incoming gas flow is led through a reaction chamber where it is submitted to a very strong electrical field (20–30 kV) generated by electrodes, causing ions, free electrons, radicals and other highly reactive particles to be formed. The highly reactive compounds lead to an oxidation of the pollutants present in the incoming gas.</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 scrubbing</td>
<td>The removal of gaseous or particulate pollutants from a waste gas stream via mass transfer to water or an aqueous solution. It may involve a chemical reaction (e.g. in an acid or alkaline scrubber).</td>
</tr>
</tbody>
</table>
### 5.9.3 Techniques to reduce emissions to water

<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>Adsorption</td>
<td>Separation method in which compounds in a fluid (e.g. waste water) are retained on a solid surface (typically activated carbon).</td>
</tr>
<tr>
<td>Anaerobic treatment</td>
<td>The biological transformation of dissolved organic and inorganic pollutants in the absence of oxygen using the metabolism of microorganisms. Transformation products include methane, carbon dioxide, and sulphide. The process is carried out in an airtight stirred reactor. The most commonly used reactor types are: • anaerobic contact reactor; • upflow anaerobic sludge blanket; • fixed-bed reactor; • expanded-bed reactor. Anaerobic bioreactors are used to treat textile effluents with high COD concentrations and containing dyestuffs.</td>
</tr>
<tr>
<td>Chemical oxidation</td>
<td>Organic compounds are oxidised to less harmful and more easily biodegradable compounds. Techniques include wet oxidation or oxidation with ozone or hydrogen peroxide, optionally supported by catalysts or UV radiation. Chemical oxidation is also used to degrade organic compounds causing odour, taste and colour nuisances and for disinfection purposes.</td>
</tr>
<tr>
<td>Chemical reduction</td>
<td>Chemical reduction is the conversion of pollutants by chemical reducing agents into less harmful compounds.</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. The flocs formed are subsequently separated by sedimentation, air flotation or filtration.</td>
</tr>
<tr>
<td>Equalisation</td>
<td>Balancing of flows and pollutant loads by using tanks or other management techniques.</td>
</tr>
<tr>
<td>Evaporation</td>
<td>The use of distillation to concentrate aqueous solutions of high-boiling substances for further use, processing or disposal (e.g. waste water incineration) by transferring water to the vapour phase. It is typically carried out in multistage units with increasing vacuum, to reduce the energy demand. The water vapours are condensed, to be reused or discharged as waste water.</td>
</tr>
<tr>
<td>Filtration</td>
<td>The separation of solids from waste water by passing them through a porous medium, e.g. sand or membrane filtration (see Membrane filtration below).</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: a) an external recirculation loop between the activated sludge tank and the membrane module; and b) immersion of the membrane module in the aerated activated sludge tank, where the effluent is filtered through a hollow fibre membrane, the biomass remaining in the tank.</td>
</tr>
</tbody>
</table>
| Membrane filtration     | Microfiltration, ultrafiltration, nanofiltration and reverse osmosis are membrane filtration processes that retain and concentrate, on one side of
the membrane, pollutants such as suspended particles and colloidal particles contained in waste waters. They differ for membrane pore sizes and hydrostatic pressure.

Neutralisation

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)\(_2\)) may be used to increase the pH, whereas sulphuric acid (H\(_2\)SO\(_4\)), hydrochloric acid (HCl) or carbon dioxide (CO\(_2\)) may be used to decrease the pH. Some pollutants may precipitate as insoluble compounds during neutralisation.

Nitrification/denitrification

A two-step process that is typically incorporated into biological waste water treatment plants. The first step is 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.

Oil-water separation

The separation of oil and water including the subsequent oil removal by gravity separation of free oil, using separation equipment or emulsion breaking (using emulsion-breaking chemicals such as metal salts, mineral acids, adsorbents and organic polymers).

Screening and grit separation

The separation of water and insoluble contaminants such as sand, fibre, fluff or other coarse materials from the textile effluent by filtering through screens or gravitational settling in grit chambers.

Precipitation

The conversion of dissolved pollutants into insoluble compounds by adding precipitants. The solid precipitates formed are subsequently separated by sedimentation, air flotation or filtration.

Sedimentation

The separation of suspended particles by gravitational settling.

### 5.9.4 Techniques to reduce the consumption of water, energy and chemicals

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold pad-batch treatment</td>
<td>In cold pad-batch treatment, the process liquor is applied by padding (e.g. with a foulard) and the impregnated fabric is slowly rotated at room temperature for a prolonged period. This technique allows a reduced consumption of chemicals and does not require subsequent steps such as thermal fixation and thereby reduces energy consumption.</td>
</tr>
<tr>
<td>Low-liquor-ratio systems (for batch processes)</td>
<td>A low liquor ratio can be achieved by improving the contact between the textile materials and the process liquor (e.g. by creating turbulence in the process liquor), by advanced process monitoring, by improved dosage and application of process liquor (e.g. by jets or spraying) and by avoiding the mixing of process liquor with washing or rinsing water.</td>
</tr>
<tr>
<td>Low-volume application systems (for continuous processes)</td>
<td>The fabric is impregnated with process liquor by spraying, vacuum suction through the fabric, foaming, padding, dipping in nips (process liquor contained in the gap between two rollers) or in reduced-volume tanks, etc.</td>
</tr>
</tbody>
</table>
6 EMERGING TECHNIQUES

Except where otherwise specified the information in this chapter has been provided by [179, UBA, 2001] and [77, EURATEX, 2000].

[Fuzzy logic]

Significant improvements in process reliability are achievable with the use of fuzzy logic (i.e. expert systems based on self-learning software systems, which auto-enlarge their knowledge by algorithms). The application of fuzzy logic in the textile industry is the object of a number of research projects. Two examples are reported concerning the control of the sizing process and the control of the condensation reaction of cross-linking agents.

The main advantages to be expected are the improved process control, which subsequently can result in increased productivity and enhanced quality of the final product.

Indirect environmental benefits are associated with the potential savings in energy and chemicals as a result of the improved process control.

The main limitation in the implementation of these expert systems in the textile industry is often the lack of a reliable database.

[On-line monitoring]

Process control by on-line monitoring enhances operation liability in the direction of “right first time production”.

Examples of on-going research in this area are:

- **dyeing**: the concentration of the COD (related with the dyestuff concentration) is measured on-line during washing and rinsing operations in discontinuous dyeing processes. When the dyestuff concentration in the rinsing bath is negligible, the rinsing process is automatically stopped. This technique allows considerable water and energy savings.

- **dyeing and bleaching**: by using a special amperometric sensor, the concentration of reducing or oxidising agents on fabrics can be controlled on-line. For example, the completeness of H₂O₂ removal after bleaching or the concentration of reducing agents in vat dyeing can be monitored and excess use of chemicals avoided.

- **dyeing with vat dyes**: by monitoring the redox potential, it is possible to detect exactly the point at which the reducing agent is completely rinsed off. When this point is reached the rinsing process can be stopped and the oxidant added to the bath.
6.1 Substitution of hazardous substances

Enzyme-catalysed finishing processes

Enzymes are proteins that act as biocatalysts activating and accelerating chemical reactions which would otherwise normally need more energy. Their excellent substrate selectivity allows more gentle process conditions compared to conventional processes. Enzymes are present in bacteria, yeasts and fungi.

At present enzymes are used and under study only for natural fibres, the use of enzymes for man-made fibres is not mentioned in literature. Some enzymes, such as the amylases in the desizing process, have been widely applied for a long time; other enzymes are still the object of investigations. Figure 6.1 lists the main enzymatic processes already in use or currently emerging in the textile sector.

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Treatment</th>
<th>Enzymes</th>
<th>Substrate</th>
<th>Degree of development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>Desizing</td>
<td>Amylases, amylglucosidases</td>
<td>Starch</td>
<td>State of the art</td>
</tr>
<tr>
<td></td>
<td>Scouring</td>
<td>Pectinases</td>
<td>Cotton fibre adjacent material</td>
<td>Available</td>
</tr>
<tr>
<td></td>
<td>Scouring</td>
<td>Enzymatic mixture</td>
<td>Cotton fibre adjacent material</td>
<td>Emerging</td>
</tr>
<tr>
<td></td>
<td>Bleaching</td>
<td>Laccases, glucoseosidases</td>
<td>Lignin, dyestuffs, glucose</td>
<td>Available</td>
</tr>
<tr>
<td></td>
<td>Degradation of residual H₂O₂ after bleaching</td>
<td>Peroxidases</td>
<td>H₂O₂</td>
<td>Available</td>
</tr>
<tr>
<td></td>
<td>Bio-polishing</td>
<td>Cellulases</td>
<td>Cellulose</td>
<td>Available</td>
</tr>
<tr>
<td></td>
<td>Bio-stoning</td>
<td>Celluloses</td>
<td>Cellulose</td>
<td>Available</td>
</tr>
<tr>
<td>Wool</td>
<td>Scouring</td>
<td>Lipases</td>
<td>Lanolin</td>
<td>Emerging</td>
</tr>
<tr>
<td></td>
<td>Anti-felting</td>
<td>Special enzymes</td>
<td></td>
<td>Emerging</td>
</tr>
<tr>
<td>Silk</td>
<td>Degumming</td>
<td>Sericinases</td>
<td>Sericin</td>
<td>Emerging</td>
</tr>
<tr>
<td>Flax</td>
<td>Softening</td>
<td>Pectinestearases</td>
<td>Flax fibre adjacent material</td>
<td>Emerging</td>
</tr>
<tr>
<td>Jute</td>
<td>Bleaching, softening</td>
<td>Cellulase, xylanases</td>
<td>Jute fibre adjacent material</td>
<td>Emerging</td>
</tr>
</tbody>
</table>

Figure 6.1: Enzymatic processes in textile finishing
[77, EURATEX, 2000], [179, UBA, 2001]

Energy savings (lower processing temperatures) and lower water consumption (reduced number of rinsing steps) are some of the promising advantages of enzymatic processes, along with the omission, in some cases, of the use of hazardous/harmful substances. Also enzymes can be used in catalytic amounts and as a biocatalyst they can be recycled.

Alternative textile auxiliaries

Complexing agents

The use of polyaspartic acid as a substitute for conventional dispersing and complexing agents is under study.
6.1.1 Use of biodegradable complexing agents based on polylaspartic acid and salts

**Description**
Polyaspartic acid (PAA) and its derivatives are used as biodegradable alternatives to EDTA or NTA in desizing or dyeing processes.

**Technical description**
Hydroxycarboxylic acids, polyaspartic acids, acrylic acid homopolymers or acrylic acid copolymers can be used as the complexing agent or dispersing agent. Iminodi-succinic acid or salts are used for the finishing of keratine textile fibre material in oxidant-free treatment stages at pH values of 4 to 7. Polylaspartic acid and salts are a complexing agent alternative for the reagents of the ethylenediaminetetraacetic acid (EDTA) or nitrilotriacetic acid (NTA) type. They form stable complexes with metal ions and mobilise contaminating metal ions.

**Achieved environmental benefits**
Reduced emissions to water.

**Environmental performance and operational data**
The technique reduces emissions to water from textile dyeing and finishing processes. PAA is biodegradable. Preliminary toxicity studies indicate that it is non-toxic. It can be used as a biodegradable detergent and dispersant for various applications.

**Example plants**
No information provided.

**Reference literature**
[135, RICARDO 2019], [241, Lanxess 2019]

6.1.2 Use of chitosan-based auxiliaries and/or finishing agents

**Description**
Chitosan-based agents are used in dyeing and finishing (e.g. antimicrobial).

**Technical description**

**Biopolymers**
Besides cellulose, chitin, the main structural component of crustacean shells (crabs, lobster, etc.) and insects, is the second main biopolymer. Its deacetylated derivative, chitosan, which is easier to handle due to its higher solubility, is increasing gaining in importance.

Some examples of potential applications of chitosan and its derivatives in the textile sector include the following:

- Antimicrobial blends with cotton and viscose fibres: a permanent antimicrobial effect can be obtained by blending 10% of chitosan fibres with cotton fibres to produce a mixed fibre yarn or by spraying chitosan solutions on non-woven fabrics. Compared to other commonly used antimicrobials, chitosan is not toxic to aquatic life or to humans (it is therefore of special interest for those fabrics that stay in close contact with the skin, e.g. in medical, health and pharmacological applications).
- Antimicrobial finishing treatment for textiles: chitosan’s structure is very similar to cellulose, so it bonds with cotton and viscose fibres. Chitosan-based finishing preparation is applied with impregnation by pad-dry-cure. [135, RICARDO 2019]
- After treatment to improve fastness properties when dyeing with direct dyes: cationic modified derivatives of chitosan are reported to be suitable for this application.
• Dye-fixing (deepening) agent for dyeing with reactive dyes. Since it is a cationic polymer, chitosan is considered to be an ideal fixing agent for anionic dyes (it lowers the surface tension/repulsion of fibre). [ 135, RICARDO 2019 ]

Furthermore, chitosan increases the dyestuff uptake and can act as a softening agent or binding agent for non-woven fabrics. It can also be used as an additive in printing pastes and in sizing agents. Its application can also be interesting in waste water treatment.

Achieved environmental benefits
• Reduced chemicals consumption.
• Reduced emissions to water.

Environmental performance and operational data
The use of chitosan as an exhausting agent reduces the amount of dye necessary for dyeing the cotton fabric and improves the washing and rubbing fastness properties. Cationic modified derivatives of chitosan are reported to be suitable for improving fastness when dyeing with direct dyes. The application of acidic solution of chitosan on cotton fabric before dyeing can boost the exhaustion of the dye bath as well as improve the substantivity of reactive dyes.

For antimicrobial treatment, the antibacterial colloid is prepared by blending chitosan with another antibacterial agent (e.g. AgCl-TiO₂ at a ratio of 1:5) in order to protect against a broad range of microbes (gram positive and negative). The application of chitosan and its derivatives on fabric/fibre is followed by the covalent cross-linking into cellulose or wool substrates (in the pad-dry-cure process).

Example plants
No information provided.

Reference literature
No reference literature provided.

Cross-linking agents

Polycarboxylic acids can be used as an alternative to N-methylol-based cross-linking agents, which are responsible for formaldehyde emissions.

6.1.3 Use of natural or biosynthetic dyes

Description
Natural or biosynthetic dyes are used instead of conventional synthetic dyes.

Technical description
Natural dyes are extracted from plants (e.g. with organic solvents) and used as an alternative to conventional synthetic dyes. An example of such dye is a natural indigo extracted from plants. [ 243, AMA Herbal Laboratories 2019 ]

Biosynthetic dyes are derived from natural waste products of the agriculture and herbal industries, e.g. from non-edible leftovers (i.e. almond shells, orange peel, beet residues), saw palmetto, or rosemary leaves [ 242, ARCHROMA 2019 ], microalgae, cyanobacteria as well as seaweed species. [ 244, AITEX 2019 ] Enzymatic processes are used to synthesize biodyes. [ 247, UNISI 2019 ].

Achieved environmental benefits
Reduced emissions to water.

Environmental performance and operational data
These materials are free from priority chemicals (hazardous or toxic species), thus reducing the impact of the dyeing process in the waste water streams. According to the LCA, the use of natural dyes was found to have a much smaller water and CO$_2$ footprint, and they have a less harmful impact on human health.

These dyes have good affinity for cellulosic fibres (e.g. cotton, viscose, linen) and during the dyeing process they are directly linked to the fibre by covalent bonds. Therefore, these dyes equal the fixation rate, fastness and overall performance of the existing range of sulphur dyes made from conventional petroleum-based raw materials.

The dyes can be applied using common dyeing technologies

**Example plants**
Apparantly some denim mills in Turkey, India, Pakistan, China, Italy, and Japan already use natural indigo in their rope dyeing machines. Also, there is a commercially available palette of dyes from chemical suppliers of textile dyes.

**Reference literature**
[135, RICARDO 2019 ], [ 242, ARCHROMA 2019 ], [ 243, AMA Herbal Laboratories 2019 ], [ 244, AITEX 2019 ], [ 247, UNISI 2019 ]

### 6.1.4 Use of flame retardants based on nano-clay

**Description**
The process consists of the application of nano-clay finishing by a back-coating technique. Dosage of chemicals is done automatically, in a closed-circuit system connected to the coating machine to avoid possible human contact. During the drying process, the temperature is controlled in order to avoid migration to air of non-fixed nanoparticles.

**Achieved environmental benefits**
Reduced use of hazardous substances, such as halogenated compounds.

**Environmental performance and operational data**
The clay (montmorillonite) is biodegradable and has very little effect on the environment and human health.

No differences have been found in the operational conditions between the nano-based and conventional process, such as electricity and gas consumption. As for the conventional process, the generated residues are only related to the jerry cans of chemicals and the scraps of fabric after the cutting stage.

**Cross-media effects**
None identified.

**Technical considerations relevant to applicability**
The treated fabrics may not meet the most stringent fire safety requirement, for example in the UK and Ireland.

**Economics**
The investment cost is related to the machinery needed (knife-coating machine and stenter) and the closed dosing circuit system. Operating costs are related to the purchase of the montmorillonite nano-clay product, the binder and thickener used to formulate the applied solution, as well as to energy and workforce.

**Driving force for implementation**
Legislation related to the use of hazardous substances and to environmental protection.
Example plants
The innovative process based on the nano-clay application has not been completely tested at industrial scale due to the lack of methods and equipment necessary for the product formulation in the industry, but the optimal application conditions of the nano-based formula have been investigated. Analysing the results, it has been observed that methods developed at lab scale could be escalated to industrial scale without significant differences, and working with nano-based products does not seem to pose a problem in terms of manipulation, preparation and application.

Reference literature
[151, LEITAT 2016]

6.1.5 Use of liposomes as a carrier for auxiliary chemicals in dyeing and finishing

Description
Liposomes are used as a carrier for auxiliary materials (e.g. levelling, retarding, wetting agents) in dyeing (for wool see Section 4.5.3.4) and finishing processes.

Technical description
With respect to the carrier role of liposomes, they can be used in several textile processes such as textile finishing and dyeing, with several types of dyes and fibres.

Liposomes can be prepared according to the type of process, solute material and fibre structure. Due to their structural properties, liposomes can encapsulate hydrophilic dyes (reactive, acid and basic dyes) in the aqueous phase, and hydrophobic dyes (disperse dyes) in the phospholipid bilayers. Several applications have been reported:

- for stabilising the bleaching process using hydrogen peroxide: liposomes can be used to gradually deliver bleaching agent but also stabilisers or catalyst retarding or accelerating the decomposition of hydroxyl radicals;
- as dispersing agent in dyeing of polyester fibres with disperse dyes;
- for dyeing wool and wool blends (see Section 4.5.3.4).

Achieved environmental benefits
- Reduced consumption of chemicals.
- Reduced emissions to water.
- Better quality of processing.

Environmental performance and operational data
Conventional dyeing processes consume a lot of energy and chemicals, a significant amount of which is wasted in controlling the process parameters in order to achieve uniform results. With respect to the carrier role of liposomes, they can be used in several textile processes such as textile finishing and dyeing, with several types of dyes and fibres. They are non-toxic, biodegradable, and can encapsulate a wide range of solutes, and help in their precise dosage and application.

Example plants
No information provided.

Reference literature
[248, Drumond Chequer et al. 2013], [135, RICARDO 2019]
6.2 Dyeing

Use of supercritical CO2 in dyeing processes

Supercritical fluids are capable of dissolving organic molecules of low to medium polarity.

CO2 has the advantage over other gases of being non-flammable, non-explosive and non-toxic.

CO2 dyeing of PES and PP fibre is already developed on an industrial scale, however the application of this technique on wool, PA and cotton is still problematic due to the polar nature of the dyestuffs used to colour these fibres.

CO2 dyeing of PES and PP can be carried out under optimal isothermal and isobaric conditions at 120 and 300°C. Dye uptake and fastness properties are very similar to water dyeing. Nevertheless some precautions need to be taken.

Excess dye dissolved in the dyeing medium must be extracted with fresh supercritical CO2 at the end of the dyeing cycle.

In conclusion, only special dye formulations can be used because dispersing agents and other auxiliaries typically present in conventional dye formulations strongly influence dye uptake in supercritical CO2.

Hydrophobic preparation agents should be extracted before dyeing because of their solubility in supercritical CO2. They are first extracted from the fibre during the dyeing process, and then precipitate as oily droplets at the end of the process.

CO2 dyeing has a number of advantages:
- almost zero water consumption
- zero off-gas emission (CO2 can be recycled)
- no drying step necessary after dyeing
- levelling and dispersing agents are not needed at all or, in some cases, they are added in very small amounts
- the dyestuff residues can be recycled.

Nevertheless, the investment cost for the equipment is high and this is a significant drawback, especially when considering that PES textiles are normally low-price products.

6.2.1 Ultrasonic treatments

Description

Use of ultrasounds to disperse dyestuffs and auxiliaries.

Technical description

Ultrasonic treatments improve the dispersion of dyestuffs and auxiliaries and enhance their ability to emulsify and solubilise. This allows improved liquor homogenisation, which then results in higher bath exhaustion and level dyeing properties. In addition, ultrasounds produce a de-aeration effect in the liquor and on the fabric, which is normally obtained by adding special auxiliaries (de-aerating agents).

Achieved environmental benefits

The main environmental benefits achievable with ultrasonic treatments in textile finishing are:
- Energy savings (lower process temperatures and shorter cycle times).
- Reduction in auxiliaries consumption.

Example plants
No information provided. In fact, this technique was not reported in the data collection.

Reference literature
[179, UBA, 2001], [77, EURATEX, 2000].

### 6.2.2 Electrochemical dyeing

**Description**
Reduction of the dyestuff by electrolysis.

**Technical description**
Vat and sulphur dyeing involves both a reducing and an oxidising step, which are carried out with chemical oxidants and reducing agents. The environmental concerns associated with the use of these chemicals are described in Section 2.7.8.1. An attractive alternative technique is to reduce and oxidise the dye by means of electrochemical methods.

With direct electrolysis, the dye itself is reduced at the surface of the cathode. In indirect electrolysis, the reducing power of the cathode is transferred to the solution by a soluble reversible redox system (e.g. based on anthraquinone chemistry or iron complexes). With this reversible redox system the reducing agent is continuously regenerated at the cathode, which thus allows full recycling of the dye bath and the reducing agent.

**Achieved environmental benefits**
- Reduced chemicals consumption.
- Reduced emissions to water.

**Environmental performance and operational data**
Direct cathodic reduction in an electrochemical cell is applicable to sulphur dyes. Vat dyes are reduced by indirect electrolysis.

**Example plants**
No information provided. In fact, this technique was not reported in the data collection.

Reference literature
[179, UBA, 2001], [77, EURATEX, 2000].

### 6.2.3 Salt-free reactive dyeing

**Description**
As an alternative to cationic cotton (see Section 4.1.5.3.2), a cationic reactive dye is used for exhaust dyeing of cotton, which renders the use of salts obsolete.

**Technical description**
Cationic reactive dyes are synthetised by incorporating cationic groups in the dye formulation, such as quaternary ammonium compounds or pyridinium chloride. This allows the electric charge repulsion between the cotton fibres and the reactive dye to be overcome.

**Achieved environmental benefits**
No emission of salts to water.

**Environmental performance and operational data**
Table 6.1 below gives an overview of the performance of various cationic dyes which were synthesised and tested.
### Table 6.1: Performance of various synthesised cationic dyes

<table>
<thead>
<tr>
<th>Dye</th>
<th>Dye type</th>
<th>Cationic group</th>
<th>Reactive group</th>
<th>Exhaustion rate (%)</th>
<th>Fization rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dye 1</td>
<td>Azo</td>
<td>Pyridinium chloride</td>
<td>Vinyl sulphone group</td>
<td>73</td>
<td>NI</td>
</tr>
<tr>
<td>Dye 2</td>
<td>Anthraquinone</td>
<td>Quaternary ammonium salt group</td>
<td>Monochlorotriazine</td>
<td>90</td>
<td>60</td>
</tr>
<tr>
<td>Dye 3</td>
<td>Anthraquinone</td>
<td>Quaternary ammonium salt group</td>
<td>Monochlorotriazine</td>
<td>90.8</td>
<td>64.4</td>
</tr>
<tr>
<td>Dye 4</td>
<td>Anthraquinone</td>
<td>Quaternary ammonium salt group and poly ether amine</td>
<td>Monochlorotriazine</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Dye 5</td>
<td>Anthraquinone</td>
<td>Quaternary ammonium salt group</td>
<td>Monofluorotriazine</td>
<td>91.1</td>
<td>76.5</td>
</tr>
<tr>
<td>Dye 6</td>
<td>Anthraquinone</td>
<td>N-(2-aminoethyl)pyridinium chloride</td>
<td>Monochlorotriazine</td>
<td>93.6</td>
<td>83.6</td>
</tr>
<tr>
<td>Dye 7</td>
<td>Anthraquinone</td>
<td>Quaternary ammonium salt group</td>
<td>Epoxy group</td>
<td>99.7</td>
<td>83.6</td>
</tr>
<tr>
<td>Dye 8</td>
<td>Anthraquinone</td>
<td>Quaternary ammonium salt group</td>
<td>Nicotinic acid quaternary triazine</td>
<td>94.2</td>
<td>72.8</td>
</tr>
</tbody>
</table>

*Source: based on [170, Aktek et al. 2017]*

**Cross-media effects**
No information provided.

**Technical considerations relevant to applicability**
No information provided.

**Economics**
No information provided.

**Driving force for implementation**
Environmental legislation.

**Example plants**
At the time of drafting, cationic dyes are not yet commercialised.

**Reference literature**
[170, Aktek et al. 2017]

### 6.2.4 Recovery of direct dyes with cyclodextrins

**Description**
Cyclodextrins (CD) are used to encapsulate the direct dyes contained in the waste water. The dyes may be then recovered and reused.

**Technical description**
Cyclodextrins are a group of structurally related natural products formed during bacterial digestion of cellulose. These cyclic oligosaccharides consist of \((\alpha-1,4)\)-linked \(\alpha\)-D-glucopyranose units and contain a somewhat lipophilic central cavity and a hydrophilic outer surface. Due to the chair conformation of the solubilising agents to increase the water solubility of lipophilic glucopyranose units, the cyclodextrins are shaped like a truncated cone rather than perfect cylinders (see Figure 6.2 below). The hydroxyl functions orientated to the cone exterior with the primary hydroxyl groups of the sugar residues at the narrow edge of the cone and the
secondary hydroxyl groups at the wider edge. The central cavity is lined by the skeletal carbons and ethereal oxygens of the residues, which gives it a lipophilic character.

![Examples of cyclodextrins presented in the literature](image)

Source: [224, AITEX 2016]

Figure 6.2: Examples of cyclodextrins presented in the literature.

The CD are injected in the waste water in a 25-litre device at the outlet of a dye bath. When the waste water has filled the device, the agitator blades provide sufficient energy to for the cyclodextrins to encapsulate the dyestuff. After the agitation stage and decantation, the cleaned water is released.

The cyclodextrins are captured on a paper filter located at the bottom of the device. This filter is removed and the dyestuff may be recovered in a solid form, and then reused for dyeing.

CD treatment has allowed the reduction of the COD and BOD concentration in waste water between 2% and 5% depending on the dye.

**Achieved environmental benefits**
- Reduction of pollutant load in the waste water.
- Reduced consumption of dyestuff.

**Environmental performance and operational data**
The average temperature of the water during the encapsulation process is 60 ºC and depends on the type of materials used. Water is heated up in the upstream dyeing process, so no additional heating is needed.

The recovered encapsulated dyestuff can be used directly for dyeing without it being necessary to separate the dye from the CD. Encapsulated dyestuff has been reused twice with satisfactory results.

Cleaned water may be reused for dyeing, but only in dyeing process that uses dark colours, because the remaining colours in the cleaned water interfere with the final colour of the textile.

**Cross-media effects**
No information provided.

**Technical considerations relevant to applicability**
No information provided.
Economics
Currently, the technique has the disadvantage of high costs for raw material (CD-based polymers), which may be higher than the cost of recovered dyes.

Driving force for implementation
Reduced costs for waste water treatment and reduced costs for the purchase of dyestuff.

Example plants
No information provided.

Reference literature
[ 224, AITEX 2016 ] [ 225, AITEX 2016 ] [ 135, RICARDO 2019 ]

6.2.5 Online process monitoring for direct reuse/recycling of spent dyeing baths

Description
A self-monitoring system based on Raman spectroscopy is applied to analyse the bath exhaustion online (in real time) in order to reuse the bath in the subsequent dyeing step.

Technical description
A Raman spectrometer unit (instead of the more common UV-VIS spectrometer) is used to analyse online the exhaustion rate (remaining colourants) of the process bath. The calibration of the system is needed to customise it for the dyes used. It is applicable to all dyes regardless of their chemistry (organic or inorganic).

Achieved environmental benefits
- Reduced consumption of chemicals (including dyes).
- Reduced emissions to water (of dyes).

Environmental performance and operational data
The savings/reductions achieved at a textile plant in Spain are as follows:
- pigments savings: 10-15 %;
- auxiliaries savings: 90-100 %;
- water consumption reduction: 60-80 % (applicable to washing baths);
- waste water pollutant load reduction: 70-90 %
- energy consumption reduction: 20-25 %
- increase in correct dyeing: from 80-98 %.

Example plants
No information provided.

Reference literature
[ 246, INTEXTER 2019 ]
6.3 Printing

6.3.1 Use of casein-based printing binders

Description
Casein acid is used as a printing binder as an alternative to the acrylic resins used in textile printing.

Technical description
The use of acrylic resins is problematic since these are sensitisers and also because they require the use of additional additives that may also be problematic, such as alkyl phenols, phthalates and organotins.

The casein acid binders are compatible with all existing textile printing pigments and can be used in printing paste for ink-jet printing.

Achieved environmental benefits
- Reduced consumption of chemicals.
- Reduced emissions to water.

Environmental performance and operational data
This technique provides an alternative to the acrylic resins used in textile printing (reducing the ecotoxicity of water effluents). The discharge of printing waste allows for a simple biological purification and it may be converted into fertiliser. Since the product is bio-based and biodegradable it can easily be attacked by microorganisms and therefore it should be stored in temperature-controlled areas at 10 °C or below.

Example plants
No information provided.

Reference literature
[ 249, SUBSPORT 2019 ], [ 135, RICARDO 2019 ]

6.3.2 Phthalates-free plasticisers for textile printing

Description
Polyurethane and polyacrylate are used as alternative materials to substitute phthalates and PVC from children’s wear prints.

Technical description
There are several substances and which are already being implemented (and evaluated) as phthalates substitutes and PVC plasticisers, although their use is not yet widespread in textile applications: acetyl tributyl citrate (ATBC), (2-ethylhexyl) adipate (DEHA), cyclohexane-1,2-dicarboxylic acid diisononyl ester (DINCH), and trioctyl trimellitate (TOTM).

Achieved environmental benefits
- Reduced emissions to water.
- Avoiding hazardous substances in the textile product.

Environmental performance and operational data
By using the substitutes, plastisol printing is replaced by water-based printing.

Example plants
No information provided.
Reference literature
[ 135, RICARDO 2019 ]
6.4 Finishing

Future development of Advanced Oxidation Processes in the textile industry

Advanced oxidation processes are already applied in the textile industry (see Section 4.1.7.3.4.1) and further research is under way. The BIOFL-UV project is one example. The aim of this research is to develop and test a waste water treatment based on the UV-activated photolysis of hydrogen peroxide (for the decolouration of the spent bath) combined with a bioflotation process (for the destruction of the residual organic load). The combination of these waste water treatment processes is expected to achieve a complete decolourisation of the process waters for every type of wet process (finishing, bleaching, dyeing, etc.). The project will also develop and implement a process control software based on artificial neural network and systems dynamics. The ultimate goal is the recycling, after filtration of 75% of the process water and dye destruction [313, BIOFL-UV, 2002].

Reed bed systems for waste water treatment

For a long time researchers have pointed out the high removal capacity of natural environments (soil, wet lands, etc.) and have studied the possibility of using such environments (ecosystems) in order to purify, or at least to complete the waste water purification process. Purification techniques that use these principles in constructed plants (artificially reconstructed and confined) are commonly defined as “RBSs” or “constructed wet lands”. These techniques involve the use of plants for waste water treatment, although plants do not always play a primary role in the process. Indeed, the removal of pollutants and the consequent waste water purification are the results of a series of processes which involve reactions and interactions among substratum, micro-organisms and plants.

At present, industrial testing has proven that reed bed techniques and plants can be applied both for the secondary or tertiary treatment of industrial, municipal and zootechnical waste water.

Two textile finishing mills in Italy (Prisma Ricerche in Belluno and Filati di Ziche in the Treviso area) are assessing this technique. In one mill, the waste water coming from the dye-house (all kind of fibres and dye groups) is treated, after equalisation, in a reed bed system of five tanks in series. It is reported that 90% COD reduction is achieved [106, Vekos, 2001].

The other company treats the effluent coming from the activated sludge system. This enables a further 51% reduction of the residual COD [106, Vekos, 2001].

6.4.1 Enzymatic anti-felting

Description
Enzymes are used for the second treatment step of the more conventional anti-felting treatments of wool fabric.

Technical description
Typically, enzyme treatment is carried out as a secondary (subsequent) step to a milder chemical pretreatment (e.g. with hydrogen peroxide or dichlorodicyanuric acid (DCCA)), physical pretreatment (e.g. atmospheric plasma) or as a cascade of treatments with different enzymes. Chlorination pretreatment with DCCA followed by protease treatment has been tested for use in the textile industry.
Enzymes used for anti-felting wool treatment are proteases (e.g. savinase, papain), esperase, and porcin trypsin.

**Achieved environmental benefit**
- No chlorine compounds used or emitted.
- Reduced use of hazardous chemicals.

**Environmental performance and operational data**
Using enzymes with DCCA is claimed to reduce the dosage of chlorination agents by around half. This does not eliminate the AOX release problem, it only diminishes it. Hydrogen peroxide pretreatment followed by protease treatment offers better anti-felting processing of wool fabric in view of the effluent released, but the effectiveness of the process is lower.

Any novel shrink-resist treatment to be successful to replace the widely practised chlorine/Hercosett treatment must meet the following conditions and challenges [218, Hassan et al. 2019]:

- the processing cost must be similar or marginally higher than the cost of the chlorine-Hercosett treatment;
- the process needs to be continuous;
- the process must be robust and should provide long-term durability to washing;
- the treatment must not negatively affect the dyeability, light fastness, yellowness, abrasion resistance, stain-resistance, wash fastness and handle properties of the treated fabric;
- it must be eco-friendly and energy efficient.

Enzymatic treatment is not the answer as the treatment is very slow, unpredictable and the shrink-resistance achieved is not comparable to the shrink-resistance provided by the chlorine-Hercosett process.

**Cross-media effects**
None identified.

**Technical considerations relevant to applicability**
No information provided.

**Economics**
No information provided.

**Driving force for implementation**
- Environmental legislation.
- Reduced load of chlorine in the effluent to be pretreated.

**Example plants**
No information provided.

**Reference literature**
[218, Hassan et al. 2019]
6.5 Laminating and coating

6.5.1 Electron [ray treatment] beam curing

Description
Curing with electron beams.

Technical description
Electron rays start free-radical-initiated polymerisation reactions that can then be used for coating, lamination and for graft co-polymerisation reactions on textiles pre-coated with monomers or pre-polymers.

The advantage over thermal curing is that solvent-free formulations can be used. This reduces the emissions of VOCs during drying operations. The technique is already established in other sectors and therefore its implementation in the textile sector is foreseeable in the next five years.

Achieved environmental benefits
Reduced VOC emissions to air

Example plants
No information provided.

Reference literature
[179, UBA, 2001], [77, EURATEX, 2000].
6.6 Alternative processes

6.6.1 Plasma technology

Description
Use of plasma to modify the fibre surface in order to increase the efficiency of subsequent fibre treatments.

Technical description
A plasma can be described as a mixture of partially ionised gases. Atoms, radicals and electrons can be found in the plasma. The electrons in low-temperature plasmas are able to cleave covalent chemical bonds, thereby producing physical and chemical modifications of the surface of the treated substrate.

Two types of plasma are generally used: corona plasma and low-pressure plasma.

Plasma treatment can be performed on natural fibres as well as on synthetic fibres, to achieve the following effects:

- wool degreasing;
- desizing;
- change of fibre wettability (hydrophilic, hydrophobic properties);
- increase in dyestuff affinity;
- improved dye levelling properties;
- anti-felt finishing in wool (see Section 4.7.6.2);
- sterilisation (bactericidal treatment), etc.

Anti-felt finishing effects for wool is one of the most studied applications of plasma technology in the textile sector. Plasma treatment, instead of the conventional anti-felt treatment (see Section 2.9.2.8), is very attractive because this technique causes less degradation of the wool fibre and avoids the presence of AOX in the waste water.

Achieved environmental benefits

- Reduced consumption of water and chemicals.
- Reduced amount of waste water.

Environmental performance and operational data
In general, the main advantages of plasma technology are the extremely short treatment time and the low application temperature, along with the fact that water and solvents can be avoided and no or less chemicals are required.

Table 6.2 compares the characteristics of plasma and traditional wet processing.
Table 6.2: Comparison between plasma and traditional wet processing

<table>
<thead>
<tr>
<th></th>
<th>Plasma processing</th>
<th>Traditional wet processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>No water used. Treatment by excited gas phase</td>
<td>Water-based</td>
</tr>
<tr>
<td>Energy</td>
<td>Electricity – only free electrons heated (&lt; 1% of system mass)</td>
<td>Heat – entire system mass temperature raised.</td>
</tr>
<tr>
<td>Reaction type</td>
<td>Complex and multifunctional; many simultaneous processes</td>
<td>Simpler, well established</td>
</tr>
<tr>
<td>Reaction locality</td>
<td>Highly surface specific, no effect on bulk properties</td>
<td>Bulk of the material generally affected</td>
</tr>
<tr>
<td>Potential for new processes</td>
<td>Great potential, technology in rapid development</td>
<td>Very low</td>
</tr>
<tr>
<td>Equipment</td>
<td>Experimental, laboratory and industrial prototypes; rapid industrial developments</td>
<td>Mature, slow evolution</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Water consumption</td>
<td>Negligible</td>
<td>High</td>
</tr>
</tbody>
</table>

*Source: based on [222, Shishoo 2007]*

Low-pressure plasma contains a high concentration of reactive species compared to corona plasma. It requires a longer process time and only batch processes can be performed. The low-pressure plasma process has been difficult to upscale for continuous processes and batch processing limits the commercial application.

Table 6.3 describes the main characteristics for corona and low-pressure plasma.

Table 6.3: Process characteristics for corona plasma and low-pressure plasma

<table>
<thead>
<tr>
<th>Process</th>
<th>Corona plasma</th>
<th>Low-pressure plasma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation of plasma</td>
<td>High voltage between coated electrodes</td>
<td>Direct current or high frequency</td>
</tr>
<tr>
<td>Pressure</td>
<td>Atmospheric pressure (1 bar)</td>
<td>Low pressure (1 mbar)</td>
</tr>
<tr>
<td>Continuous process</td>
<td>Easy</td>
<td>Difficult</td>
</tr>
</tbody>
</table>

*Source: based on [26, UBA 2001]*

With this technology, the following can be achieved: [220, TextileLearner 2019]

- Desizing: Plasma technology can be used to remove PVA sizing material from cotton fibres. In the conventional desizing process, chemicals and hot water are used to remove size. But desizing with plasma technology uses either O₂/He plasma or air/He plasma. O₂/He plasma has a greater effect on PVA surface chemical changes than air/He plasma.
- Dyeing: The dye exhaustion rate of plasma-pretreated wool has been shown to increase by nearly 50%; plasma-pretreated wool can achieve 90% exhaustion in 30 minutes as compared to 60 minutes for untreated samples. O₂ plasma treatment increases the wettability of wool fabric, thus leading to a dramatic increase in its wicking properties.

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
The investment costs for an atmospheric plasma machine are estimated to be around SEK 2-3 million. [221, Swedish EPA 2018]
Driving force for implementation
- Increased energy efficiency of treatment processes.
- Higher productivity (shorter treatment times)

Example plants
No information is available about the industrial use of plasma technology for textile treatment, except for wool anti-felting (see Section 4.7.6.2).

Reference literature
[220, TextileLearner 2019] [26, UBA 2001] [221, Swedish EPA 2018] [135, RICARDO 2019] [222, Shishoo 2007]
Chapter 7

7 CONCLUDING REMARKS AND RECOMMENDATIONS FOR FUTURE WORK

This Chapter will be completed after the Final TWG meeting

Note to the TWG: this Annex has not been reviewed. It has not been edited and formatted either.
Please provide information to update this Annex.
8 ANNEX I TEXTILE AUXILIARIES

8.1 Surfactants

The description of surfactants in this section is somehow anomalous because they do not represent a category of auxiliaries, but rather a category of organic compounds. The reason for dedicating a section to these compounds is that they are used in the textile industry for many different purposes (e.g. lubricants, antistatics, wetting agents, etc.). Dealing with them in a common section such as this avoids repetitions in other parts of this annex.

Surfactants can be the essential active substance in a textile auxiliary or can be used as additives in the formulation of auxiliaries, dyes, printing pastes, coating pastes (e.g. dispersing agents in dyestuffs, emulsifiers in preparation agents, etc.).

The surfactants used in the textile industry are classified under four major headings, namely: scouring agents, dye bath additives, softeners and antistatic agents.

Surfactants are organic polar compounds containing in their molecule at least one hydrophobic and one hydrophilic group. According to their chemical structure, surfactants are classified as non-ionic, anionic, cationic and amphoteric.

Non-ionic surfactants

Non-ionic surfactants are widely used in the textile industry for various purposes (e.g. as washing/ dispersing agents, as levelling agents, etc.). Some examples of commonly used non-ionic surfactants are:
- fatty alcohol ethoxylates
- fatty amines ethoxylates
- fatty acids ethoxylates
- triglyceride ethoxylates
- alkylphenol ethoxylates
- ethylene oxide/propylene oxide adducts.

Ethoxylated fatty alcohols, acids and triglycerides are generally easy to biodegrade. On the other hand, ethylene oxide/propylene oxide adducts, fatty amines and alkylphenol ethoxylates (APEO) are examples of surfactants that are difficult to biodegrade and, due to their solubility in water, are also difficult to eliminate.

The APEO in particular and the well-known nonyl phenol ethoxylates (NPE), which are the most commonly used surfactants in the group of alkyl phenol ethoxylates, pose serious environmental concerns. APEO degrade by stepwise removal of the ethoxy groups. In this way they form the corresponding alkyl phenols, which are bioaccumulative due to their lipophilic character and poor degradability. Alkyl phenols (particularly octyl- and nonyl phenols) are highly toxic to aquatic life and are reported to influence the reproduction of aquatic species by disrupting the endocrine system.

Even with highly effective effluent treatment systems, which allow only trivial amounts of APEO or their metabolites to enter the aquatic environment, concerns arise from the resultant sludge. Unless these sludge are subject to treatments such as incineration or pyrolisis, capable of destroying the organic material, the APEO or their metabolites may enter surface water or groundwaters in run-off from composting, spreading of treated or untreated sludge on agricultural land, or in leachate from landfill.

Several countries have already placed restrictions on the use of NPE. Moreover, these surfactants are on the list of "Priority Hazardous Substances" targeted for priority regulatory action under the Water Framework Directive.
Anionic surfactants

Anionic surfactants commonly used in textile processing are:

- sulphates (e.g. alcohol ethoxysulphates, alkanolamides sulphates, sulphated vegetable oils)
- sulphonates (e.g. alkylbenzene sulphonates, sulphonated vegetable oils, naphthalene sulphonates, ligninsulphonates)
- alkyl ether phosphates
- carboxylates (fatty acid condensation products, alkali salts of fatty acids).

The linear, more biodegradable compounds are the most commonly used (e.g. alkylbenzene sulphonates, fatty alkyl sulphonates, etc.). Examples of recalcitrant anionic surfactants are the common lignin sulphonates and condensation products of naphthalene sulphonic acid with formaldehyde, which are widely used as dispersants for vat, sulphur and disperse dyes.

Anionic surfactants have several advantages: they are good oil emulsifiers and dye dispersants, they are excellent wetting agents and they are not expensive. In turn, they generate high levels of foam, and sulphate surfactants can be sensitive to calcium and magnesium [11, US EPA, 1995].

Cationic surfactants

Cationic surfactants are relatively uncommon in textile processing. One example is quaternary ammonium compounds (salts) used as retarders for cationic dyes, which are water-soluble recalcitrant substances. Cationic surfactants have by far the highest toxicity of all classes of surfactants [179, UBA, 2001].

Amphoteric surfactants

Amphoteric surfactants are not widely used in the textile industry. Their main advantage is the fact that they can be used in alkaline and acidic media and in combination with either cationic or anionic surfactants.

Quaternary ammonium compound derivatives are very rarely applied, while other low-toxicity types are increasing in use. Examples are:

- betaine derivatives
- imidazolines
- modified fatty amino ethylates (they have very good emulsifying and dissolving capacity for removing oligomers in the reductive cleaning of polyester fibres).

Amphoteric surfactants are expensive and their use is required only in specialised situations where wide ranges of compatibility are needed.
8.2 Auxiliaries and finishing agents for fibre and yarn manufacturing

Within this class are included those organic compounds that are applied to the fibre during its manufacturing and yarn formation processes. The names used for these auxiliaries in this section are taken from the TEGEWA nomenclature (“TEGEWA nomenclature, 1987”). They are classified as follows:

- spinning solution additives, spinning additives and spinning bath additives
- preparation agents for primary spinning
- preparation agents for secondary spinning (conditioning agents and lubricants)
- coning oils, warping oils and twisting oils.

Special attention is given to them because they are removed during textile pretreatment, in most cases contributing to a significant proportion of the emissions to water and to air at finishing mills.

The general chemical composition of yarn and fibre preparation agents is based on four main classes of components, the proportions depending on the function of the specific preparation agent:

- lubricants
- emulsifiers
- wetting agents
- antistatic agents
- additives (e.g. biocides, antioxidants, agents for the compactness of the thread).

**Lubricants**

Typical applied lubricants are:

- mineral oils
- ester oils
- synthetic lubricants (which include synthetic esters, EO/PO adducts, silicones, etc.).

The term “mineral oils” is used to indicate lubricants derived from refined crude oil. They are mixtures of hydrocarbons with C\textsubscript{12} – C\textsubscript{50} chain length, having a range of boiling points between 220 °C and 450 °C. Due to the presence of undesirable and unstable impurities, mineral oils smoke and give rise to air emissions during high-temperature treatments.

Mineral oils are hardly biodegradable and can only be removed by absorption. However, as regards water pollution, the main concern is over the presence of polyaromatic hydrocarbons (these compounds are included in the list of priority hazardous substances to be controlled through EU-wide measures under the Water Framework Directive).

The amount of polyaromatic compounds in mineral oils varies according to the refining process adopted and decreases as the oils become less polydisperse (refined mineral oils are commonly known as white oils). Pharmaceutical-grade mineral oils contain less than 0.1 ppm of polyaromatic hydrocarbons, but they are about three times more expensive than conventional mineral oils.

The use of mineral oils is declining. Because of their low cost, however, they are still widely used in applications where cheap products are needed (mainly as coning oils and, to a lesser extent nowadays, as wool processing auxiliaries).

**Esters oils** are usually fatty acids esterified with fatty alcohols, alcohols or polyhydroxylic alcohols. They are normally obtained by saponification of natural fats or oils.
Ester oils are used as lubricants as an alternative to mineral oils. Compared to mineral oils, ester oils are more thermally stable, biodegradable and easier to emulsify. They are increasingly substituting mineral oils in primary spinning, but mineral oils still have the highest market share in secondary spinning.

**Synthetic lubricants** (so-called synthetic oils) are synthetic base fluids especially tailored to the lubrication function. Because synthetic oils are composed of molecules that are uniform in weight and structure, they can withstand temperatures exceeding 200 °C, which also results in higher oxidative and thermal stability than mineral oils. For these reasons they outperform mineral oil-based products in many respects, allowing for higher operating temperatures, less lubricant loss and improved flexibility in a wide range of operating conditions.

Synthetic oils are free of all metals, sulphur, phosphorus and wax. Certain lubricants are highly biodegradable, thereby having reduced negative impact on the environment.

There are several major classes of synthetic lubricants:
- synthesised hydrocarbons, such as polyalphaolefins (PAO) and dialkylated benzenes, which are the most common type
- synthetic esters, such as dibasic acid and polyl esters
- polyglycols
- silicones.

Synthetic esters are synthesised from relatively pure and simple starting materials to produce predetermined molecular structures designed specifically for high performance lubrication. Compared to ester oils obtained from natural fats and oils, these molecules are more uniform in size, which means that they are more thermally and oxidatively stable.

EO/PO copolymers are used for texturised chemical fibres because they do not interfere with the process as mineral oils do.

The chemical structure of these synthetic lubricants can be schematised as follows:

\[ S-(EO)_x-(PO)_y-B \]

- \( S \) = starting component which can be short-chain alcohols (e.g. \( C_4 \)), polyols, organic acids or primary amines;
- \( B \) = block component which can be ethers (OR), esters (COOR), acetales \( CH(OR)_2 \) or \( OH \)

The high molecular EO/PO-adducts (sum of EO and PO units is more than 15 moles and the sequence of PO units is higher than 5) are non- or hardly biodegradable.

Silicones are used as lubricants in several areas, including the manufacturing of fibres such as elastane and polyamide. They are chemically inert, non-toxic, fire resistant and water repellent. They are of great value in applications involving extreme temperatures, where high oxidative and thermal stability is required.

Silicones show the highest level of COD of all lubricants and they are hardly biodegradable, but they are bioeliminable and not dangerous to aquatic life. The main disadvantage is that they are difficult to emulsify and remove from the fibre. APEO are usually used to remove them and quite a high percentage (approximately 40 %) remains on the fibre after washing, giving rise to air emissions in the subsequent high-temperature treatments.

**Emulsifiers**

In order to apply the preparation agent as an aqueous system when the lubricant is not soluble in water, an emulsifier is normally present in the formulation. Anionic and non-ionic surfactants are used as emulsifiers. The main surfactants employed are:
Annexes

Anionic surfactants:  - sulphonated and sulphated vegetable oils

Non-ionic surfactants:  - ethoxylated fatty alcohols
               - ethoxylated fatty acids
               - ethoxylated sorbitan esters
               - alkyl phenol ethoxylates (APEO)
               - partial glycerides and ethoxylated triglycerides.

Wetting agents

These are usually short-chain alkyl phosphates.

Antistatic agents

The anionic surfactants also have anti-electrostatic properties. Mono and diesters of phosphorus pentoxides (mainly their potassium salts) are in use as special anti-electrostatic agents as well as amphoteric surfactants such as sarcosides, amine oxides and sulphone succinates.

Additives

Aqueous systems can be attacked by bacteria and so must incorporate a bactericide. Biocides such as formaldehyde-containing compounds are applied as preservatives with a load of about 50 mg/kg fibre. Heterocyclic compounds (imidazolinone and isothiazolinone derivatives) with a load of about 2 mg/kg fibre are also encountered.

When the preparation agents are applied as neat oils or sufficiently stable solutions, instead of aqueous emulsions, the addition of biocides can be avoided, unless they are needed to protect the yarn during storage.

The amounts of active substances added to the fibres and the composition of the applied formulations may vary widely with fibre type and end-use. A rough overview is given in Table 8.1, but a more detailed description of typical formulations used and the load applied on the substrate is given in the following sections (based on an updated version of [7, UBA, 1994]). In Table 8.1 no distinction has been made between the different types of fibres; only elastomeric fibres and fibres destined for the manufacturing of knitted fabric have been considered separately because of the higher amount applied to the substrate in these cases. Furthermore, the load indicated under the column "Yarn manufacturing" refers to the overall amount of preparation agents applied to the fibre after the production of the fibre itself (including coning oils, twisting oils, oils applied to the filament after the texturising process, etc.).
Table 8.1: Overview of the loads of auxiliary agents applied on the fibre and yarn during the production process

<table>
<thead>
<tr>
<th></th>
<th>Fibre manufacturing</th>
<th>Yarn manufacturing</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/kg substrate COD</td>
<td>g/kg substrate COD</td>
<td>g/kg</td>
</tr>
<tr>
<td></td>
<td>mgO₂/g</td>
<td>mgO₂/g</td>
<td>substrate</td>
</tr>
<tr>
<td>Flat filament</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-elastomeric</td>
<td>10 2000</td>
<td>20 3000</td>
<td>30 2700</td>
</tr>
<tr>
<td>Elastomeric</td>
<td>100 1000</td>
<td>50 1000</td>
<td>150 1000</td>
</tr>
<tr>
<td>Filament for knitted fabric</td>
<td>10 2000</td>
<td>30 3000</td>
<td>40 2750</td>
</tr>
<tr>
<td>Texturised filament</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-elastomeric</td>
<td>8 2000</td>
<td>20 3000</td>
<td>28 2700</td>
</tr>
<tr>
<td>Filament for knitted fabric</td>
<td>8 2000</td>
<td>30 3000</td>
<td>38 2800</td>
</tr>
<tr>
<td>Staple fibres</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-elastomeric</td>
<td>3 2000</td>
<td>20 3000</td>
<td>23 2850</td>
</tr>
<tr>
<td>Elastomeric</td>
<td>50 1000</td>
<td>50 1000</td>
<td>100 1000</td>
</tr>
<tr>
<td>Yarn for knitted fabric</td>
<td>3 2000</td>
<td>30 3000</td>
<td>33 2900</td>
</tr>
</tbody>
</table>

Source: [194, Comm., 2001]

8.2.1 Spinning solution additives, spinning additives and spinning bath additives

Within this group of auxiliaries only those that are washed off during pretreatment operations are mentioned. In this respect, the so-called “modifiers” used for viscose are most relevant. The applied load varies between 5 mg/kg fibres to a few grams per kg of fibre depending on the application field. They mainly consist of ethoxylated fatty amines or polyethylene glycol ethers with molecular weights of about 1500. During pretreatment, more than 90% of these substances are washed off.

8.2.2 Preparation agents for primary spinning

These preparation agents are applied (mainly as aqueous solutions) during the manufacture of chemical fibres, directly after primary spinning (see Section 2.2). They enable subsequent processes such as drawing, twisting, warping, texturising and further spinning (secondary spinning, in the case of staple fibres).

The preparation agents give the chemical fibres the necessary properties (optimal friction, avoidance of electrostatic charging and cohesion in the case of multifilament yarns) not only between the fibres, but also between the fibres and the guide elements of the machines.

In general the substances applied have high affinity with water, either because the emulsifiers are already contained in the formulations or because the lubricant molecules themselves are self-emulsifying systems.

The application loads and the characteristics of the formulations applied are given for:

- non-texturised filament fibres (Table 8.2)
- texturised filament fibres (Table 8.3)
- staple fibres (Table 8.4).
### Table 8.2: Load of preparation agents on non-texturised filament yarns (flat yarns)

<table>
<thead>
<tr>
<th>Textile substrate</th>
<th>Load (g/kg textile substrate)</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>PES</td>
<td>5–10</td>
<td>The content of lubricants is 40-70%, the remaining fraction consists of emulsifiers (mixtures of non-ionic and anionic surfactants such as fatty alcohols and fatty acids ethoxylates, sulphonated and sulphated vegetable oils), wetting agents (short chain alkyl phosphates), antistatic agents (e.g. mono and diesters of phosphorous pentoxides, sarcosides, amine oxides and sulphonates).</td>
</tr>
<tr>
<td>PA</td>
<td>8–12</td>
<td>Same composition as above</td>
</tr>
<tr>
<td>CA</td>
<td>20</td>
<td>The content of lubricants in the formulations is about 60-85%. Less refined mineral oils can be used than for PES and PA fibres</td>
</tr>
<tr>
<td>CV</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>PP</td>
<td>5–15</td>
<td>Preparation agents consist of 100% surfactants (typically 90% alkoxylated components, 10% phosphoric esters as anti-electrostatic agents and additives)</td>
</tr>
<tr>
<td>EL</td>
<td>30–70</td>
<td>Preparation agents mainly consist of dimethyl polysiloxanes</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Notes:
The reported loads relate to the quantity of active substance, not to the quantity of applied aqueous emulsion

### Table 8.3: Load of preparation agents applied on texturised filament yarns (texturised yarns)

<table>
<thead>
<tr>
<th>Textile substrate</th>
<th>Load (g/kg textile substrate)</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>PES</td>
<td>3–8</td>
<td>Spinning preparation agents consist of 50-90% EO/PO-adducts. As with flat filaments, they contain non-ionic and anionic components (see Table 8.2)</td>
</tr>
<tr>
<td>PA</td>
<td>3.5–5.5</td>
<td>Preparation agents are based on EO/PO-adducts as well as on ester oils (mineral oils are not used). Load used for carpet yarn. In the past, preparation agents consisted of emulsified mineral oils, but today these formulations are very rarely used. They have been substituted by ester oils (trimethylol propane ester and pentaerythril ester) applied together with non-ionic surfactants</td>
</tr>
<tr>
<td>PP</td>
<td>8–12</td>
<td>The preparation agents consist of 100% surfactants (the same used for flat filaments seeTable 8.2) Load used for carpet yarns</td>
</tr>
<tr>
<td></td>
<td>8–15</td>
<td></td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Notes:
The reported loads relate to the quantity of active substance, not to the quantity of applied aqueous emulsion
Table 8.4: Load of preparation agents applied on chemical staple fibres

<table>
<thead>
<tr>
<th>Textile substrate</th>
<th>Load (g/kg textile substrate)</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>PES - CO-type</td>
<td>1 – 1.8</td>
<td>They consist of 50 – 80% phosphoric esters and their salts and of 20 – 50% non-ionic surfactants such as fatty acid ethoxylates and fatty alcohol ethoxylates and various additives in minor amounts</td>
</tr>
<tr>
<td>PES - WO-type</td>
<td>2 – 2.5</td>
<td></td>
</tr>
<tr>
<td>PA</td>
<td>4 – 6</td>
<td>PA staple fibres are normally used for carpet yarns. Their preparation agents have compositions similar to those used for PES. Mineral oils and ester oils can also be part of the recipes</td>
</tr>
<tr>
<td>CV</td>
<td>3 – 6</td>
<td>Non-ionic surfactants (fatty acid ethoxylates) are used; fatty acid soaps and phosphoric ester salts are additional typical ingredients</td>
</tr>
<tr>
<td>PP</td>
<td>5 – 10</td>
<td>The formulations have the same composition as those used for filament yarns (see Table 8.2)</td>
</tr>
<tr>
<td>PAC</td>
<td>3 - 8</td>
<td>Different types of formulations are used (e.g. polyamine fatty condensates, short-chain quaternary ammonium compounds). These compounds are difficult to remove in the subsequent processes. Anionic systems as well as non-ionic systems are applied (the same used for PES)</td>
</tr>
</tbody>
</table>

Notes:
The reported loads relate to the quantity of active substance, not to the quantity of applied aqueous emulsion
Source: [179, UBA, 2001]

8.2.3 Preparation agents for secondary spinning (conditioning agents and spinning lubricants)

For these agents there is no clear definition. In the following, preparation agents for secondary spinning of synthetic staple fibres and cotton are referred to as "conditioning agents", while preparation agents for wool will be referred to as "spinning lubricants".

Conditioning agents are also required during secondary spinning of synthetic fibres, when the fibres have been previously submitted to bleaching or dyeing processes. The amount initially applied is in fact lost during these processes.

The chemical composition of conditioning agents for synthetic fibres is similar to that of the preparation agents used for primary spinning of staple fibres (see Table 8.4). The load ranges between 1 and 10 g/kg fibres.

Spinning lubricants are applied to wool fibres to assist efficient mechanical processing during yarn manufacturing (spinning). They are generally applied as aqueous emulsions and for this reason they also contain an emulsifier and a biocide to prevent bio-attack. In most cases the emulsification system is based on APEO [66, CRIT, 1999], although according to other sources ([32, ENco, 2001]) the major suppliers have sought to eliminate alkylphenol ethoxylates by substituting them with linear alcohol ethoxylates.

When the spinning lubricant is to be applied to wool blends with synthetic fibres, an antistatic agent is also needed.

As regards wool and blends of wool with synthetic fibres, four basic types of spinning lubricants can be identified [32, ENco, 2001]:
- emulsifiable mineral wool oils based on a mixture of refined mineral oil (<1% polyaromatic content) and an emulsification system
- water-dispersible lubricants (sometimes referred to as "Super Mineral Oils" or "Semi synthetics") based on a mixture of refined mineral oil, saponifiable fatty oils and an
emulsification system. These formulations generally contain a higher proportion of emulsifiers than emulsifiable wool oils

- synthetic water-soluble lubricants based on polyethylene- polypropylene glycols, which are particularly useful when the yarn is to be scoured in the dye bath, but may also be used on yarns that will be scoured in a separate operation

- dry spinning lubricants (only for carpet yarn – see Section 2.13.5.1), which differ from the above in that they are applied at lower levels and they remain on the yarn following conversion to carpet. These materials generally contain a higher proportion of antistatic agents.

The loads for cotton, viscose staple fibres and wool are reported in Table 8.5

Table 8.5: Load of conditioning agents and lubricants applied on cotton, viscose (staple fibres) and wool

<table>
<thead>
<tr>
<th>Textile Substrate</th>
<th>Load (g/kg textile substrate)</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>WO and CO-wool-type; (staple fibre length &gt; 60 mm)</td>
<td>30 - 50</td>
<td>Load applied during “oil spinning” of carded yarns</td>
</tr>
<tr>
<td></td>
<td>8 – 10</td>
<td>Load applied during “dry spinning” of carded yarns without subsequent dyeing</td>
</tr>
<tr>
<td></td>
<td>&lt;10</td>
<td>Load applied during spinning of semi-worsted yarn (oil at a level of less than 1% is normally not removed from the yarn before dyeing)</td>
</tr>
<tr>
<td>CO or CV</td>
<td>4</td>
<td>Many recipes are in use, mostly containing white oils and ester oils (30 – 40 %) and non-ionic surfactants. Mineral oil-free systems are also available.</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Notes:
The reported loads relate to the quantity of active substance, not to the quantity of applied aqueous emulsion

If further processing of dyed yarns or flocs is planned, an additional amount of conditioning agents (3 - 5 g/kg) is applied normally in discontinuous by bath exhaustion at the textile finishing mill. Thereby the exhaustion rates for PES and PA can be very low (10 – 30 %). Conversely, they are relatively high for CO and PAC (>80 %).

8.2.4 Coning oils, warping and twisting oils

For processes such as coning, twisting and warping of flat and texturised filament yarns as well as of staple fibre yarns, chemicals have to be applied in order to enhance smoothness, lubrication and antistatic properties.

Oils for coning, warping, twisting and those applied to the filament after the texturing process (sometimes called overlay oils) consist of 70 – 95 % white oils and of 5 – 30 % non-ionic surfactants, especially fatty alcohols and fatty acids ethoxylates. Twisting oils often consist of ester oils which are more biodegradable than white oils. Ester oils are used especially if evaporation has to be avoided or minimised, especially during heat-setting.

The load of coning oils depends on the further processing and the volume of the yarn. It varies for PES from 5 to 30 g/kg (15 g/kg average). For common PA the load is 5 g/kg and in the case
of highly elastic PA it is up to 15 - 20 g/kg. It is reported that imported fabric can have loads of coning oils above 50 g/kg.

The load for warping oils and twisting oils is about 5 g/kg.

8.2.5 Knitting oils

The needles of knitting machines have to be lubricated with so-called knitting machine oils. Due to machine losses, these oils remain on the knitted fabric (about 4 – 8 % of the weight of the fibre). They should now be based on synthetic oils, but in practice mineral oil-based formulations are still common. This also means that surfactant aids need to be added in the scouring bath in order to emulsify them.
8.3 Sizing agents

In this section the following information is presented:
- characteristics of the most common sizing agents
- typical amounts of sizing agents applied on the different substrates (Table 8.6)
- specific COD and BOD\textsubscript{5} values for the most common sizing agents (Table 8.7).

Starch

Starch is the most common natural size and can be derived from various substances, especially corn and potatoes. It is not always suitable for high performance weaving mills. When stored at lower temperatures, it tends to solidify to pulpy mass and lose the hydration water (retrogradation). This retrogradation leads to poor storage properties, skin formation, formation of deposits on the rollers and reduced adhesive strength. As a result, natural starch is commonly used in formulation with other sizes [186, Ullmann's, 2000].

Starch is completely biologically removed, but it is only sparingly soluble in water; the action of animal or vegetable enzymes is needed. These enzymes decompose the starch into water-soluble sugars, which are then removed by washing before scouring. As a result, starch cannot be recycled and is responsible for most of the COD load in finishing effluents. Moreover, in comparison with other sizing agents, starch must be applied at about twice the rate of carboxymethyl cellulose, because of the poorer sizing effect, thereby leading to a higher COD in the waste water.

Starch derivatives

Starch derivatives include dextrins, starch esters and starch ethers. They are increasingly replacing natural starches, as their tendency to retrograde is considerably reduced.

The starch esters most commonly used are the esters with phosphoric acid (phosphate starches) and acetic acid (acetyl starches).

The three most important starch ethers are the hydroxyethyl, hydroxypropyl and carboxymethyl starches.

Starch derivatives based on esters can, to a great extent be biologically reduced, while starches based on ethers are more difficult to biodegrade. However, the great variety of possible chemical modifications makes it possible to produce good slashing agents, which can be virtually completely biodegraded.

Like natural starch, starch derivatives must be also applied at about twice the rate of CMC or synthetic agents, thereby leading to higher COD in the effluents.

Cellulose derivatives (carboxymethyl cellulose)

Sodium carboxymethyl cellulose (CMC) is the only water-soluble cellulose derivative used as a sizing agent. It is produced by reacting cellulose with sodium hydroxide and sodium chloroacetate, whereby the cellulose polymer is also depolymerised.

CMC is the preferred additive for increasing the adhesion of starch sizes for cotton.

Its chain length and degree of substitution influence the level of biological reduction. However, carboxymethylcellulose (CMC) must be classified as being very difficult to degrade.

According to UBA, only 20% of the initial amount is eliminated after 7 days. However, it is also reported that CMC can be reduced after long periods of adaptation (>4 weeks) and favourable conditions (especially higher temperatures) [7, UBA, 1994]. Other sources mentioned by UBA state that a biological reduction rate of 60% is attained after 7 days.
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Galactomannan derivatives

Hydroxypropyl and carboxymethyl galactomannan derivatives are water-soluble and easy to remove by washing. In general they can reach high levels of biological reduction (greater than 90%). However, biodegradability as well as other properties can vary significantly with molecular weight and the mannose/galactose ratio.

Polyvinyl alcohol (PVA)

Since the monomeric vinyl alcohol does not exist, poly(vinyl alcohol) is produced by the hydrolysis of the poly(vinylacetate).

The parameters that determine sizing properties are the degree of polymerisation and the degree of hydrolysis. There are two grades: the partly hydrolysed grade with a degree of hydrolysis of ca. 88% and the fully hydrolysed grade with a degree of hydrolysis of ca. 98%.

Partially hydrolysed PVA grades are preferred for use as sizing agents because they show maximum water solubility and they adhere strongly to non-polar fibres such as PES. In addition to these conventional poly(vinyl alcohol) grades, copolymers with methyl methacrylate or with co-monomers having carboxyl groups are also used as sizing agents.

The degree of polymerisation and the degree of hydrolysis lead to significant differences in terms of biodegradability between the individual types of polyvinyl alcohols. PVA is not acutely toxic to micro-organisms and does not inhibit nitrification. It can be quantitatively eliminated by biological degradation after adaptation of the sludge. The conditions for a 90% reduction are: relatively high concentrations (20 mg/l), temperature above 18 ºC and a regular load over a long period of time (in wintertime and in the holiday period problems can occur) [7, UBA, 1994]. Given such adaptation, PVA can be classified as having good bioeliminability.

Poly(meth)acrylates

Poly(meth)acrylates show considerable variation in chemical structure (the building blocks can be: acrylic acid, acrylic esters, acrylamide, acrylonitrile, methacrylic acid) and therefore have a very wide range of applications. Hydrophilic monomers like methacrylic acid and its salts and acrylamide give good adhesion to polar fibres and ease of removal by washing. Hydrophobic monomers such as the acrylic esters increase the elasticity of the sizing film and improve the ease of removal from waste water.

Poly(methacrylates) cannot be reduced biologically, not even after a period of adaptation. Hydrophilic products cannot even be eliminated from the aqueous phase, because they behave as hydrophilic polyelectrolytes. An improvement is represented by poly(methacrylates) based on esters. In this case, thanks to the presence of hydrophobic groups, the poly(methacrylates) can be 90% bio-eliminated by adsorption onto sludge after a residence time of 6 – 9 hours (which in practice is secured many times over) [18, VITO, 1998]. However, it is important to point out that the bio-elimination curve gives rise to a number of questions about the elimination mechanisms (the elimination mechanisms are not clear).

Polyesters

Polyesters are generally condensates of aromatic dicarboxylic acids with diols (e.g. ethylene glycol, diethylene glycol) and sulphonated aromatic dicarboxylic acids (the latter provide solubility or dispersability in water, they are mainly added to improve dyeability). Their biodegradability is bad, but they show a certain degree of bioelimination [77, EURATEX, 2000]. They are mainly used for sizing flat filament yarns. They are also found as co-components in sizing agents for staple fibres made of polyester blends.
Table 8.6: Amounts of sizing agents applied on different types of substrates

<table>
<thead>
<tr>
<th>Textile substrate</th>
<th>Load (g/kg warp yarn)</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Staple fibres</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- CO and CO/PES</td>
<td>80 – 200</td>
<td>As sizing agents starch and starch derivates, very often in combination with PVA, CMC or polyacrylates are applied. Thereby the ratio of starch/starch derivates to synthetic sizing agents is generally 3:1, and 1:1 for air jet weaving machines. The loads depend especially on the density of warp yarns and on the kind of sizing agent (for starch/starch derivates is significantly higher (150 – 200 g/kg)).</td>
</tr>
<tr>
<td>- CV</td>
<td>40 – 120</td>
<td>The load is 60 g/kg average. Normally combinations of all available sizing agents are applied, e.g. polyacrylates in combination with CMC and/or starch derivates</td>
</tr>
<tr>
<td>- WO</td>
<td>0 – 20 (2)</td>
<td>Woven fabric consisting of wool is usually produced with twisted yarn, so the warp yarns for the weaving process do not need to be sized. In the case of simple yarns (in practice not very significant) up to 200 g/kg starch/starch derivate (80 %) in combination with synthetic sizing agents are applied.</td>
</tr>
<tr>
<td><strong>Filament yarns</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- PES</td>
<td>40 – 60</td>
<td>For 90 % of PES flat yarns polyester sizing agents (which can be dispersed) are applied; the rest is sized with modified PVA and polyacrylate.</td>
</tr>
<tr>
<td></td>
<td>80 – 120</td>
<td>This is the load for texturised yarns; about 80 g/kg for polyester sizing agents, about 120 g/kg for PVA and about 100 g/kg for polyacrylates</td>
</tr>
<tr>
<td>- PA</td>
<td>20 – 50</td>
<td>PolyaCRYlic acid is used as sizing agent; 50 g/kg is applied for very thin fabric only</td>
</tr>
<tr>
<td>- CV</td>
<td>15 – 30</td>
<td>Mostly for linings for which polyacrylates are used as sizing agents</td>
</tr>
<tr>
<td>- CA</td>
<td>15 - 60</td>
<td>PolyaCRYlics and polyvinylacetate are applied</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Notes:
(1) the figures refer to woven fabrics with 60 % of warp yarn
(2) as wax

Knowing the loads of sizing agents on the different substrates the calculation/estimation of organic loads as BOD₅ and COD is possible, provided that specific BOD₅ and COD values are available. These values are given in Table 8.7.
### Table 8.7: Specific COD and BOD₅ values for the most common sizing agents

<table>
<thead>
<tr>
<th>Kind of sizing agent</th>
<th>Specific COD-value (mg O₂/g)</th>
<th>Specific BOD₅-value (mg O₂/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>900 – 1000 *₁</td>
<td>500 – 600</td>
</tr>
<tr>
<td>CMC</td>
<td>800 – 1000 *₁</td>
<td>50 – 90</td>
</tr>
<tr>
<td>PVA</td>
<td>c. 1700 *₁</td>
<td>30 – 80 *₂</td>
</tr>
<tr>
<td>Polyacrylates</td>
<td>900 – 1650</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>Galactomannans</td>
<td>1000 – 1150 *₁</td>
<td>400</td>
</tr>
<tr>
<td>PES-dispersions</td>
<td>1450 – 1700</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>Protein sizing agents</td>
<td>1200</td>
<td>700 – 800</td>
</tr>
<tr>
<td>Protein sizing agents</td>
<td>1200</td>
<td>700 – 800</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]

Notes:
*₁ Considering the usual moisture content of commodity
*₂ For non-adapted "inocula"
8.4 Detergents/ wetting agents

These auxiliaries are mainly used in pretreatment operations (scouring, mercerising, bleaching) in order to allow:

- thorough wetting of the textile material
- emulsification of lipophilic impurities
- dispersion of insoluble matter and degradation products.

Non-ionic and anionic surfactants are the compounds more frequently used for this purpose (see also Section 8.1). Some examples of products available on the market are listed in Table 8.8.

**Table 8.8: Typical compounds used as detergents/ wetting agents**

<table>
<thead>
<tr>
<th>Class</th>
<th>Examples of products available on the market</th>
<th>Bio-degradability (1)</th>
<th>Bio-eliminability (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-ionic</td>
<td>Alcohol and fatty alcohols ethoxylates</td>
<td>&gt;90 %</td>
<td>80 – 85 %</td>
</tr>
<tr>
<td></td>
<td>Fatty acids ethoxylates</td>
<td>&gt;90 %</td>
<td>80 – 85 %</td>
</tr>
<tr>
<td></td>
<td>Alkylphenol ethoxylates (APEOs)</td>
<td>~60 %</td>
<td>54 – 58 % (toxic metabolites)</td>
</tr>
<tr>
<td></td>
<td>Fatty amines ethoxylates</td>
<td>60 – 80 %</td>
<td>72 – 73 %</td>
</tr>
<tr>
<td>Anionic</td>
<td>Alkyl sulphonates</td>
<td>&gt;98 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alkyl aryl sulphonates</td>
<td>&gt;98 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alkyl sulphates</td>
<td>&gt;98 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dialkylsulphosuccinates</td>
<td>&gt;98 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alkyl carboxylates (e.g. sodium palmitate, stearate)</td>
<td>&gt;98 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sulphated alkanolamides</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
(1) OECD-test 301 E
(2) OECD-test 302 B
Source: [77, EURATEX, 2000], [218, Comm., 2000]
8.5 Auxiliaries containing sequestering agents

The presence of ions of alkaline earth metals (calcium and magnesium) and/or other metals (especially iron) may have important negative effects on various wet processes not only in pretreatment, but also in dyeing. Purified and softened water is used in textile finishing mills, but often this is not enough and specific auxiliary formulations containing complexing agents need to be added to the baths.

Auxiliaries with this effect are often classified according to the specific process for which they are applied (extractants, sequestering agents/ dispersants, etc.). Commonly used complexing agents are EDTA, NTA, DTPA, phosphonic acid and gluconic acid derivatives.

The hydrogen peroxide stabilisers represent another important category of auxiliaries containing complexing agents. The uncontrolled decomposition of hydrogen peroxide gives rise to OH* radicals. These radicals attack the cellulose fibre starting with oxidation of the hydroxyl groups and eventually ending with the cleavage of the cellulose molecules, decreasing the degree of polymerisation. This reaction is catalysed by heavy metals such as iron, manganese, copper and cobalt.

In order to inhibit these reactions, bleach stabilisers, containing sequestering agents, are usually applied. EDTA, DTPA, NTA, gluconates, phosphonates and polyacrylates are typical stabilisers.

Environmental problems associated with sequestering agents arise from the same properties for which they are used, which is their ability to form stable complexes with heavy metals. EDTA, NTA, and DTPA in particular form very stable metal complexes. EDTA and DTPA are also poorly eliminable compounds. There is therefore there is the risk they can pass undegraded through the common waste water treatment system and then eventually release the metals into the receiving effluent or that they may remobilise heavy metals in aquatic sediments.

NTA is biodegradable (when treated in waste water treatment plants under nitrifying conditions) and recent studies have shown that it only plays a minor role, if any, in the remobilisation of heavy metals in aquatic sediments [280, Germany, 2002].

Concerning the other organic substances used as complexing agents, gluconates are biodegradable; phosphonates are not biodegradable, but they are bioeliminable (photocatalytic degradation is also observed [77, EURATEX, 2000]).
### 8.6 Dyeing auxiliaries

#### 8.6.1 General characteristics and environmental aspects

Auxiliaries are essential components in dyeing processes. This section describes the ones most commonly used to assist the dyeing process. They are presented based on their function in the process as follows:

- wetting, penetrating agents
- dispersing agents
- levelling agents
- acid donors
- antifoaming
- carriers.

Other auxiliaries such as, for example, the complexing agents that are also commonly used in dyeing processes but that can also be encountered in other operations, are described in other parts of this annex.

Commercial products are in general preparations containing several components. These are mainly surfactants, but non-surface-active substances such as water-soluble polymers and oligomers and polymer dispersions are also frequently employed.

With a few exceptions dyeing auxiliaries are released to waste water. Some of them are biodegradable (e.g. fatty alcohol ethoxylates, linear alkylbenzene sulphonates), while others have poor biodegradability, but they are sparingly soluble in water and are therefore largely eliminated by absorption on the activated sludge in waste water treatment plants. There is, however, a list of substances that are soluble in water and poorly eliminable in common waste water systems. Compounds that belong to this category and that are frequently encountered in dyeing auxiliaries are listed as follows:

<table>
<thead>
<tr>
<th>Substances</th>
<th>Additional remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condensation products of beta-naphthale sulphonic acids and formaldehyde</td>
<td>Modified condensation products of naphthalene sulphonic acid with formaldehyde are reported to have about 70% bioeliminability, according to test method OECD 302 B (see also Section 4.5.1.1)</td>
</tr>
<tr>
<td>Lignin sulphonates</td>
<td></td>
</tr>
<tr>
<td>Acrylic acid-maleic acid co-polymers</td>
<td>Elimination rate depends on the content of Ca^{++} ions in the waste water</td>
</tr>
<tr>
<td>o-phenylphenol derivatives</td>
<td>Also toxic for aquatic species</td>
</tr>
<tr>
<td>Methylaromatic derivatives</td>
<td></td>
</tr>
<tr>
<td>Cyanamid-ammonia salt condensation products</td>
<td></td>
</tr>
<tr>
<td>Polyvinilpyrrolidones</td>
<td></td>
</tr>
<tr>
<td>Quaternary ammonium compounds</td>
<td>Also toxic for aquatic species</td>
</tr>
<tr>
<td>Ethoxylated fatty amines</td>
<td></td>
</tr>
<tr>
<td>Alkylphenol ethoxylates</td>
<td>Metabolites of alkylphenol ethoxylates are reported to influence the reproduction of aquatic species by disrupting the endocrine system (see also Section 8.1)</td>
</tr>
<tr>
<td>Chlorinated aromatic compounds such as trichlorobenzenes or dichlorotoluene (carriers)</td>
<td>Also characterised by high acute toxicity</td>
</tr>
<tr>
<td>Biphenyl derivatives (carriers)</td>
<td>Also characterised by high acute toxicity</td>
</tr>
</tbody>
</table>
8.6.2 Wetting, penetrating and de-aerating agents

This group of products is perhaps the most difficult to define in terms of technical function. Wetting and de-aerating agents often perform the same function: that of expelling air from the textile assembly contained in the dye bath. The use of penetrating agents is invariably associated with the dyeing of yarns with a high twist factor, where they enhance transport of the dye into the yarn assembly. In this respect it could be argued that they are in fact a levelling agent. All the products in this class are invariably powerful surfactants.

Commonly used commercial products are mainly readily bio-eliminable compounds such as alcohol polyglycol ethers and esters (also in blends with alkane sulphone), but poorly degradable products such as ethoxylated amines can also be encountered.

8.6.3 Dispersing agents

Vat, disperse and sulphur dyes already have a high content of dispersing agents in their formulation, which allows the application of these colourants in the form of aqueous dispersions. Additional amounts of dispersants are usually added (also for other classes of dyes) in the subsequent steps of the dyeing process to maintain the stability of the dispersion throughout the dyeing (or printing) process.

Substances commonly used as dispersing agents are condensation products of naphthalene sulphonic acid with formaldehyde, lignosulphonates. Anionic and non-ionic surfactants (e.g. ethoxylated alcohols, phosphated alcohols and naphthalene sulphonates) are also applied. Environmental aspects of these substances are reported in Section 8.6.1, whereas more general information about surfactants can also be found in Section 8.1. Dispersing agents with improved bioeliminability are now available for some dye formulations (see Section 4.5.1.1).

8.6.4 Levelling agents

Levelling agents are used in batch dyeing processes to improve the uniform distribution of the dye in the fibre. They are probably the most important class of dyeing auxiliaries, as a grossly unlevel dyeing is of no commercial value and is difficult to correct. They are employed for different types of fibres, therefore the substances employed can be different. Nevertheless two main groups of levelling agents can be identified: products which have an affinity for the fibre and products which have an affinity for the dye. Products which have an affinity for the fibreCompete with the dye for dye-sites on the fibre. In this way they reduce the rate of absorption of the dye and improve their migration. To the second group belong substances that form loosely bound complexes with the dye, reducing its mobility and in some cases neutralising the electrostatic attraction between the dye and the fibre.

The most common substances used as levelling agents are reported below, divided on the basis of the fibre to which they are applied and dyestuff.
Table 8.9: Typical compounds encountered in levelling agents

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Dye</th>
<th>Possible components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose fibres</td>
<td>Vat dyes</td>
<td>Fatty alcohol ethoxylates, fatty amines ethoxylates, polyamide amines, polyvinylpyrrolidone</td>
</tr>
<tr>
<td></td>
<td>Direct dyes</td>
<td>Non-ionic surfactants such as ethoxylated fatty alcohols, fatty amines, fatty acids, alkylphenols or propylene oxide polymers, anionic surfactants such as fatty alcohol sulphates and alkyl aryl sulphates, polyvinylpyrrolidone</td>
</tr>
<tr>
<td>Wool</td>
<td>Acid, metal complex and reactive dyes</td>
<td>Ethoxylated fatty amines, quaternary ammonium compounds, bisulphate anion (HSO₄⁻), other non-ionic surfactants such as ethoxylated fatty alcohols, fatty acids, alkylphenol and fatty mercaptans may also be found in specific products</td>
</tr>
<tr>
<td>Polyamide</td>
<td>Acid and metal complex dyes</td>
<td>Anionic, cationic and non-ionic surfactants used for wool, condensation products of aromatic sulphonic acids, alkyl sulphates (also called “PA reserving/blocking agents”)</td>
</tr>
<tr>
<td>Polyester</td>
<td>Disperse dyes (at HT conditions)</td>
<td>Ethoxylated castor oil, stearic acid, alkylphenols, mixtures of alcohols, esters or ketones of medium chain length with emulsifying systems, hazardous carriers were used in the past as levelling agents, today they are no longer used in high-temperature dyeing processes</td>
</tr>
<tr>
<td>Polyacrylonitrile</td>
<td>Basic dyes</td>
<td>Quaternary ammonium salts with C₁₂-C₁₄ fatty alkyl side chains (also known as retarders), quaternary ammonium salts with aromatic ring systems</td>
</tr>
</tbody>
</table>

Consideration of the environmental aspects associated with the use of these compounds is reported in Section 8.6.1 and more general information about surfactants can be found in Section 8.1.

8.6.5 Acid donors

The so-called acid donors represent a more sophisticated range of formulated products designed to create shifts in dye bath pH. They are hydrolysable acid esters which break down during dyeing, progressively lowering the pH. The shift of pH occurs as the acid is released by hydrolysis during heating or as one of the acid/base components is transferred to another phase such as the fibre or the air, e.g. ammonia release to air with ammonium sulphate.

They are widely used for wool and/or polyamide fibres to control the absorption of anionic dye onto the fibre. They are also employed for cotton and polyester blends when dyeing with disperse and reactive dyes in the one-bath one-step procedure.

Organic acid esters, fatty alcohol ethoxylates and aromatic sulphonates are commonly found in commercial products. They usually have good bio-eliminability.

8.6.6 Antifoaming agents

Formulated products designed to suppress foam formation are used, which do not adversely influence the quality of the resultant dyeing. The majority are based on silicone derivatives.
8.6.7 Carriers

Dyeing accelerants (so-called carriers) are used in batch dyeing of synthetic fibres (particularly polyester fibres) to promote the absorption and diffusion of disperse dyes into the fibre under low-temperature conditions. They are still important for dyeing blended fibres of wool and polyester, as wool cannot withstand dyeing under high temperature conditions (above 100 °C). Typical carrier formulations contain 60 – 80 % of active substance and 10 – 30 % of emulsifier and sometimes a small percentage of solvent.

Typical active substances for dyeing accelerants include:

- halogenated benzenes (1,2 dichlorobenzene; 1,2,4-trichlorobenzene; dichlorotoluene)
- aromatic hydrocarbons such as alpha- and beta-methylnaphthalene, diphenyl, trimethyl benzene, etc.
- phenols such as o-phenylphenol, benzylphenol, etc.
- carboxylic acid and their esters such as methyl, butyl and benzyl benzoate, methylsalicylate, phthalic acid, dimethylphthalate, dibutylphthalate and diethylhexylphthalate
- alkyl phthalimides such as N-butylphthalimide.

Most of the above-mentioned substances are toxic to humans, aquatic organisms and sewage sludge. *Hydrophobic* carriers exhaust at about 75 – 90 % onto the substrate, while *hydrophilic* types like phenols (e.g. o-phenylphenol), benzoate derivatives, N-alkylphthalimides and methylnaphthalene are mainly found in waste water. Exception made for benzoates (biodegradable) and N-alkylphthalimide derivatives (bioeliminable), the others are all poorly degradable and may pass undegraded through the waste water treatment system. On the other hand the carriers that remain on the textile material (hydrophobic types) are partially volatilised during the subsequent heat treatments (drying or fixing processes), thus producing air emissions.

Carboxylic acid esters and alkylphthlamides derivatives are the substances that are most frequently used in Europe today as carriers. However, it is reported that carriers such as methyl naphthalene, mono-, di-, tri-chlorobenzene, biphenyl, orthophenyl phenol and benzyl alcohol are still found in use [61, L. Bettens, 1999].
8.7  Printing auxiliaries

8.7.1  Auxiliaries for dye printing

Thickening agents

Thickening agents are essential components of printing pastes. They are responsible for preventing capillary flow between the threads of the fabric, thus inhibiting dye diffusion. Oil/water emulsions, used in the past as thickeners, have now been largely replaced by formulations similar to those used for warp sizes. Standard components of modern thickeners include natural polysaccharides, both unmodified and chemically modified (e.g. seed derivatives, starch degradation products, alginates) and fully synthetic polymers (mainly based on polyacrylic acid). Thanks to the improvements made in the characteristics of the starting materials, thickening agents are now supplied almost exclusively in cold-soluble form.

8.7.2  Auxiliaries for pigment printing

Thickening agents

Water-in-oil emulsions were widely used in the past as thickeners. They contained up to 70 % of white spirit (mixture of aliphatic hydrocarbons with C_{12} to C_{50} chain length), which resulted in emissions of volatile organic carbon in the exhaust air from drying and curing ovens. Half-emulsion printing pastes (oil in water) are only occasionally employed today. Nevertheless, modern thickeners can still contain approximately 10 % of mineral oils, which are ultimately found in exhaust air. New generation thickeners have been developed which do not contain any volatile solvents. They are supplied in the form of non-dusting granules [64, BASF, 1994].

Binders

The pigment has no affinity for the fibre. Therefore, in order to coat the pigment and protect it from mechanical abrasion, a binder is added to the printing paste. Binders are in general self-cross-linking polymers which reticulate during the fixation step. They are supplied as aqueous polymer dispersions, based mainly on acrylates and less commonly on butadiene and vinylacetate.

Fixing agents

Additional fixing agents are sometimes necessary to enhance the level of wet-fastness, especially with smooth fibres such as PES. Melamine-formaldehyde condensates are used for this purpose. In order to reduce the consequent formaldehyde emissions, modified compounds of the same chemical type, but with a low formaldehyde content, are now common.

Plasticisers

Plasticisers are mainly silicones or fatty acid esters, which are used to improve the dry rubbing fastness and give a smooth dry handle to the fabric.

Emulsifiers

In high- and low solvent pigment printing pastes, the emulsifiers serve to stabilise the solvent (white spirit). In solvent-free pigment printing they are used to prevent agglomeration of the pigment, screen blocking and separation of components of the print paste [186, Ullmann's, 2000]. Non-ionic surfactants such as aryl- and alkyl polyglycol ethers are the most commonly used for this purpose.
8.8 Finishing auxiliaries

8.8.1 Easy-care finishing agents

Easy-care finishing agents are chemical finishes which are applied to woven and knitted fabrics composed of cotton, other cellulosic fibres and their blends with synthetic fibres. Their function is to reduce the propensity of cellulose-containing fabrics for wrinkling when treated under wet and dry conditions and to stabilise them against progressive shrinkage during laundering. Their action is based on the introduction of cross-links between the cellulose molecules of cotton and viscose, thus reducing swellability and extensibility of the fibre (the fabric tends to return to the state in which it was when the cross-links were introduced).

Other names also commonly used to name these finishing agents are: resin-finishing, wash-and-wear finishing, no-iron, wrinkle resistant, etc.

Recipes for resin-finishing liquors are in general aqueous solutions or dispersions which consist of a cross-linking agent, a catalyst, a wetting agent/emulsifier (mainly a non-ionic surfactant) and a number of additives.

Among the additives a distinction is drawn between those that are used to improve the handle and to compensate the adverse effects of the cross-linking agent and some others that serve to impart additional functional properties to the final textile good (e.g. water-repellents, hydrophilising agents, etc.). Only the first group of additives is discussed in this section while the others, being less specific to this finishing treatment, are described in other parts of this Annex.

Cross-linking agents

The cross-linking agents play an essential role in this finishing treatment: they are also the major components in the formulation (they represent approximately 60 to 70% of the total preparation).

From a chemical point of view there are three distinct groups:

- cross-linking agents based on melamine and formaldehyde
- cross-linking agents based on urea and formaldehyde
- heterocyclic linking agents based on urea, formaldehyde and various other substances such as diamines and, in particular, glyoxal.

All these products may potentially produce emissions of free formaldehyde and methanol. In particular, formaldehyde is suspected of carcinogenity and its presence in these finishing agents represents a potential risk not only for waste water and exhausted air, but also for the workplace and the final user of the textile good.

Manufacturers have put much effort into producing cross-linking agents with a low to very low content of free formaldehyde and one compound is also available on the market, which is formaldehyde-free.

Existing cross-linking agents are therefore better classified as:

- formaldehyde-rich
- formaldehyde-poor or very poor
- formaldehyde-free.

The first group includes compounds (so-called “self-crosslinking” agents) like (HOCH₂-NH-CONH-CH₂OH) hydroxymethyl urea and (CH₃OCH₂-NH-CONH-CH₂OCH₃) (bis(methoxymethyl) urea or the correspondent melamine derivatives (hydroxymethyl melamine and bis(methoxymethyl) melamine).
Low to very low levels of free formaldehyde are achievable with heterocyclic compounds (so-called “reactant cross-linking” agents) which are mainly based on the derivatives of the molecule better known as bis(hydroxymethyl)-dihydroxyethylene urea (see Figure below).

![Formaldehyde derivative](image)

Modified derivatives of this compound with methanol and diethyleneglycol are among those reported to have a very low free-formaldehyde content in the product (<0.5 %, but also <0.1 % for some products is now achievable).

Among the formaldehyde-free cross-linking agents, only the compounds based on dimethyl urea and glyoxal (see Figure below) have gained a small share of the market [36, BASF, 2000]. In the absence of other sources of formaldehyde such as fixing agents and preservatives, the finishes obtained using these cross-linking agents are formaldehyde-free.

![Formaldehyde-free cross-linker](image)

The emissions of formaldehyde, methanol and other volatile organic substances in the exhaust air (from curing and drying operations) and in the workplace (especially with melamine resins) represent the main environmental issue in the application of these agents.

Water pollution is also an issue since these active substances (ethylene urea and melamine derivatives), when in their not-cross-linked form, are water-soluble and in general hardly biodegradable. This problem is, however, restricted to residual liquors, which as a fundamental rule should not be discharged together with the other effluents in order to avoid contamination with these concentrated liquors.

**Catalyst**

The function of the catalyst in the resin-finishing recipe is to allow the curing reaction to be carried out at the usually employed curing temperatures (130 – 180 °C) and times.

The most commonly used catalyst is magnesium chloride. In many cases liquid mixtures are used, based on magnesium chloride and organic acids (e.g. alpha-hydroxycarboxylic acids) or inorganic Lewis acids.

Ammonium salts (e.g. chloride, sulphate and nitrate) commonly used in the past, particularly with cross-linkers based on urea and formaldehyde or melamine, are in decline today, following the corresponding decline in importance of these cross-linking agents.

**Additives (softeners, stiffening agents, etc.)**

As mentioned above, easy-care recipes contain various different additives. Attention is given here only to:
• products that are added to easy-care recipes to offset the reduction in softness, tear strength and abrasion resistance that is produced on the fibre as a secondary effect of the cross-linking reaction (their content in easy-care recipes is in general in the range of 10 – 40 %): these can be dispersions of polyacrylates, polysiloxanes, polyethylene waxes (partially oxidised polyethylene), polyurethanes

• products that are added as softeners to improve the handle of the fabric: fatty acid condensation products (cationic softners) represent the most important group. They can also be supplied as emulsified mixtures with other products (e.g. polyethylene wax)

• products that are used as stiffeners, hand builders: these can be dispersions of polyvinylacetate, polyacrylate derivatives.

These substances are responsible for emissions of VOCs in the exhaust air from curing and drying operations.

The poor biodegradability of the above-mentioned polymer dispersions has also to be taken into account when considering water pollution.

8.8.2 Biocides

Some commonly used biocides are those that are applied in the carpet sector to impart wool fibre lifetime protection against a range of textile pests. These auxiliaries are usually known as mothproofing agents.

Currently used mothproofing agents are formulated from the following active ingredients:

• permethrin (synthetic pyrethroid)
• cyfluthrin (synthetic pyrethroid)
• sulcofuron (halogenated diphenylurea derivative).

Permethrin-based formulations account for approximately 90 % of the market. Cyfluthrin based products are only available in the UK, while sulcofuron-based products are currently not used to any significant degree.

Permethrin and synthetic pyrethroids in general are reported to have low toxicity to humans but high aquatic toxicity. Dyphenylurea derivatives may exhibit less aquatic toxicity but, in some cases, are less biodegradable [11, US EPA, 1995].

Other types of biocides are used in the textile industry, mainly as antimicrobial finishes, (e.g. hospital textile material), or as odour suppressants for socks and hosiery. The active substances used for this purpose are most commonly [77, EURATEX, 2000]:

• zinc organic compounds
• tin organic compounds
• dichlorophenyl(ester) compounds
• benzimidazole derivatives
• triclosane
• isothiazolinones (the most commonly used today).

All biocides give rise to environmental concern when they are discharged in waste water, because of their toxicity to aquatic life.

8.8.3 Antistatic agents

This section focuses on the antistatic agents that are applied as functional finishes to selected textile materials for use in static-sensitive environments. They are commonly used in the carpet sector.
From a chemical point of view, formulated products are mostly based on:
- quaternary ammonium compounds
- phosphoric acid ester derivatives.

Quaternary ammonium compounds are highly toxic to aquatic life. Furthermore, the discharge of these substances in waste water can give rise to high levels of AOX due to incomplete quaternisation (epichlorhidrine and chloromethane are often used as initial reagents).

Alkylphosphates and alkyl ether phosphates used as antistatic agents are water-soluble, hard-to-treat substances which may pass undegraded through common waste water systems. Nevertheless, the use of phosphoric acid esters in antistatic finishing treatment leads to emissions loads that are negligible if compared with other potential sources of this pollutant. According to [77, EURATEX, 2000], in fact, the pollution load released during pretreatment and attributable to antistatics from preparation agents is more than 100 times higher compared to the amount of antistatics discharged in waste water from antistatic finishing treatments.

On the other hand, for air emissions, the use of phosphoric esters-based antistatics may lead to the release of non-reacted alcohols (mostly n-butanol, which is very odour intensive) and phosphoric acid (corrosive).

### 8.8.4 Flame-retardants

When speaking about flame-retardant finishing it is useful to differentiate between durable and non-durable treatments. Durable flame-retardants react with the fibre, thereby providing permanent fire retardancy properties to the treated product. This is not the case with non-durable retardants, which although effective, are removed by laundering and are thus suitable only for fabrics which are seldom or never laundered or which can be re-treated whenever laundering is carried out.

Flame retardant (FR) agents function by different mechanisms depending on their chemical characteristics. The most commonly used FR agents in the textile sector belong to the following chemical classes:
- inorganic compounds
- halogenated organic compounds
- organo-phosphorus compounds.

**Inorganic FR agents**

Inorganic FR agents, used for cellulosic fibres, are water-soluble salts such as diammonium phosphate, aluminium sulphate, ammonium sulphate, etc. They are applied from aqueous solution by padding or spraying followed by drying. They are non-durable retardants, which means that they render the product flame retardant until it is laundered or otherwise exposed to water.

Other types of inorganic FR agents are used in the wool carpet sector. Although wool may be generally regarded as resistant to burning, the introduction of stringent flammability standards for floorcoverings fitted in aircraft and public service buildings necessitates the use of FR agents in some specific cases. Zirconium and titanium salts have been developed to meet the needs of this specialised market. Zirconium salts, commonly referred to as “Zirpro treatments”, are the most widely used (potassium hexafluorozirconate). They do not give rise to significant water pollution. However, emissions of zirconium- and fluorine-containing compounds along with fairly high water consumption levels (four rinsing-baths are needed with the conventional IWS procedure) should be taken into account [281, Belgium, 2002].

Aluminum hydroxide (Al₂O₃·3H₂O) is another flame-retardant widely used in the carpet sector. It is commonly added to the foam coating of the carpet, partially replacing CaCO₃ (inactive
filler). Aluminum hydroxide starts to break down at 180 to 200°C, the conversion to aluminium oxide taking place in an endothermic reaction. Aluminum hydroxide treatments do not pose significant environmental concerns.

**Halogenated FR agents**

Halogenated flame-retardants react in the gas phase by free-radical inhibition. The hydrogen and hydroxyl free radicals formed during the combustion process are high in energy and give rise to highly exothermic chain radical reactions (flame propagation). Halogenated flame-retardants are capable of interrupting this radical reaction. The halogen deactivates the free radical in the vapour phase according to the reaction (1):

\[
(1) \text{HX} + \text{OH}^* = \text{H}_2\text{O} + \text{X}^* \quad (\text{the X}^* \text{ radical formed is very low in energy})
\]

The effectiveness of halogen-containing flame-retardants increases in the order F<Cl<Br<I. However, only brominated and chlorinated compounds are used in practice. Fluorine and iodine based flame retardants are not used because neither of them interfere with the combustion process at the right point (the bond between the halogen atom and carbon is too strong for fluorine, and too loose for iodine).

**Brominated** compounds are the most effective ones. Bromine can be bound aliphatically or aromatically; the aromatic derivatives are widely used because of their high thermal stability.

**Chlorinated** flame-retardants include chlorinated aliphatic and cycloaliphatic compounds. Chlorinated flame-retardants are less expensive than the brominated homologues, but higher amounts of active substance are required in order to achieve an equivalent performance. Chlorinated compounds are thermally less stable and more corrosive to the equipment compared to the brominated forms.

Compounds in which **antimony trioxide** (Sb\textsubscript{2}O\textsubscript{3}) is used together with halogens represent another group of halogen-containing FR. Antimony trioxide is almost totally ineffective if used on its own. However, it shows a good synergistic effect with halogens, particularly chlorine and bromine. Antimony trioxide acts as a radical interceptor and with HBr forms a dense white smoke (SbBr\textsubscript{3}) that snuffs the flame by excluding oxygen from the front of the flame [303, Ullmann's, 2001]. Decabromodiphenyl ether, hexabromocyclododecane and chloroparaffins are typically used as synergistic agents.

Halogenated flame-retardants have come under intense environmental scrutiny in recent years. Their properties and their effects on the environment vary depending on the different type of chemicals used.

Polybrominated flame-retardants include the following compounds:

- polybrominated diphenyl ethers (PBDE, sometimes also referred to as PBBE)
  - pentabromodiphenyl ether (penta-BDE)
  - octabromodiphenyl ether (octa-BDE)
  - decabromodiphenyl ether (deca-BDE)
- polybromo biphenyls (PBB)
  - decabromobiphenyl
- tetrabromobisphenol A (TBBA)

Polybrominated FR used for textiles applications are almost mainly diphenyl ethers. Commercially available, technical grade PBDE, are mixtures and contain molecules with different numbers of bromine atoms. For example, technical grade octabromodiphenyl ether contains penta-BDE in low concentrations and hepta-BDE.
Penta-BDE is a persistent substance liable to biocumulate. The risk assessment, which has been carried out under Council Regulation (EEC) 793/93 on the evaluation and control of the risks of existing substances, identified a need for specific measures for reducing risks of penta-BDE to the environment.

As a consequence of this risk assessment there is already EU agreement for a ban on penta-BDE, which is confirmed by the inclusion of this chemical under the “Priority Hazardous Substances” targeted for priority regulatory action under the Water Framework Directive 2000/60/EC.

Penta-BDE is not reported as being used in the textiles sector. There are suspicions that deca-BDE, the major PBDE for textile applications, and octa-BDE could break down to penta-BDE and tetra-BDE after release into the environment. This theory is the subject of the EU risk assessment and OSPAR Working Groups. A ban covering deca-BDE and octa-BDE is being considered following the conclusions of the official EU risk assessments for these compounds. Deca-BDE should be prohibited from 1 January [299, Environment Daily 1054, 2001]. At Member States level, countries such as Sweden, the Netherlands and Norway are already taking actions to implement wide-ranging marketing restrictions covering the octa and deca forms of BDE, as an application of the precautionary principle.

As for chlorinated flame-retardants, short chain- (SCCP C10-13) and medium chain chlorinated paraffins (MCCP C14-17) have been the object of a risk assessment under the Council Regulation 793/93/EEC. SCCP and MCCP are acutely toxic for aquatic life. For SCCP long-term toxicity is observed in algae, fish and mussels. Medium-chain chlorinated paraffins are toxic to Daphnia, whereas no toxicity has been observed in the available experiments with fish, other invertebrates or algae. For both classes of compounds the hormonal effects seen in animals are considered unlikely to be relevant to humans [301, CIA, 2002]. No studies have been carried out on long-chain chlorinated paraffins.

Short-chain chloroparaffins (C_{10-13}) have been identified as “Priority Hazardous Substances” targeted for priority regulatory action under the Water Framework Directive 2000/60/EC. Moreover, both SCCP and MCCP are included on the List of Substances for Priority Action set under the OSPAR Convention.

Discharges of halogenated FR into waste water from textile finishing operations may come from excess liquor dumps, end-of-run bath drops and draining of washing water.

Deca-BDE is poorly water-soluble and should be largely retained by the sludge in the waste water treatment system. Chlorinated paraffins are also potentially bioeliminable by adsorption to the sludge (93% removal from water during waste water treatment has been reported) [301, CIA, 2002]. However, since the amount/load of active substance applied on the fabric is typically in the order of 20–30% w/w, the amount of FR not retained by the sludge and therefore potentially released into the environment may be significant. Process design and operation should avoid the discharge of concentrated liquors to waste water, minimise losses to the effluent, and ensure that adsorption to the sludge is effective in the waste water treatment plant.

Furthermore, special care should be taken for the disposal of the sludge and solid waste containing these halogenated compounds. All halogenated FR (less for aliphatic derivatives), are involved in the formation of dioxins and furans when submitted to high temperature treatments. Dioxins and furans can be formed in small amounts during the synthesis of these compounds and as a side reaction when they are subjected to combustion/burnt for disposal [302, VITO, 2002]. Incineration should therefore only be carried out in properly constituted incinerators, running at consistently optimal conditions.

For the widely used antimony-organo-halogen FR systems, in addition to the considerations reported above for brominated and chlorinated compounds, dust emissions of Sb_{2}O_{3}...
(carcinogenic) from dried pastes and mechanical treatment (cutting, etc.) on finished fabrics also need to be taken into account.

### Phosphor-organic FR agents

Phosphorus-based flame retardants can be active in the vapour phase or in the condensed phase. Phosphine oxides and phosphate esters are thought to act in the vapour phase through the formation of PO* radicals, which terminates the highly active flame propagating radicals (OH* and H*). The condensed phase mechanism arises as a consequence of the thermal generation of phosphoric acids from the flame retardant, e.g. phosphoric acid or polyphosphoric acid. These acids act as dehydrating agents on the polymer (they decompose to form water vapour and phosphorus oxides which then react with the polymer matrix and dehydrate it, reforming phosphoric acids). The fire retardancy effect is produced via the alteration of the thermal degradation of the polymer and the formation of a very high melting point char at the interface of the polymer and the heat source [303, Ullmann's, 2001].

Organo-phosphorus compounds used in textile applications, particularly for cotton, are available as reactive (durable) and non-reactive (non-durable) systems.

There are two principle chemical types of reactive phosphor-organic FR agents. Both of them are halogen-free formulations.

One type (fibre-reactive systems) is widely commercialised under trade names as Pyrovatex and Spolapret. The phosphor-organic compound is represented by the molecule: phosphonic acid, (2-((hydroxymethyl)carbamyl)ethyl)-dimethyl ester.

The FR is applied to cotton via the pad-dry-bake technique in combination with a melamine resin, a fabric softener and phosphoric acid. After padding, the fabric is dried and cured thermally to achieve fixation. No ammonia is used in curing. Because of the presence of melamine resins as cross-linking agents, formaldehyde and methanol are evolved as off-gases (emissions are normally abated via scrubbers). Following the curing process, the fabric is washed off, resulting in some unreacted P-containing reagents being discharged to the waste water. These compounds are non-readily biodegradable and water-soluble (they are not bioeliminated by adsorption on the sludge). According to one source, this product is not toxic or harmful to aquatic organisms and shows no potential to bioaccumulate [301, CIA, 2002]. Another source concludes that too little is known about the toxicology of the compound for a health risk assessment to be made. The same source states that no summaries of the environmental toxicity and fate have been identified [304, Danish EPA, Lokke et al., 1999].

Residual finishing liquors and rinsing water containing phosphor-organic flame retardant of this type should be collected and not mixed with the other effluent in the waste water treatment system [200, Sweden, 2001].

With the other type of reactive phosphor-organic FR (self-reactive systems), the fabric is impregnated with phosphonium salt and urea precondensates. The subsequent drying process step does not require complete drying. Processing temperatures are therefore low (between 60 and 100°C). After drying, the fabric is treated with ammonia to produce an insoluble polymer within the fibres. The fabric is subsequently oxidised with hydrogen peroxide and washed. In this process there is no curing treatment other than the treatment with ammonia.

The levels of formaldehyde evolved during drying are reported to be within the OEL limits for worker exposure over an eight hour period and maximum concentration limits over a fifteen minute reference period [301, CIA, 2002]. According to the same source, limits set for atmospheric emission of formaldehyde (20 mg/m³) are achieved at the majority of finishing sites without the need to install a scrubber.
No methanol is present in the emissions and no melamine resins or cross-linking agents are used in the process.

Phosphonium salt and urea precondensates have been shown to have levels of fixation of 95% or higher [301, CIA, 2002]. However, since washing is necessary with these flame-retardants to remove unreacted agents and by-products, some residual phosphorous organic compounds end up in the waste water treatment plant. These compounds are non-readily biodegradable and because of their water-solubility they may pass undegraded through the waste water treatment system.

Concentrated padding liquors and rinsing water containing phosphor-organic flame retardants of this type should be collected and not discharged with the other effluents in the waste water treatment [200, Sweden, 2001].

According to FR manufacturers, the phosphorous compounds from these treatments do not have the capability to bioaccumulate. It is also stated that the effluent can be converted to an inorganic phosphorous effluent [301, CIA, 2002]. In this way phosphorous can be removed as phosphate, which would prevent the release of organo-phosphorous compounds into the environment.

*Non-durable phosphor-organic* flame-retardants do not react with the fibre. It has been reported that some of them release organic volatile compounds like glycols, alcohols, glycolether or parts of the active substances [77, EURATEX, 2000]. This information is contradicted by EFRA and CIA FR manufacturers who state that non-durable flame-retardants of this chemical classification produced by EFRA and CIA member companies do not release any of the above-mentioned compounds [301, CIA, 2002].

As articles treated with *non-durable phosphor-organic* flame-retardants are not washed after the finishing treatment (and also as the final product is rarely washed), this results in a minimisation of any release of P-containing reagents to waste water [301, CIA, 2002].

### 8.8.5 Hydrophobic/ Oleophobic agents

The most commonly applied commercial formulations fall under the following categories:
- wax-based repellents (paraffin-metal salt formulations)
- resin-based repellents (fatty modified melamine resins)
- silicone repellents
- fluorochemical repellents.

**Wax-based repellents**

These formulations consist of ca. 25% of a paraffin and 5 – 10% of zirconium-, aluminium-based salts. They are usually applied to natural and synthetic fibres by padding and drying without curing. The discharge of residual liquors leads to emissions of metals. Concentrations can be high in some cases. However, from a global point of view the amounts discharged can be considered negligible compared to emissions of metals from dyeing and printing.

Moreover metals like Zr and Al should not be confused with more hazardous metals such as Cu, Ni, Co, Cr used in dyeing processes (note that Zr is also used in the “Zirpo process” in carpets – see Section 8.8.4) [281, Belgium, 2002].

Concerning exhaust air emissions, the presence of paraffin waxes may produce fumes and high levels of volatile organic carbon during heat treatments.
Resin-based repellents

Resin-based repellents (mainly applied as “extenders”) are produced by condensing fatty compounds (acids, alcohols or amines) with methylolated melamines. Formulations often also contain paraffin wax. They are applied by the pad-dry-cure process, often together with cross-linking agents in the presence of a catalyst.

Depending on the degree of completeness of the cross-linking reaction and on the temperature employed in heat treatments, different levels of formaldehyde and aliphatic alcohols are found in the exhaust air. The presence of paraffin wax contributes to increased levels of volatile organic carbon in the emissions.

Silicone repellents

These products are generally supplied as aqueous emulsions consisting of polysiloxane-active substances (dimethylpolysiloxane and modified derivatives), emulsifiers, hydrotropic agents (glycols) and water.

In the case of modified polysiloxanes with reactive functional groups, and depending on the drying and curing conditions, cyclic dimethylsiloxanes can be released in the exhaust air.

Fluorochemical repellents

The success of these agents, despite their high cost compared to other types of water repellents, is especially due to the fact that they are permanent and they provide both oil and water repellency.

Commercial fluorochemical repellents are mostly copolymers of fluoroalkyl acrylates and methacrylates. Marketed formulations contain the active agent together with emulsifiers (ethoxylated fatty alcohols and acids, but also fatty amines and alkylphenols) and other by-products which are often solvents such as:

- acetic acid esters (e.g. butyl/ethyl acetate)
- ketones (e.g. methylisobutyl ketone)
- diols (e.g. ethandiol, propandiol)
- glycolethers (e.g. dipropylenglycol).

Fluorochemical repellents are usually applied in combination with other finishing auxiliaries by a pad-dry-cure process. In many cases they are applied with “extenders” which can be other repellents themselves (e.g. melamine resins repellents or polyisocyanates). The use of these “extenders” allows a reduction in the required amount of fluorochemical, with a corresponding reduction in costs for this treatment.

Finishing treatments with fluorochemical repellents produce emissions of volatile organic compounds in exhaust air. These emissions are attributable to:

- the solvents contained in the formulations (as regards ketons, esters, alcohols, diols)
- the “extenders”, which under high-temperature conditions give rise to cracked by-products such as alcohols and ketones, but also oximes and in particular butanoxime (which is carcinogenic)
- the organo-fluoro components which also release cracked fluor-organic by-products.

As regards water pollution, it has to be taken into account that polysiloxanes, melamine and fluorocarbon resins are all characterised by poor biodegradability and bio-eliminability.
8.8.6 Softeners

This group of chemicals is designed for hand modification of fabric. Softeners reduce the fibre/fibre friction, an effect which hand-feel describes as “soft or smooth”.

Quite often softeners are used together with resins and/or optical brighteners in sometimes complex finishing recipes. Fabric softeners are water-based emulsions or dispersions of water-insoluble active materials such as:

- non-ionic surfactants
- cationic surfactants
- paraffin and polyethylene waxes
- organo-modified silicones.

Note that phthalates are plasticisers for e.g. PVC, but never textile softeners [195, Germany, 2001].

The formulation of the above-mentioned ingredients often requires additives such as emulsifiers and compatibilisers (e.g. glycols). Problematic APEO emulsifiers are no longer used by European producers.

As for surfactant-type softeners the trend is towards mainly non-ionic and cationic compounds.

Non-ionic softeners do not have substantivity for the fibres and are as wash-fast as the cationics. In spite of this, their usage is increasing as the volume of textiles with more permanence and increased wrinkle resistance is growing. Non-ionic surfactants such as fatty acids, fatty esters and fatty amides belong to this group.

Because of their substantivity, cationic softeners produce a more permanent softening effect than non-ionic compounds. Furthermore, they are more effective at much lower concentrations. Their substantivity for synthetic hydrophobic fibres is limited, increasing in the order: polyester, polyamide, acetate, cotton, viscose and wool. Some disadvantages of cationic agents are their lack of compatibility with anionic compounds typically employed as detergents and soaps, etc. As such, cationic softeners are applied after the complete removal of anionic detergents from the fabric [298, Dyechem Pharma, 2001].

Cationics used as softeners are [298, Dyechem Pharma, 2001]:

- quaternary ammonium compounds such as stearyl or distearyl dimethyl ammonium chloride
- amido amines formed by reaction of a fatty acid or a glyceride and a substituted or unsubstituted short chain polyamine (e.g. diethylene triamine, N, N-diethyl ethylenediamine). The amide thus formed is quaternised with acetic acid or hydrochloric acid to give the cationic softener (especially used for chlorinated wool)
- imidazolines which can be acetylated or reacted with ethylene oxide.

Polyethylene wax emulsions are widely used for towelling, where a good “bunch” hand is required, rather than in applications such as dress apparel. Among the advantages, it is worth mentioning their compatibility with cationic, non-ionic and anionic softeners [298, Dyechem Pharma, 2001].

Silicone softeners, used as emulsions or additives to other softeners, are increasing in importance. They have good effectiveness and besides softening they impart to the fabric additional properties such as water repellency.

Softeners are mostly applied by forced application (padding, spraying) from relatively concentrated solutions, which transfers all of the liquor onto the fabric [195, Germany, 2001]. In batch processing softeners are often applied by exhaustion from diluted baths on machines such as jet, overflow or winch. Here the exhaustion rate is relevant to ecological considerations.
of waste water loads. Machine technology with extremely short liquor ratios and skilled formulation of products help to minimise losses of active material [195, Germany, 2001].

If softeners enter the waste water, their behaviour in biological waste water treatment has to be taken into account.

Fatty derivatives generally are highly biodegradable. Cationic softeners are known to be toxic to aquatic life. Silicones and waxes are partially removed from the waste water by adsorption onto the sludge, after the stabilising emulsifiers have been degraded.

As the active ingredients of softener formulations are chemicals with high molecular weight (even polymers), the volatility is low. Volatile by-products of silicones (cyclics) are stripped before the production of the softener. Some waxes or fatty ingredients, however, may have some sensitivity towards cracking, if stenter temperatures are too high [195, Germany, 2001].
8.9 Coating compounds and auxiliaries

According to their chemical composition, coating agents can be classified as follows [179, UBA, 2001].

**Coating powders**

They can be based on polyolefins (especially polyethylene), polyamide 6, polyamide 6.6, copolyamides, polyester, polyurethane, polyvinylchloride, polytetrafluoroethylene.

**Coating pastes**

They are based on the chemicals mentioned above, but they also contain additives such as:
- dispersing agents (surfactants, often alkylphenol ethoxylates)
- solubilising agents (glycols, N-methylpyrrolidone, hydrocarbons)
- foaming agents (mineral oils, fatty acids, fatty acid ammonia salts)
- softeners (especially phthalates, sulphonamides)
- thickeners (polyacrylates)
- ammonia.

**Polymer dispersions (aqueous formulations)**

They contain approximately 50 % water and are based on:
- poly(meth)acrylate (butyl, ethyl, methyl etc.)
- polyacrylic acid
- polyacrylonitrile
- polyacryloamide
- 1,3-polybutadiene
- polystyrene
- polyurethane
- polyvinylchloride
- polyvinylacetate
- and copolymers of the above-mentioned polymers.

Additives are also present, as they are in coating pastes.

**Melamine resins**

They are produced by reaction of melamine and formaldehyde and subsequent etherification mainly with methanol in aqueous medium (water content 50 – 70 %).

**Polymers dispersions (organic solvent-based formulations)**

They are based on polyurethane and silicones dispersed in organic solvent.
9 ANNEX II DYES AND PIGMENTS

Textile dyes can be classified according to their chemical composition (azo, antrachinone, sulphur, triphenilmethane, indigoid, phtalocyanine, etc.) or according to their application class. At the industrial level the second method is preferred.

9.1 Acid dyes

Applicability

Acid dyes are mainly applied to polyamide (70 – 75 %) and wool (25 – 30 %). They are also used for silk and some modified acrylic fibres. Acid dyes exhibit little affinity for cellulose and polyester fibre.

Properties

Colours are generally bright and fastness to light and washing range from poor to excellent, depending on the chemical structure of the dyestuff.

Chemical characteristics and general application conditions

Acid dyes are azo (the largest group), anthraquinone, triphenylmethane, Cu phthalocyanine chromophoric systems which are made water-soluble by the introduction in the molecule of up to four sulphonate groups.
<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Chemical Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>42640</td>
<td>C.I. acid violet 49</td>
<td><img src="image" alt="Triphenylmethane dye" /></td>
</tr>
<tr>
<td>13390</td>
<td>C.I. acid blue 92</td>
<td><img src="image" alt="Azoic dye" /></td>
</tr>
<tr>
<td>63010</td>
<td>C.I. acid blue 45</td>
<td><img src="image" alt="Anthraquinone dye" /></td>
</tr>
<tr>
<td>74220</td>
<td>C.I. acid blue 249</td>
<td><img src="image" alt="Phthalocyanine dye" /></td>
</tr>
<tr>
<td>45186</td>
<td>C.I. Acid violet 30</td>
<td><img src="image" alt="Xanthene dye" /></td>
</tr>
<tr>
<td>10316</td>
<td>C.I. acid yellow 1</td>
<td><img src="image" alt="Nitro-derivative dye" /></td>
</tr>
</tbody>
</table>

**Figure 9.1: Examples of acid dyes**

Their interaction with the fibre is based partly on ionic bonds between sulphonate anions and the ammonium groups of the fibre, as shown below for wool.
and for polyamide, at different pH conditions.

Moreover, the fibre/dye interaction is based on secondary bonds such as Van der Waals forces. Secondary bonds are established in particular in the case of higher molecular weight dyes, which form aggregates with high affinity for the fibre.

In use, acid dyes are classified by their dyeing behaviour and wet-fastness properties, rather than chemical composition, hence the generic term acid dyes includes several individual dye classes. The arbitrary classification normally adopted, in order of increasing fastness is:

- level-dyeing or equalising acid dyes
- fast acid, half-milling or perspiration-fast dyes
- acid milling dyes
- supermilling dyes.

*Level-dyeing or equalising dyes* are subdivided into two classes, monosulphonated (mainly for PA) and disulphonated (mainly for wool). Due to their poor affinity for the fibre, they all have very good levelling properties. Their wet-fastness is, however, sometimes poor, limiting their use to pale/medium shades.

*Fast acid dyes* (also known as half-milling dyes or perspiration-fast dyes) are only used for PA. They are generally monosulphonated and exhibit superior fastness properties to level-dyeing acid dyes, while retaining some of the migration properties. The shade range available in this class is not as wide as that of the levelling or milling dyes and they therefore tend only to be used when alternatives would have poorer fastness properties.

*Acid milling dyes* are so named because they have a degree of fastness to the wet treatments employed when milling (mild felting) woollen fabrics. The class is further subdivided to include supermilling dyes, which have good wet-fastness properties, arising from long alkyl side-chains attached to the chromophore. Due to their high molecular weight, milling dyes have a good affinity for the fibre and do not migrate well at the boil. Milling dyes are used mainly for wool for those applications where good wet-fastness is required, for example in the dyeing of loose fibre which will receive a further wet treatment during hank scouring.

Depending on the class they belong to, acid dyes are applied under pH conditions that vary from strongly acidic to more neutral ones (3 – 7.5). For low-affinity dyes it is necessary to increase the level of cationisation of the fibre (by acidification) in order to improve dye uptake. Conversely, dyes with higher molecular weight and high affinity would adsorb too rapidly on the fibre if applied under such strongly acidic conditions.

The most common *chemicals and auxiliaries* applied when dyeing with acid dyes are:

- sodium sulphate (for level-dyeing and fast acid dyes), sodium acetate and ammonium sulphate (for acid milling dyes)
- pH regulators: acetic, formic and sulphuric acid, but also (typically for PA in the carpet sector) NaOH, NH₃ salts, phosphoric acid salts and higher (hydroxy)carboxylates
- levelling agents, mainly cationic compounds such as ethoxylated fatty amines.

The most common *chemicals and auxiliaries* applied when printing with acid dyes are:

- thickening agents
- solubilising agents such as urea, thiourea, thiodiglycol, glycerine
- acid donors: ammonium sulphate, tartrate or oxalate
- antifoaming agents (e.g. silicone oils, organic and inorganic esters) and “printing oils” (mainly mineral oils)
- after-treatment agents such as formaldehyde condensates with aromatic sulphonic acids.

Environmental issues

The environmental properties of acid dyes are assessed under the following parameters. Note, however, that the following table does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process.

Table 9.1: Overview of the ecological properties of acid dyes

<table>
<thead>
<tr>
<th>Parameters of concern</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-eliminability</td>
<td></td>
</tr>
<tr>
<td>Organic halogens (AOX)</td>
<td></td>
</tr>
<tr>
<td>Eco-toxicity</td>
<td>Acid dyes are in general not toxic. However, two dyes (Acid orange 156 and Acid orange 165) have been classified as toxic by ETAD. Acid Violet 17 (triphenylmethane dye) is reported to have an allergenic effect.</td>
</tr>
<tr>
<td>Heavy metals</td>
<td></td>
</tr>
<tr>
<td>Aromatic amines</td>
<td></td>
</tr>
<tr>
<td>Unfixed colourant</td>
<td>Degrees of fixation in batch dyeing are found to be in the range of 85 - 93% for monosulphonated dyes and in the range of 85 - 98% for di- and tri-sulphonated dyes</td>
</tr>
<tr>
<td>Effluent contamination by additives in the dye formulation</td>
<td></td>
</tr>
</tbody>
</table>
9.2 Basic (cationic) dyes

Applicability

Basic dyes were initially used to dye silk and wool (using a mordant), but they exhibited poor fastness properties. Nowadays these dyestuffs are almost exclusively used on acrylic fibres, modified polyamide fibres, and blends.

Properties

On acrylic fibres fastness performances are excellent.

Chemical characteristics and general application conditions

Cationic dyes contain a quaternary amino group which can be an integral part (more common) or not of the conjugated system. Sometimes a positively-charged atom of oxygen or sulphur can be found instead of nitrogen.

Ionic bonds are formed between the cation in the dye and the anionic site on the fibre.

\[
\text{Basic Blue 3} \\
\text{C.I. 51004}
\]

\[
\text{Basic Red 18} \\
\text{C.I. 11085}
\]

Figure 9.2: Examples of typical basic dyes

Cationic dyes are slightly soluble in water, while they show higher solubility in acetic acid, ethanol, ether and other organic solvents. In dyeing processes, they are applied in weak acid conditions. Basic dyes are strongly bound to the fibre and do not migrate easily. In order to achieve level dyeing, specific levelling auxiliaries, (also called retarders) are normally employed (unless a pH controlled absorption process is used). The most important group of retarders is represented by quaternary ammonium compounds with long alkyl side-chains (cationic retarders). Electrolytes and anionic condensation products between formaldehyde and naphthalenesulphonic acid may also be found.

Environmental issues

Many basic dyes exhibit high aquatic toxicity but, when applied properly, they show fixation degrees close to 100%. Problems are more often attributable to improper handling procedures, spill clean-up and other upsets [11, US EPA, 1995]. The following dyestuffs have been classified as toxic by ETAD:
- Basic Blue 3, 7, 81
- Basic Red 12
- Basic Violet 16
- Basic Yellow 21.
9.3 Direct (substantive) dyes

Applicability

Direct dyes are used for dyeing cotton, rayon, linen, jute, silk and polyamide fibres.

Properties

Colours are bright and deep, but light-fastness can vary greatly depending on the dyestuff. Wash-fastness properties are also limited unless the textile is after-treated. Only occasionally are direct dyes used in direct printing processes.

Chemical characteristics and general application conditions

Direct dyes (also called substantive dyes) can be azo compounds, stilbenes, oxazines, or phthalocyanines. They always contain solubilising groups (mainly sulphonic acid groups, but carboxylic and hydroxyl groups can also be found) that ionise in aqueous solution.

Direct dyes are characterised by long planar molecular structures that allow these molecules to align with the flat cellulose macromolecules, the dye molecules being held in place mainly through Van der Waals forces and hydrogen bonds.

Direct dyes may require the use of the following chemicals and auxiliaries for satisfactory dyeing:

- electrolytes, usually sodium chloride or sodium sulphate. Their function is to favour the aggregation of dye ions on the fibre
- wetting and dispersing agents: mixtures of non-ionic and anionic surfactants are used for this aim
- after-treatment agents: they are used to improve wet-fastness properties. So-called fixative cationic agents are the most commonly used. They are usually quaternary ammonium compounds with long hydrocarbon chains. Formaldehyde condensation products with amines, polynuclear aromatic phenols, cyanamide or dicyandiamide may also be used for this purpose.
### Environmental issues

The environmental properties of direct dyes are assessed under the following parameters. Note, however, that Table 9.2 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

#### Figure 9.3: Examples of typical direct dyes

<table>
<thead>
<tr>
<th>Direct red 81 (disazo)</th>
<th>Direct green 23 (trisazo)</th>
<th>Direct brown 44 (polyazo)</th>
<th>Direct yellow 12 (stilbene dye)</th>
<th>Direct yellow 59 (tiazoline dye)</th>
</tr>
</thead>
</table>

WORKING DRAFT IN PROGRESS
Table 9.2: Overview of the ecological properties of direct dyes

<table>
<thead>
<tr>
<th>Parameters of concern</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-eliminability</td>
<td></td>
</tr>
<tr>
<td>Organic halogens (AOX)</td>
<td></td>
</tr>
<tr>
<td>Eco-toxicity</td>
<td>Direct Orange 62 has been classified as toxic by ETAD</td>
</tr>
<tr>
<td>Heavy metals</td>
<td></td>
</tr>
<tr>
<td>Aromatic amines</td>
<td>The main emphasis of research for direct dyes was actually on the replacement of possibly carcinogenic benzidine dyes [186, Ullmann's, 2000]</td>
</tr>
<tr>
<td>Unfixed colourant</td>
<td>Degree of fixation in batch dyeing processes ranges from 64 - 96 % [77, EURATEX, 2000] (70 - 95 % according to [11, US EPA, 1995])</td>
</tr>
<tr>
<td>Effluent contamination by additives in the dye formulation</td>
<td></td>
</tr>
</tbody>
</table>
9.4 Disperse dyes

Applicability

Disperse dyes are used mainly for polyester, but also for cellulose (acetate and triacetate), polyamide and acrylic fibres.

Properties

Fastness to light is generally quite good, while fastness to washing is highly dependent on the fibre. In particular, in polyamides and acrylics they are used mostly for pastel shades because in dark shades they have limited build-up properties and poor wash fastness.

Chemical characteristics and general application conditions

Disperse dyes are characterised by the absence of solubilising groups and low molecular weight. From a chemical point of view more than 50% of disperse dyes are simple azo compounds, about 25% are anthraquinones and the rest are methine, nitro and naphthoquinone dyes.

The dye-fibre affinity is the result of different types of interactions:
  - hydrogen bonds
  - dipole-dipole interactions
  - Van der Waals forces.

Disperse dyes have hydrogen atoms in their molecule, which are capable of forming hydrogen bonds with oxygen and nitrogen atoms on the fibre.

Dipole-dipole interactions result from the asymmetrical structure of the dye molecules, which makes possible electrostatic interactions between dipoles on the dye molecules and polarised bonds on the fibre.

Van der Waals forces take effect when the molecules of the fibre and colourant are aligned and close to each other. These forces are very important in polyester fibres because they can take effect between the aromatic groups of the fibre and those of the colourant.

Disperse dyes are supplied as powder and liquid products. Powder dyes contain 40 – 60% of dispersing agents, while in liquid formulations the content of these substances is in the range of 10 – 30%. Formaldehyde condensation products and ligninsulphonates are widely used for this purpose.

Dyeing with disperse dyes may require the use of the following chemicals and auxiliaries:
  - dispersants: although all disperse dyes already have a high content of dispersants, they are further added to the dyeing liquor and in the final washing step
  - carriers: for some fibres, dyeing with disperse dyes at temperatures below 100 °C requires the use of carriers. This is the case with polyester, which needs the assistance of carriers to enable an even penetration of disperse dyes below boiling temperature. Because of environmental problems associated with the use of these substances, polyester is preferably dyed under pressure at temperature >100 °C without carriers. However, carrier dyeing is still important for polyester-wool blends, as wool must not be submitted to wet treatment at temperatures significantly above 100 °C
  - thickeners: polyacrylates or alginates are usually added to the dye liquor in padding processes. Their function is to prevent migration of the dye liquor on the surface during drying
  - reducing agents (mainly sodium hydrosulphite): they are added in solution with alkali in the final washing step.
Annexes

Disperse dyes are widely used not only for dyeing, but also for printing synthetic fibres.

Environmental issues

The environmental properties of disperse dyes are assessed under the following parameters. Note, however, that Table 9.3 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

Table 9.3: Overview of the ecological properties of disperse dyes

<table>
<thead>
<tr>
<th>Parameters of concern</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-eliminability</td>
<td>Owing to their low water-solubility, they are largely eliminated by absorption on activated sludge in the waste water treatment plant</td>
</tr>
<tr>
<td>Organic halogens (AOX)</td>
<td>Some disperse dyes can contain organic halogens, but they are not expected to be found in the effluent after waste water treatment (because they are easily eliminated by absorption on the activated sludge) (see also Section 2.7.8.1)</td>
</tr>
<tr>
<td>Toxicology</td>
<td>The following disperse dyes potentially have an allergenic effect: Disperse Red 1, 11, 17, 15; Disperse Blue 1, 3, 7, 26, 35, 102, 124; Disperse Orange 1, 3, 76; Disperse Yellow 1, 9, 39, 49, 54, 64.</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Aromatic amines: These dyes are still offered by some Far East dealers and manufacturers [294, ETAD, 2001]</td>
</tr>
<tr>
<td></td>
<td>Unfixed colourant: Level of fixation is in the range of 88 - 99 % for continuous dyeing and 91 - 99 % for printing</td>
</tr>
<tr>
<td>Effluent contamination by additives in the dye formulation</td>
<td>Conventional dispersants (formaldehyde condensation compounds, lignosulphonates, etc.) are poorly biodegradable (&lt;30 % according to [186, Ullmann's, 2000], ca. 15 % according to [18, VITO, 1998]). Some dyes are formulated with more readily eliminable dispersants (albeit not suitable for all formulations). More information is reported in Section 4.5.1.1</td>
</tr>
</tbody>
</table>
9.5 **Metal-complex dyes**

*Applicability*

Metal-complex dyes (also called pre-metallised dyes) have great affinity for protein fibres. Among metal-complex dyes, 1:2 metal-complex dyes are also suitable for polyamide fibres.

More than 65% of wool is today dyed with chrome dyes (see next section) or metal-complex dyes and about 30% of PA is dyed with 1:2 metal-complex dyes.

*Properties*

Light-fastness is excellent, while washing fastness is not as good as with chrome dyes (particularly in darker shades).

*Chemical characteristics and general application conditions*

Metal-complex dyes may be broadly divided into two classes, 1:1 metal-complexes, in which one dye molecule is co-ordinated with one metal atom and 1:2 metal complexes, in which one metal atom is co-ordinated with two dye molecules. The dye molecule will be typically a monoazo structure containing additional groups such as hydroxyl, carboxyl or amino groups, which are capable of forming strong co-ordination complexes with transition metal ions, typically chromium, cobalt, nickel and copper. Note that phthalocyanine dyes cannot be classified as metal-complex dyes.

Typical examples of pre-metallised dyes are shown in Figure 9.4 and Figure 9.5.

![Figure 9.4: Examples of molecular structures typical of 1:1 metal-complex dyes](image)

**Acid Violet 56**
C.I. 16055

**Acid Blue 158**
C.I. 14880

**Figure 9.4:** Examples of molecular structures typical of 1:1 metal-complex dyes
Metal-complex dyes do not represent a specific application dye class. Metal-complex dyes belong in fact to many application classes of dyes (i.e. they can be found, for example, among acid, direct and reactive dyes). When used in dyeing processes, metal-complex dyes are applied in pH conditions regulated by the user class and the fibre type (wool, polyamide, etc.). The pH levels for wool range from strongly acidic (1.8 - 4 for 1:1 metal-complex dyes) to moderately acidic neutral (4 - 7 for 1:2 metal-complex dyes). For polyamide fibres higher pH conditions are becoming more and more common.

1:1 metal-complex dyes exhibit excellent level dyeing and penetration characteristics and have the ability to cover irregularities in the substrate. Their light and wet-fastness properties are good even in deep shades. They are particularly suitable for yarn and for piece dyeing of carbonised wool.

1:2 metal-complex dyes are used for both wool and polyamide. They form the most important group in this class and may be divided into two sub-groups:

- weakly polar 1:2 complexes – solubilised by the inherent anionicity of the complex or containing non-ionic, hydrophilic substituents such as methylsulphone (-SO₂CH₃). These dyes exhibit excellent fastness to light and wet treatments and excellent penetration properties.
- strongly polar 1:2 complexes – solubilised by one or more sulphonic or carboxylic acid residues, these dyes possess lower levelling power than the weakly polar dyes mentioned above but superior wet-fastness properties and are generally suitable for use in those applications where mordant dyes are used. This second group is also more suitable for dyeing polyamide fibres.

Dyeing with metal-complex dyes may require the use of the following chemicals and auxiliaries:

- pH regulators: sulphuric, formic, acetic acid
- electrolytes: sodium sulphate, ammonium acetate and sulphate
- levelling agents: mixtures of anionic and non-ionic surfactants (these auxiliaries are not needed when using pH controlled adsorption dyeing techniques).

Environmental issues

The environmental properties of metal-complex dyes are assessed under the following parameters. Note, however, that Table 9.4 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.
### Table 9.4: Overview of the ecological properties of metal complex dyes

<table>
<thead>
<tr>
<th>Parameters of concern</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-eliminability</td>
<td>Great differences from dye to dye (bio-eliminability can be &lt;50 %)</td>
</tr>
<tr>
<td>Organic halogens (AOX)</td>
<td>Some products contain organic halogens: AOX in waste water, therefore depends on the eliminability of the dyes concerned (see also Section 2.7.8.1)</td>
</tr>
<tr>
<td>Eco-toxicity</td>
<td>Metals can be found in the effluent due to unfixed dye. However, Cr III and the other transition metals used in metal-complex dyes are an integral part of the chromophore (see also Section 2.7.8.1 &quot;heavy metals&quot;)</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Degree of fixation ranges from moderate to excellent (from 85 to 98 % and greater in some cases)</td>
</tr>
<tr>
<td>Aromatic amines</td>
<td>Inorganic salts are present in the preparation of powder dyes. These salts, however, do not present any ecological or toxicological problems [64, BASF, 1994]</td>
</tr>
<tr>
<td>Unfixed colourant</td>
<td></td>
</tr>
<tr>
<td>Effluent contamination by additives in the dye formulation</td>
<td></td>
</tr>
</tbody>
</table>
9.6 Mordant dyes (chrome dyes)

Applicability

Mordant dyestuffs are generally used for protein (wool and silk). They are practically no longer used for polyamide fibres or for printing.

Properties

Thanks to their good levelling properties and very good wet-fastness after chroming, chrome dyes are used principally to obtain dark shades (greens, blues and blacks) at moderate cost. There are disadvantages, however, in their use: long dyeing times, difficulties with shading, the risk of chemical damage to the fibre during chroming and the potential release of chromium in waste water.

Chemical characteristics and general application conditions

The Colour Index classifies these colourants as mordant dyes, but chromium has become the almost universally used mordant and the class is commonly referred to as chrome dyes.

From a chemical point of view they can be regarded as acid dyestuffs that contain suitable functional groups capable of forming metal complexes with chrome. They do not contain chrome in their molecule, which instead is added as dichromate, or chromate salt to allow dye fixation.

Interaction with the fibre is established through ionic bonds formed between the anionic groups of the colourant and ammonium cations available on the fibre. In addition chromium acts as a link between dye and fibre. This gives rise to a very strong bond, which is reflected in the excellent fastness obtained. Figure 9.6 shows the ionic and coordination bonds in the case of wool.

Figure 9.6: Representation of possible ionic and coordination bonds between wool and chrome dyes

Source: [69, Corbani, 1994]
The use of chrome dyes in *dyeing* processes requires the use of the following chemicals and auxiliaries:

- potassium and dichromate or chromate
- formic or acetic acid as pH regulators
- other organic acids such as tartaric and lactic acid. They are used to enhance the degree of conversion of Cr VI to Cr III
- sodium or ammonium sulphate.

*Environmental issues*

The environmental properties of chrome dyes are assessed under the following parameters. Note, however, that Table 9.5 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

<table>
<thead>
<tr>
<th>Parameters of concern</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-eliminability</td>
<td></td>
</tr>
<tr>
<td>Organic halogens (AOX)</td>
<td></td>
</tr>
<tr>
<td>Eco-toxicity</td>
<td></td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Chromium present in the final colourant is not contained in the molecule, being instead added as dichromate, or chromate salt during the dyeing process to allow dye fixation (see also Section 2.7.8.1)</td>
</tr>
<tr>
<td>Aromatic amines</td>
<td></td>
</tr>
<tr>
<td>Unfixed colourant</td>
<td></td>
</tr>
<tr>
<td>Effluent contamination by additives in the dye formulation</td>
<td></td>
</tr>
</tbody>
</table>
9.7 Naphthol dyes (azoic dyes developed on the fibre)

Applicability

Azoic dyes, also known as naphthol dyes, are used for cellulosic fibres (particularly cotton), but may also be applied to viscose, cellulose acetate, linen and sometimes polyester.

Properties

Azoic dyes have excellent wet-fastness properties as well as good light, chlorine and alkali fastness, while rubbing fastness is poor.

Chemical characteristics and general application conditions

From a chemical point of view naphtol dyes are very similar to azo dyes, the main difference being the absence of sulphonic solubilising groups.

They are made up of two chemically reactive compounds that are applied to the fabric in a two-stage process. The insoluble dye is synthesised directly in the fibre as the result of the coupling reaction between a diazotised base (developing agent) and a coupling component.

The coupling components are usually derivatives of the anilides of the 2-hydroxy-3-naphthoic acid (also called naphthol AS). These naphthols are available in powder form or in liquid form (in this case the solution also contains caustic soda, the naphthol concentration ranges between 30 % and 60 %).
Developing agents can be derivatives of aniline, toluidine, orto and meta anisidine, diphenyl amine. They are available as:

- free bases (fast colour bases)
- liquid bases (these formulations are aqueous dispersions of the aromatic amines, they are safer and simpler to apply than solid bases)
- fast colour salts (these are already diazotised diazonium compounds that are marketed in stabilised forms and do not need to be diazotised before use in dyeing: some examples are given in the figure below).
### Colour Index

<table>
<thead>
<tr>
<th>Diazo component no</th>
<th>Chemical composition no</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>37005</td>
<td>![Formula2]</td>
</tr>
<tr>
<td>3</td>
<td>37010</td>
<td>![Formula3]</td>
</tr>
<tr>
<td>6</td>
<td>37025</td>
<td>![Formula6]</td>
</tr>
<tr>
<td>32</td>
<td>37090</td>
<td>![Formula32]</td>
</tr>
<tr>
<td>5</td>
<td>37125</td>
<td>![Formula5]</td>
</tr>
<tr>
<td>41</td>
<td>37165</td>
<td>![Formula41]</td>
</tr>
<tr>
<td>35</td>
<td>37255</td>
<td>![Formula35]</td>
</tr>
</tbody>
</table>

**Figure 9.8:** Examples of typical developing agents (fast colour base) for naphthol dyes
Application of azoic colourants involves a number of steps:
• preparation of the naphtholate solution: naphthol is converted to the naphtholate form to be able to couple with the diazonium salt
• application of the naphtholate to the fibre
• preparation of the diazotised base: in order to make the coupling reaction possible, the base must first be diazotised in the cold, using sodium nitrite and hydrochloric acid (this step can be avoided when using fast colour salts)
• formation of the azoic dye into the fibre.

Environmental issues

The environmental properties of naphthol dyes are assessed under the following parameters. Note, however, that Table 9.6 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

<table>
<thead>
<tr>
<th>Parameters of concern</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-eliminability</td>
<td></td>
</tr>
<tr>
<td>Organic halogens (AOX)</td>
<td></td>
</tr>
<tr>
<td>Eco-toxicity</td>
<td></td>
</tr>
<tr>
<td>Heavy metals</td>
<td></td>
</tr>
<tr>
<td>Aromatic amines</td>
<td>Developing agents are all diazotisable amines or diamines or substituted anilines, toluidines, anisides, azobenzenes or diphenylamines. Some of these amines and in particular, p-nitroaniline, chloroaniline and β-naphtilamine are on the 1980 US EPA priority list as harmful pollutants and their use is forbidden.</td>
</tr>
<tr>
<td>Unfixed colourant</td>
<td>Degree of fixation in continuous dyeing processes ranges between 76 and 89 % and between 80 and 91 % in printing processes [77, EURATEX, 2000]</td>
</tr>
<tr>
<td>Effluent contamination by dispersants and additives in the dye</td>
<td></td>
</tr>
</tbody>
</table>
9.8 Reactive dyes

Applicability

Reactive dyes are mainly used for dyeing cellulose fibres such as cotton and viscose, but they are also increasingly gaining importance for wool and polyamide.

Properties

They provide high wet-fastness (better than the less expensive direct dyes), but their use is not always viable because of the difficulty in obtaining level dyeing. Chlorine fastness is slightly poorer than that of vat dyes, as is light fastness under severe conditions.

The range of available reactive dyes is wide and enables a large number of dyeing techniques to be used.

Chemical characteristics

Reactive dyes are unique in that they contain specific chemical groups capable of forming covalent links with the textile substrate.

The energy required to break this bond is similar to that required to degrade the substrate itself, thus accounting for the high wet-fastness of these dyes.

The structure of Reactive Black 5, one of the most important reactive dyestuffs in terms of volumes consumed, is illustrated in Figure 9.10.

![Chemical structure of reactive dyes](image)

Figure 9.10: Reactive Black 5

Chemical structure of reactive dyes can be schematically represented by the following formula: Col-B-R, where:

- Col is the chromophore that is in general constituted by monoazoic, anthraquinone, phthalocyanine and metal-complex compounds
- B is the linking group between the chromophore and the reactive group
- R represents the reactive group (anchor system with the leaving group). The anchor systems are characterised by their reactivity. Based on this, they are classified as hot, warm or cold dyers.

Some typical examples of reactive systems for cellulose and wool or polyamide fibres are reported in the following tables.
### Table 9.7: Typical anchor systems for cellulose fibres

<table>
<thead>
<tr>
<th>Anchor system</th>
<th>Denomination</th>
<th>Commercial name</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Dichloro-s-triazine" /></td>
<td>Dichloro-s-triazine (cold dyer)</td>
<td>Procion MX</td>
</tr>
<tr>
<td><img src="image" alt="Amino-fluoro-s-triazine" /></td>
<td>Amino-fluoro-s-triazine (warm dyer)</td>
<td>Cibacron F</td>
</tr>
<tr>
<td><img src="image" alt="Trichloro-pyrimidine" /></td>
<td>Trichloro-pyrimidine (hot dyer)</td>
<td>Cibacron T-E Dimaren X, Z</td>
</tr>
<tr>
<td>-SO₂-CH₂-CH₂-O-SO₃Na</td>
<td>Beta-sulphate-ethyl-sulphone (warm dyer)</td>
<td>Remazol</td>
</tr>
</tbody>
</table>

### Table 9.8: Typical anchor systems for wool and polyamide fibres

<table>
<thead>
<tr>
<th>Anchor system</th>
<th>Denomination</th>
<th>Commercial name</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="2,4-difluoro 5-chloro pyrimidine" /></td>
<td>2,4-difluoro 5-chloro pyrimidine</td>
<td>Verofix Drimalan F</td>
</tr>
<tr>
<td>-SO₂-CH₂-CH₂-O-SO₃Na</td>
<td>Beta-sulphate-ethyl-sulphone</td>
<td>Remazolan</td>
</tr>
<tr>
<td>-SO₂-NH-CH₂-CH₂-O-SO₃H</td>
<td>Sulphate-ethyl sulphonamide</td>
<td>Levafix</td>
</tr>
<tr>
<td>-NHCO-CBr=CH₂</td>
<td>Bromoacrylamide</td>
<td>Lanasol</td>
</tr>
</tbody>
</table>

The reactive groups of the colourant react with the amino groups of the fibre in the case of protein and polyamide fibres, and with the hydroxyl groups in the case of cellulose.

In both cases, depending on the anchor system, two reaction mechanisms are possible: a nucleophilic substitution mechanism or a nucleophylic addition mechanism.

An important issue to consider when dealing with reactive dyes is the fact that two competing reactions are always involved in the colouring process:

1. **alcoholysis**: dye + fibre → dye fixed on the fibre
2. **hydrolysis**: dye + water → hydrolysed dye washed away after dyeing (undesired reaction)

This fact has important consequences, especially in the case of cellulose fibres. In fact, the alkaline conditions in which reactive dyes react with cellulose fibres, increase the rate of the hydrolysis reaction. The characteristics of the resulting hydrolysed dye are such that the dye is no longer a reactive substance and it is therefore discharged in the effluent.

*Dyeing cellulose fibres* with reactive dyes may imply the use of the following *chemicals* and *auxiliaries*:

- alkali (sodium carbonate, bicarbonate and caustic soda)
- salt (mainly sodium chloride and sulphate)
- urea may be added to the padding liquor in continuous processes in the one-bath method (see also Section 4.5.2.6 for alternative techniques)
- sodium silicate may be added in the cold pad-batch method (see also Section 4.5.2.2).
Annexes

Reactive dyes are applied to wool or polyamide fibres under different conditions. In the case of wool and polyamide fibres, reactivity of the amino groups is considerably higher than that of hydroxyl groups in cellulose.

Levelling properties are often achieved with the use of speciality amphoteric levelling agents.

Reactive dyes are generally applied at pH values of between 4.5 and 7, depending on depth of shade, in the presence of ammonium sulphate and the specialised levelling agents mentioned above.

In cellulose printing, moderately reactive dyes are generally employed (mainly mochlorotriazine systems). Highly reactive sulphoethyl sulphones are also sometimes used.

Printing with reactive dyes requires the use of:
- thickening agents (mainly polyacrylates in combination with alginates)
- urea
- alkali (e.g. sodium carbonate and bicarbonate)
- oxidising agents (mainly benzenesulphonic acid derivatives): they are used to prevent reduction of more sensitive dyes during steaming.

Environmental issues

Poor dye fixation has been a long-standing problem with reactive dyes in particular in batch dyeing of cellulose fibres, where a significant amount of salt is normally added to improve dye exhaustion (and therefore also dye fixation). On the other hand, shade reproducibility and level dyeing were the major obstacle in “right-first-time” production using the most efficient dyes (high exhaustion and fixation rate).

Research and development has been faced with a number of objectives, all of which have been or are in the process of being successfully achieved. These include [190, VITO, 2001]:
- increasing the robustness of individual dyes and dye combinations (trichromatic systems)
- enhancing reproducibility of trichromatic combinations used in most commonly applied dyeing processes
- reducing salt consumption and/or unused dye in the effluent
- improving fastness properties (e.g. light fastness, fastness to repeated laundering).

With the use of sophisticated molecular engineering techniques it has been possible to design reactive dyes (e.g. bifunctional dyes and low-salt reactive dyes) with considerably higher performances than traditional reactive dyes. These recent developments are described in more detail in Sections 4.5.2.2, 4.5.2.4 and 4.5.2.6.

The environmental properties of reactive dyes are assessed in Table 9.9. Note that the table does not consider the environmental issues related to chemicals (e.g. salt) and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.
Table 9.9: Overview of the ecological properties of reactive dyes

<table>
<thead>
<tr>
<th>Parameters of concern</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-eliminability</td>
<td>Because both unfixed reactive dye and its hydrolysed form are readily soluble they are difficult to eliminate in biological waste water treatment plants</td>
</tr>
<tr>
<td>Organic halogens (AOX)</td>
<td>Many reactive dyes contain organic halogens. However, a distinction has to be made between halogens bonded to the chromophore and halogens bonded to the anchor group (see Section 2.7.8.1 for more detailed discussion).</td>
</tr>
<tr>
<td>Eco-toxicity</td>
<td></td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Heavy metals can be present both as impurities from the production process (limits have been set by ETAD) and as an integral part of the chromophore. The latter concerns phthalocyanine dyes, which are still widely used especially for blue and turquoise shades (substitutes have not yet been found) (see also Section 2.7.8.1)</td>
</tr>
<tr>
<td>Aromatic amines</td>
<td></td>
</tr>
<tr>
<td>Unfixed colourant</td>
<td>Fixation rate can be poor (^1) (see also discussion in Section 2.7.8). Efforts have been made to increase the level of fixation. Some reactive dyes can reach &gt;95 % of fixation even for cellulosic fibres (see Sections 4.5.2.2 and 4.5.2.4 for recent developments)</td>
</tr>
<tr>
<td>Effluent contamination by dispersants and additives already in the dye</td>
<td></td>
</tr>
</tbody>
</table>

Notes:

\(^1\) [77, EURATEX, 2000] Fixation degree for:
- cotton batch dyeing: 55–80 %
- wool batch dyeing: 90 - 97 %
- printing (general): 60 %
9.9 Sulphur dyes

Applicability

Sulphur dyes are mainly used for cotton and viscose substrates. They may also be used for dyeing blends of cellulose and synthetic fibres, including polyamides and polyesters. They are occasionally used for dyeing silk. Apart from black shades, sulphur dyes play almost no part in textile printing.

Properties

Bleach and wash fastness properties are very good, while light fastness varies from moderate to good. Although they encompass a broad shade range, sulphur dyes are mostly used for dark shades because lighter shades have poor resistance to light and laundering. Sulphur dyes tend to be dull compared with other dye classes.

Chemical characteristics and general application conditions

Sulphur dyes are made up of high molecular weight compounds, obtained by reaction of sulphur or sulphides with amines and phenols. Many colourants exist that contain sulphur in their molecule, but only dyestuffs which become soluble in water after reaction with sodium sulphide under alkaline conditions can be called sulphur dyes.

The exact chemical structure is not always known because these are mixtures of molecules of a high level of complexity. Amino derivatives, nitrobenzenes, nitro and aminobiphenyls, substituted phenols, substituted naphthalenes, condensed aromatic compounds, indophenols, azines, oxazine, thiazol, azine and thiazine rings can be part of these compounds. Sulphur dyes contain sulphur both as an integral part of the chromophore and in polysulphide side chains.

As has already been mentioned, sulphur dyes are insoluble in water, but after reduction under alkaline conditions they are converted into the leuco-form, which is water-soluble and has high affinity for the fibre. After absorption into the fibre they are oxidised and converted to the original insoluble state.

Sulphur dyes are available in various modifications, which are classified under the following names:

- sulphur dyes - available as amorphous powders or dispersible pigments. Amorphous powders are insoluble or partially soluble in water and are brought into solution by boiling with sodium sulphide and water. Dispersible pigments can be used in this form for pad dying in presence of a dispersing agent. They can contain a certain amount of reducing agent already in the formulation and in this case are called "partly reduced pigments".
- leuco-sulphur dyes (ready-for-use dyes) - available in liquid form and already contain the reducing agent required for dyeing. Therefore they must simply be diluted with water before application. Low-sulphide types are also available on the market
- water-soluble sulphur dyes - available in the form of Bunte salts (Col-S-SO₃Na) obtained by treating the dye in its insoluble form (Col-S-S-Col) with sodium hydrosulphite. They can be dissolved in hot water, but they do not have affinity for the fibre. The addition of alkali and reducing agent makes them substantive for the fibre.

Sodium sulphide and sodium hydrogensulphyde are generally employed as reducing agents to bring into solution the dye (unless ready-for-use sulphur dyes are applied). Binary systems made of glucose and sodium dithionite (hydrosulphite) or thiourea dioxide are also used as alternative reducing agents.

In all processes the dye is finally fixed on the substrate by oxidation. Nowadays, hydrogen peroxide or halogen-containing compounds such as bromate, iodate and chlorite are the most commonly used oxidising agents.
Apart from the above-mentioned reducing and oxidising agents, additional chemicals and auxiliaries required when dyeing with sulphur dyes are:

- alkali (mainly caustic soda)
- salt (sodium chloride and sulphate)
- dispersing agents: usually they are naphthalenesulphonic acid-formaldehyde condensates, ligninsulphonates and sulphonated oils
- complexing agents: EDTA and polyphosphates are used in some cases to prevent negative effects due to the presence of alkaline-earth ions.

**Environmental issues**

The environmental properties of sulphur dyes are assessed under the following parameters. Note, however, that Table 9.10 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

**Table 9.10: Overview of the ecological properties of sulphur dyes**

<table>
<thead>
<tr>
<th>Parameters of concern</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-eliminability</td>
<td>Most sulphur dyes are water-insoluble after oxidation and therefore they can largely be eliminated by adsorption on the activated sludge in the waste water treatment plant</td>
</tr>
<tr>
<td>Organic halogens (AOX)</td>
<td></td>
</tr>
<tr>
<td>Eco-toxicity</td>
<td></td>
</tr>
<tr>
<td>Heavy metals</td>
<td></td>
</tr>
<tr>
<td>Aromatic amines</td>
<td></td>
</tr>
<tr>
<td>Unfixed colourant</td>
<td>Degree of fixation ranges between 60 and 90 % in continuous dyeing and 65 - 95 % in printing [77, EURATEX, 2000]</td>
</tr>
<tr>
<td>Effluent contamination by additives in the dye formulation</td>
<td>Poorly biodegradable dispersants are present. New formaldehyde condensation products with higher elimination (&gt;70 %) are already available (see Section 4.5.1.1)</td>
</tr>
</tbody>
</table>
Annexes

9.10 Vat dyes

Applicability

Vat dyes are used most often in dyeing and printing of cotton and cellulose fibres. They can also be applied for dyeing polyamide and polyester blends with cellulose fibres.

Properties

Vat dyes have excellent fastness properties when properly selected and are often used for fabrics that will be subjected to severe washing and bleaching conditions (towelling, industrial and military uniforms, etc.). The range of colours is wide, but shades are generally dull.

Chemical characteristics and general application conditions

From a chemical point of view, vat dyes can be distinguished into two groups: indigoid vat dyes and anthraquinoid dyes. Indigo dyes are almost exclusively used for dyeing warp yarn in the production of blue denim.

Like sulphur dyes, vat dyes are normally insoluble in water, but they become water-soluble and substantive for the fibre after reduction in alkaline conditions (vatting). They are then converted again to the original insoluble form by oxidation and in this way they remain fixed into the fibre.
Vat dyes are preparations that basically consist of a vattable coloured pigment and a dispersing agent (mainly formaldehyde condensation products and ligninsulphonates). They are generally supplied in powder, granules and paste form.

A wide range of different techniques are used in colouring processes with vat dyes. Nevertheless, all processes involve three steps:

- vatting
- oxidation

The step in which the reduction of the dyestuff into its leuco-form takes place is called vatting. Vat dyes are generally more difficult to reduce than sulphur dyes. Various reducing agents are used. Sodium dithionite (hydrosulphite) is still the most widely employed although it has some limits. Sodium dithionite is consumed by reduction of the dye and also by reaction with atmospheric oxygen, therefore an excess of reducing agent has to be used and various techniques have been proposed to reduce these losses (see also Section 4.5.2.1). In addition sodium dithionite cannot be used for high temperature or pad-steam dyeing processes because...
over-reduction can occur with sensitive dyes. In these application conditions and also for printing, sulphoxylic acid derivatives are normally preferred. Thiourea dioxide is also sometimes used as a reducing agent, but a risk of over-reduction exists as its reduction potential is much higher than that of hydrosulphite. Furthermore the oxidation products of thiourea dioxide contribute to nitrogen and sulphur contamination of waste water.

Following increasing environmental pressures, biodegradable sulphur-free organic reducing agents such as hydroxyacetone are now available. Their reducing effect, however, is weaker than that of hydrosulphite, so they cannot replace it in all applications. Nevertheless hydroxyacetone can be used in combination with hydrosulphite, thus reducing to a certain extent the sulphite load in the effluent.

After absorption by the fibre, the dye in its soluble leuco-form is converted to the original pigment by oxidation. This process is carried out in the course of wet treatment (washing) by addition of oxidants such as hydrogen peroxide, perborate or 3-nitrobenzenesulphonic acid to the liquor.

The final step consists in after-treating the material in weakly alkaline liquor with a detergent at boiling temperature. This soap treatment is not only aimed at removing pigment particles, but also allows the crystallisation of amorphous dye particles, which gives the material the final shade and the fastness properties typical of vat dyes.

Vat dyeing conditions can vary widely in terms of temperature and the amount of salt and alkali required, depending on the nature of the dye applied. Vat dyes are therefore divided into the following groups, according to their affinity for the fibre and the amount of alkali required for dyeing:

- **IK dyes** (I = Indanthren, K = cold) have low affinity, they are dyed at 20 – 30 °C and require little alkali and salt to increase dye absorption
- **IW dyes** (W = warm) have higher affinity, they are dyed at 40 – 45 °C with more alkali and little or no salt
- **IN dyes** (N = normal) are highly substantive and applied at 60 °C and require much alkali, but no addition of salt.

The following chemicals and auxiliaries may be found in dyeing processes:

- sodium dithionite, thiourea dioxide and sulphoxilic acid derivatives as reducing agents
- caustic soda
- sodium sulphate
- polycrylates and alginates as anti-migration agents in padding processes
- formaldehyde condensation products with naphthalenesulphonic acid and ligninsulphonates as dispersing agents
- surfactants (including ethoxylated fatty amines) and other components such as betaines, polyalkylenamines, polyvinylpyrrolidone as levelling agents
- hydrogen peroxide, perborate, 3-nitrobenzenesulphonic acid as oxidants
- soap.

The following chemicals and auxiliaries may be found in printing processes:

- thickening agents (starch esters with seed flour derivatives)
- reducing agents: various chemicals are used depending on the printing method (all-in or two-phase process), dye selected and steaming conditions. Sulphoxylic acid derivatives are the most common, but hydrosulphite can also be used (in the two-phase process when very short steaming time is required)
- alkali: potassium carbonate, sodium carbonate, sodium hydroxide
- oxidising agents (the same used for dyeing)
- soap.
Environmental issues

The environmental properties of vat dyes are assessed under the following parameters. Note, however, that Table 9.11 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

Table 9.11: Overview of the ecological properties of vat dyes

<table>
<thead>
<tr>
<th>Parameters of concern</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-eliminability</td>
<td>Vat dyes can be regarded as highly eliminable due to the fact that they are water-insoluble and therefore largely adsorbed on the activated sludge in the waste water treatment plant.</td>
</tr>
<tr>
<td>Organic halogens (AOX)</td>
<td></td>
</tr>
<tr>
<td>Eco-toxicity</td>
<td>Since they are sparingly soluble they are not bio-available [64, BASF, 1994]</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Vat dyes contain heavy metal impurities (Cu, Fe, Mn, Ba and Pb) due to their production process (in some cases it is still difficult to keep these limits below the ETAD standards) [64, BASF, 1994]</td>
</tr>
<tr>
<td>Aromatic amines</td>
<td></td>
</tr>
<tr>
<td>Unfixed colourant</td>
<td>Vat dyes show high exhaustion levels (70 - 95 % in continuous dyeing processes and 70 - 80 % in printing)</td>
</tr>
<tr>
<td>Effluent contamination by additives in the dye formulation</td>
<td>Dispersants are present in the dye formulation. As they are water-soluble and poorly degradable, they are found in the waste water. New formaldehyde condensation products with higher elimination (&gt;70 %) are already available and more readily eliminable substitutes are being developed [186, Ullmann's, 2000] (see Section 4.5.1.1)</td>
</tr>
</tbody>
</table>
9.11 Pigments

Pigments are widely used in printing processes (pigment printing).

Pigments are insoluble in water and organic solvents. Organic pigments are for a large part derived from benzoids. Inorganic pigments are derivatives of metals such as titanium, zinc, barium, lead, iron, molybdenum, antimony, zirconium, calcium, aluminium, magnesium, cadmium or chromium.
ANNEX III WET PROCESSES: MACHINERY AND TECHNIQUES

10.1 Loose fibre

10.1.1 Autoclave

Various types of machines are used for processing fibres in loose form. These include conical pan machines, pear-shaped machines and radial flow machines. They are used for all wet operations, that is, pretreatment, dyeing, application of finishing agents and washing.

In conical pan machines (Figure 10.1) the fibre is packed into a removable fibre carrier, which is located onto a central spigot in the base of the vessel. Liquor circulation is provided, via this connection, by an external pump. Associated pipework allows liquor to be circulated either from the base of the pack or from the top.

Pear-shapes machines have a removable perforated base plate through which liquor is circulated via an impeller, returning to the dyeing vessel via a weir. Fibre is loaded directly into these machines and a further perforated plate is positioned on top. Liquor circulation packs the fibre into the base of the machine between the two plates. To unload the machine both plates are removed by crane and the fibre manually removed.

Radial flow machines are characterised by a fibre carrier, equipped with a central perforated column from which liquor flows across the pack to the perforated walls of the carrier.

Loose fibre is typically packed into these machines manually. Capacity varies between 200 - 300 kg, with a working volume equivalent to between 7 and 10 litres per kg fibre. The low packing density in these machines allows liquor to circulate freely through the fibre pack at modest pressures, thus minimising mechanical damage to the fibre while ensuring level dyeing.

The bath is heated by closed steam coils in the base of the machine. In many cases the level of automation on these machines is low and temperature may be controlled manually with a simple steam valve. In other cases electro/pneumatic programmers or logic controllers may be installed to regulate time / temperature and to control the direction of liquor circulation.

Autoclaves can be equipped for operation at higher pressure (this is not the case when they are used for dyeing wool fibres).

Autoclaves of all designs may be fitted with an external holding tank, capable of accommodating at least the volume of the dyeing vessel. Such tanks are used to facilitate reuse of liquors in more than one dyeing. Occasionally more than one dyeing vessel may be connected to a common tank, allowing liquor to be shared between vessels.

The liquor ratio for loose fibre can vary between 1:4 to 1:12, depending on the type of machine, level of loading, type of fibre, etc. [32, ENco, 2001]
Figure 10.1: Schematic layout of a conical pan loose fibre dyeing machine

Source: [32, ENco, 2001]
10.2 Yarn

Yarn can be processed either in hank form or in package. Different machines are used depending on the method chosen. They are used for all wet operations, that is, pretreatment, dyeing, application of finishing agents and washing.

10.2.1 Hank dyeing machines

Hank dyeing machines are mostly of the single stick (Hussong) design, in which hanks are hung from the underside of the dyeing vessel lid on removable sticks. (Figure 10.2) The lid is lowered vertically onto the dyeing vessel, which consists of a simple box with a perforated false bottom. Liquor is circulated by a reversible impeller, located vertically in a weir chamber at one end of the machine. Heating is typically by closed steam coils beneath the false bottom and on smaller machines by live steam injection. Temperature control is provided by electro-mechanical or programmable logic controllers. These devices may also control/time the timing of chemical and dye additions and any required cooling cycles. Machine capacities vary from 10 kg sample machines to 1000 kg machines. These larger machines may be coupled together in pairs with interconnecting pipework in such a way that yarn loads of up to 4000 kg can be dyed while still retaining the flexibility to dye individual 1000 kg lots.

Variations of this design may utilise a horizontal circulation impeller passing through a sealing gland at the base of the weir chamber. Such machines invariably have a concave bottom, which is said to improve circulation and reduce fibre to liquor ratio by a small margin. [32, ENco, 2001]

Liquor ratios from 1:15 to 1:25 are typical for these machines.

Figure 10.2: Schematic diagram of a Hussong type hank dying machine

10.2.2 Package dyeing machines

Three basic types of machine may be used for package dyeing wool yarns: horizontal or vertical spindle machines or tube type machines.
Annexes

**Horizontal spindle machines** may be rectangular in design, similar to hank dyeing machines, but modified to take frames, onto which yarn packages are inserted horizontally, or alternatively may be a horizontal autoclave into which is wheeled the carrier containing the yarn packages. Both types operate with high flow rate pumps, which are necessary to give good circulation of the dye liquor. These machines are usually used for bulky yarns, which are wound onto soft packages, again to increase dye liquor penetration.

**Vertical spindle machines** are the most commonly used (see Figure 10.3). The packages may be press packed onto vertical carrier spindles to increase payload, assist in dye liquor circulation and minimise liquor to fibre ratio.

**Tube type machines** consist of a number of vertical or horizontal tubes into which package carriers are inserted, the tubes forming individual dyeing vessels linked by common pipework and circulation pumps. These machines are more flexible than the above types because individual tubes can be blanked off to vary the overall load capacity of the machine.

Liquor ratios employed in package dyeing are close to 1:12 (typically from 1:8 to 1:15). Machines with capacities of up to 500 kg are used in dyeing carpet yarns, with the facility to link two or more machine together when dyeing larger single batches. [32, ENco, 2001]

![Figure 10.3: Schematic layout of a package dyeing machine](image)

*Source:* [186, Ullmann's, 2000]
10.3 Fabric in rope form

Wet treatments on fabrics in rope form can be carried out both in batch and in continuous processes.

10.3.1 Batch processes

10.3.1.1 Winch beck

The common element in all winch beck machines is the winch mechanism used to move the fabric. The winch draws the fabric via a guide roller out of the bath and returns it in folds into the bath. In the conventional winch beck (see Figure 10.4), the bath stands still, while the fabric is kept in circulation by a reel positioned in the upper part of the machine. In modern winches both the bath and the fabric are kept in circulation, which improves homogenisation and exchange of the liquor with the fabric.

Greige goods are loaded into the winch either in rope form or in open width, which means that the winches must be 5 - 6 meters in width. The ends of the fabric piece to be dyed are sewn together to form endless loops over the rotating boom (winch).

Winch becks are primarily machines for dyeing, but for practical reasons both preparation and dyeing are normally carried out in the same machine.

These machines are essentially operated at atmospheric pressure although the development of synthetic fibres has led to the production of pressurised machines (HT machines may reach 130 – 140 °C).

Winch beck is a very versatile machine and it can be used for all types of fabric. It is a very common technique for dyeing carpets (they are usually dyed in full width).

Typical bath ratios vary from 1:15 to 1:40 (typically 1:30 in the carpet sector) [171, GuT, 2001], which makes this technique fairly expensive due to high water and energy consumption. However, recent technological developments have been made to improve its environmental performance (see Section 4.5.1.6.1)

![Source: [186, Ullmann's, 2000]](image)

Figure 10.4: Schematic representation of a winch beck dyeing machine

10.3.1.2 Jet
Annexes

Jet machines (see Figure 10.5) have been designed with the aim of eliminating some of the problems associated with the use of winch machines.

The reel is eliminated and the fabric is placed in a closed tubular system. A jet of dye liquor is supplied through a venturi to transport the fabric through the tube. Turbulence created by the jet aids in dye penetration and prevents the fabric from touching the walls of the tube.

Since the fabric is frequently exposed to high liquor concentrations within the transport tube, relatively little dye bath is needed in the bottom of the vessel: just enough to ensure smooth movement from rear to front. Advantages of this machine are therefore low consumption of water and short treatment time (e.g. short dyeing time). Typical liquor ratios vary between 1:4 and 1:20, ranging from 1:4 to 1:10 for fabric and from 1:6 to 1:20 for carpet (lower values apply to synthetic fibres while higher values are typical for cotton) [171, GuT, 2001].

Jets can usually be operated at high temperatures, which makes them very suitable for dyeing polyester fibres. A disadvantage, however, is the high mechanical stress on the textile, caused by the speed difference between the bath and the fabric. For this reason jets are not suitable for some delicate fabrics.

Depending on the shape of the fabric storage area (long shape machine or J-box compact machine), the type of nozzle and its position (above or below the level of the bath) various types of jets exist. Overflow, soft-flow and airflow dyeing machines can be regarded as developments of the conventional jet. The main features of these machines are reported in the following sections, while the latest developments in this dyeing technology are further described in Section 4.5.1.6.1.

Source: [186, Ullmann's, 2000]

Figure 10.5: Schematic representation of a jet dyeing machine

10.3.1.3 Overflow
Overflows (see Figure 10.6) have been designed for delicate knitted and woven fabrics made of natural and synthetic fibres. They are also found in the carpet sector.

The main difference between jet and overflows machines remains in the fact that in jet machines the fabric is transported by the bath flowing at high speed through the nozzle, while with overflows the fabric is transported by the gravitational force of the liquor overflow.

A winch (usually not motor driven) is located in the upper part of the machine and the fabric hangs over it. A longer length of textile hangs from the exit side of the winch than from the inlet side. Gravitational forces pull the longer length of textile downward more strongly than the shorter. The fabric is therefore soaked in the bath without any tension (transportation is very gentle).

Different designs are available on the market and some of them can operate under pressure and consequently at higher temperatures.

Typical liquor ratios for overflows range between 1:12 and 1:20.

![Figure 10.6: Schematic representation of an overflow dyeing machine](image)

Source: [69, Corbani, 1994]

10.3.1.4 Soft-flow

The so-called "soft-flow" machines use the same transport tube principle as overflow machines where the fabric is transported in a stream of dye liquor. However, while in overflow machines the reel is not motor driven, in soft-flow equipment the reel and the jet work in constant harmony to remove the fabric from the front of the storage area, expose it briefly to a high concentration of liquor within the transport tube, then return it to the rear of the vessel. The soft-flow machines are more gentle on the fabric than conventional jet overflow machines.

10.3.1.5 Airflow

The difference between air jet (see Figure 10.7) and jet machines is that in the former an air jet instead of a water jet keeps the fabric in circulation. The fabric passes into the storage area which contains a very small amount of free liquor. As a result, a reduction in water, energy and chemicals consumption can be achieved.

Because of the short liquor ratios achievable (from 1:2 to 1:5) the dye must be highly water-soluble.
10.3.2 Continuous processes

Machines for treatment in continuous processes of fabrics in rope form are essentially composed of the following parts:

- a padding device for impregnating the fabric in rope form
- a storage area for the fixation of the chemicals applied
- a washing machine for fabric in rope form.

The padding device is composed of a long basin equipped with two or three rotating rollers at the inlet and another two at the outlet. The basin contains a concentrated solution of the chemicals and auxiliaries that have to be applied (desizing agents, bleaching agents, etc.). The fabric is pressed by the rotating rollers at the inlet in order to obtain a homogeneous absorption of the chemicals and the elimination of air. The other two rollers only squeeze the fabric. After squeezing, the fabric retains only a relatively low amount of bath. As a result high concentrations of the chemicals are needed, moreover the solutions must be adequately stabilised to avoid unwanted oxidation reactions, etc.

The storage area (also called reaction chamber) can have different shapes: one typical model is the J-Box. The J-Box is filled to 1/3 of its capacity with the treatment bath.

The main advantage of this technique is the high production capacity. On the other hand there is the risk of longitudinal creases, which can negatively affect the dyeing process. As a result this technique is mainly applied for white end-products for pretreatment operations (e.g. bleaching).
Figure 10.8: Example of continuous process for knitted fabric in rope form

Source: [69, Corbani, 1994]
10.4 Fabric in open-width

10.4.1 Batch processes

10.4.1.1 Beam

The fabric is wound in open-width on a perforated cylinder called a beam (see Figure 10.9). The fabric is stationary and the bath is pumped through the beam. The direction of the flow is normally from the inside to the outside of the roll of textile.

The ends of the beam are covered with metal sheets before the fabric is wound on, to prevent a short circuit of the liquor.

Beams can operate both under pressure and at atmospheric pressure.

These machines are suitable for pretreatment operations like scouring and bleaching and also for dyeing of lightweight, wide and delicate goods. One disadvantage is represented by the risk of non-homogeneous penetration of chemicals and auxiliaries used for the treatment.

![Schematic representation of a beam dyeing machine](image)

Source: [18, VITO, 1998]

Figure 10.9: Schematic representation of a beam dyeing machine

10.4.1.2 Jigger

A jigger (see Figure 10.10) is composed of a trapezoidal tub containing the bath and two rolls on which the fabric is alternatively wound. In this type of machine the bath is stationary while the fabric is in motion. The fabric, initially wound on the first roll, flows through the bath and then is wound on the other one; the rotation is then reversed and the cycle continues. The fabric is led in its path by a few small guide rollers.

HT jiggers are also produced, allowing treatments at temperatures above 100 ºC. This type of machine is used not only for dyeing, but also for various wet treatments on fabrics in full width.

The main disadvantage of this system is the risk of non-homogeneity between the initial and final part of the roll. This is due to variations in feed speed and tension of the fabric, or temperature and chemicals concentration in the bath during the period of the treatment. However, in modern jiggers tension of the fabric is kept constant during the whole process, thanks to special devices.
10.4.2 Semi-continuous and continuous processes

Some of the most widely used continuous and semi-continuous processes are:

- pad-batch
- pad-roll
- pad-jig
- pad-steam
- pad-dry
- thermosol.

They are briefly described in the following sections.

Typical treatment steps in both semi-continuous and continuous processes are:

- application of the dye or finishing agent either by impregnation (using a padding device) or by means of other types of application systems (see Figure 10.12)
- storage/fixation, which can be carried out in different ways depending on the process applied (e.g. dry heat, steam)
- washing in continuous mode in open width.

Padding machines (foulards) are used to apply dyestuffs or other chemicals onto the fabric in open-width form. The fabric passes through the pad trough where it picks up the liquor. After leaving the pad trough, the fabric is squeezed between rubber rolls. The amount of liquor picked up depends mainly on the pressure produced by the two rolls, the speed at which the fabric is transported and the type of substrate. The level in the trough is automatically maintained to compensate for liquor picked up by the fabric. The liquor is kept in circulation to avoid differences in temperature and/or concentration.

Different designs of foulards exist: some examples are shown in Figure 10.11.
Padding is the most common application technique in textile finishing, but other application systems (see figure below) are more common in the carpet industry. Due to their higher ecological performance, some of them are increasingly used in the textile finishing sector.

Figure 10.11: Foulard types
10.4.2.1 Pad-batch process (semi-continuous)

This process includes an impregnation step on a padding machine.

After being squeezed, the fabric is wound onto a roll and stored at room temperature. The roll is kept in slow rotation until the desired chemical processes (e.g. fixation of the dyestuffs, etc.) are complete. At the end the fabric is washed in an open-width washing machine.

This process is commonly used for pretreatment (e.g. desizing) and dyeing (mainly with direct and reactive dyes). It is characterised by low water and energy consumption (about 50 – 80 % less than conventional systems) and good repeatability.

Figure 10.12: Illustration of some of the most important dye/finish applicators

Source: [211, Kuster, 2001]
10.4.2.2 Pad-roll process (semi-continuous)

This process is similar to pad-batch, but in this case the fabric, after padding, passes through an infrared oven. It is then rolled and kept in slow rotation in a hot steam chamber until fixation, or other chemical processes are complete. The fabric is then washed in an open-width washing machine.

10.4.2.3 Pad-jig process (semi-continuous)

This process is generally used as a dyeing technique, mainly used for heavy weight fabrics with direct and reactive dyes.

In this process the fabric passes through a padding machine where it is impregnated with the dye bath, then the dyestuff is fixed on a jigger.

Sometimes the fabric can be dried in a hot-flue drier after padding, before entering the jigger.

The application of the dyestuff by padding allows for homogeneous dyeing and time saving when compared to traditional jigger dyeing processes.

10.4.2.4 Pad-steam process (continuous)

This technique is mainly used for scouring woven fabric and dyeing. It is particularly suitable for the application of direct, vat, sulphur and reactive dyestuffs.

It includes the following steps:
- impregnation by padding
- steaming (at about 100 °C)
- additional impregnation of the fabric with developing agents (e.g. reducing agents in vat or sulphur dyeing)
- washing and rinsing.

Figure 10.13: Schematic layout of a pad-batch plant

Source: [69, Corbani, 1994]
10.4.2.5 Pad-dry process (continuous)

This process includes the following steps:
- impregnation by padding
- intermediate drying (optional)
- fixation in hot-flue
- washing.

10.4.2.6 Thermosol process (continuous)

This process is specific for dyeing with disperse dyestuffs polyester or cotton/polyester blends.

The process includes the following steps:
- impregnation in the dyeing liquor
- pre-drying in an infrared oven
- drying in hot-flue
- passage through a stenter frame for thermal fixation at 200 °C of the disperse dyes to the PES.

An alkaline reductive after-treatment is then carried out or, in the case of cotton/polyester blends, the second dye is developed according to the procedure typical of its class, using in general pad-steam, pad-jig or pad-batch processes.
11 ANNEX IV: TYPICAL RECIPES (WITH SOME ASSOCIATED EMISSION FACTOR) IN THE TEXTILE SECTOR

The following information is based on [179, UBA, 2001] with reference to:
[7, UBA, 1994]
Schönberger, H.; Kaps, U.
Reduktion der Abwasserbelastung in der Textilindustrie
UBA-Texte 3/94 (1994)

11.1 Pretreatment

11.1.1 Cotton and cotton blends

WOVEN FABRIC

Enzymatic desizing

Table 11.1: Standard recipe for enzymatic desizing of woven fabric consisting of CO and CO blends

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enzyme</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Complexing agent</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Surfactant</td>
<td>1 - 8</td>
<td>For discontinuous processes, e.g. desizing in a winch with liquor ratio of 1:20, up to 30 g Telquel/kg textile substrate are applied</td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>4 - 6</td>
<td></td>
</tr>
</tbody>
</table>

Removal of water-insoluble sizing agents by cold oxidative desizing

It is a semi-continuous process. The liquor for oxidative desizing is added at room temperature in a padder with a pick-up of 70 – 80%. Reaction takes place with a retention time of 16 - 24 h (max. 72 h). The fabric is then thoroughly rinsed.
Table 11.2 Standard recipe for the desizing of woven fabric consisting of CO and CO blends sized with water-insoluble sizing agents

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuous and optimised process</td>
<td>Discontinuou s process</td>
</tr>
<tr>
<td>NaOH (100 %)</td>
<td>10 - 20</td>
<td>Usually applied as 33 % or 50 % solution</td>
</tr>
<tr>
<td>H₂O₂ (100 %)</td>
<td>15 - 25</td>
<td>Usually applied as 33 % or 50 % solution</td>
</tr>
<tr>
<td>Surfactants</td>
<td>1.5 - 3</td>
<td>As surfactants a mixture of non-ionic (about 70 % average, e.g. ethoxylated fatty alcohol) and anionic surfactants (about 30 %, especially alkyl sulphonates but also alkyl sulphates and linear alkylbenzene-sulphonates) are applied</td>
</tr>
<tr>
<td>Complexing agents</td>
<td>2 - 4</td>
<td>As complexing agents polyacrylates and phosphonates are applied but not EDTA or DTPA</td>
</tr>
<tr>
<td>MgSO₄(100 %)</td>
<td>0.15 - 0.3</td>
<td>Usually applied as 40 % solution</td>
</tr>
<tr>
<td>Water glass (100 %)</td>
<td>5 - 8</td>
<td>Usually applied as 40 % solution</td>
</tr>
<tr>
<td>Na-peroxodisulphate (100 %)</td>
<td>3 - 6</td>
<td>Usually applied as 20 % solution</td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>4 – 6 or 8 - 12</td>
<td>4 - 6 l/kg in case of multi-usage of water or high efficient washing compartments; otherwise 8 - 12 l/kg</td>
</tr>
</tbody>
</table>
### Annexes

#### Removal of water-soluble sizing agents

Table 11.3: Standard recipe for the desizing of woven fabric consisting of CO and CO blends sized with water-soluble sizing agents

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuous and optimised process</td>
<td>Discontinuous process</td>
</tr>
<tr>
<td>Complexing agent</td>
<td>1</td>
<td>3 – 15</td>
</tr>
<tr>
<td>Surfactant</td>
<td>1 – 3</td>
<td>4 – 20</td>
</tr>
<tr>
<td>Soda or NaOH (100 %)</td>
<td>0 – 3</td>
<td>0 – 3</td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>4 – 6 or 8 – 12</td>
<td>4 – 6 l/kg for multi-usage of water otherwise 8 - 12 l/kg; in continuous processes washing water from bleaching and/or scouring is used for desizing</td>
</tr>
</tbody>
</table>
## Scouring

**Table 11.4: Standard recipe for scouring of woven fabric consisting of CO and CO blends**

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Continuous and optimised process</th>
<th>Discontinuous process</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOH (100 %)</td>
<td>20 – 80</td>
<td>20 - 80</td>
<td>The quantity depends both on the percentage of cotton in blends and on the applied processes.</td>
</tr>
<tr>
<td>Complexing agents</td>
<td>1 – 6</td>
<td>3 - 30</td>
<td>Some suppliers for complexing agents do not recommend more than 2 g/kg for continuous processes. The application of complexing agents is necessary to extract calcium. For this purpose NTA is not efficient enough. Normally a mixture of different complexing agents such as phosphonates, gluconates, polyphosphates, NTA, polyacrylates (in some cases are still in use EDTA and DTPA). The use of complexing agents can be reduced significantly if an acidic treatment is carried out prior to scouring (in Germany this possibility is very seldom practised). In some cases combinations of complexing agents and reducing agents are used.</td>
</tr>
<tr>
<td>Surfactant</td>
<td>5 - 6</td>
<td>5 - 30</td>
<td>Some suppliers recommend 2 – 4 g/kg for continuous processes. The composition concerns the one which is given for desizing of water-soluble sizing agents (see Table 3)</td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>8 - 10</td>
<td>ca. 50</td>
<td>Rinsing is included for continuous processes the consumption can be lower if water-recycling is practised.</td>
</tr>
</tbody>
</table>
### Bleaching

Table 11.5: Standard recipe for bleaching of woven fabric consisting of CO and CO blends

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuous and optimised process</td>
<td>Discontinuous process</td>
</tr>
<tr>
<td>H₂O₂ (100 %)</td>
<td>5 - 15</td>
<td>5 – 15</td>
</tr>
<tr>
<td></td>
<td>Stabilised by phosphoric acid and organic stabilisers</td>
<td></td>
</tr>
<tr>
<td>NaOH (100 %)</td>
<td>4 – 10</td>
<td>4 – 30</td>
</tr>
<tr>
<td></td>
<td>At the beginning of the bleaching process the phosphoric acid is neutralised and loses its stabilising effect</td>
<td></td>
</tr>
<tr>
<td>Complexing agents (1)</td>
<td>0 - 2</td>
<td>0 – 2</td>
</tr>
<tr>
<td></td>
<td>For complexing calcium and heavy metal ions the same compounds are used as for scouring; magnesium may not be complexed because it is needed for the stabilisation of H₂O₂</td>
<td></td>
</tr>
<tr>
<td>Organic stabiliser (1)</td>
<td>0 - 10</td>
<td>0 – 20</td>
</tr>
<tr>
<td></td>
<td>For the stabilisation of H₂O₂, many products are available which contain complexing agents for calcium and heavy metal ions, such as gluconate, NTA/EDTA/DTPA, polyacrylates and phosphonates; in Germany DTPA is no longer applied and EDTA only to a minor extent</td>
<td></td>
</tr>
<tr>
<td>Surfactant</td>
<td>2 - 5</td>
<td>2 – 10</td>
</tr>
<tr>
<td></td>
<td>The same compounds are applied as for desizing and scouring (see Tables 3 and 4)</td>
<td></td>
</tr>
<tr>
<td>Sodium silicate (1)</td>
<td>8 - 20</td>
<td>60 – 230</td>
</tr>
<tr>
<td></td>
<td>Sodium silicate acts as pH buffer, alkali supplier, anti-catalyse and stabiliser</td>
<td></td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>6 - 12</td>
<td>ca. 50</td>
</tr>
<tr>
<td></td>
<td>Rinsing is included</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1) The consumption of complexing agents, organic and inorganic (silicate) stabilisers vary in total from 0 – 20g/kg. As for scouring, the consumption can be significantly reduced by acidic pretreatment.</td>
<td></td>
</tr>
</tbody>
</table>

### Mercerisation

Table 11.6: Standard recipe for mercerisation of woven fabric consisting of CO and CO blends

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOH (100 %)</td>
<td>200 - 300</td>
<td></td>
</tr>
<tr>
<td>Wetting agent</td>
<td>0 - 10</td>
<td>A wetting agent is only applied in case of dry-in-wet-mercerisation (raw mercerisation). They consist of short chain anionic compounds such as alkylsulphates</td>
</tr>
<tr>
<td>Complexing agent</td>
<td>2</td>
<td>Only for raw mercerisation. The same chemicals are used as for scouring (see Table 4)</td>
</tr>
</tbody>
</table>

### Alkali treatment

Table 11.7: Standard recipe for alkali treatment of woven fabric consisting of CO and CO blends

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>KOH (100 %) or NaOH (100 %)</td>
<td>200 – 300</td>
<td>60 - 230</td>
</tr>
<tr>
<td>Sandoflex A</td>
<td>60 – 80 ml</td>
<td></td>
</tr>
<tr>
<td>Wetting agent</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
KNIT FABRIC

Pretreatment of knitted fabric does not need desizing because sizing agents are not present.

“Light scouring” is applied if bleaching is not needed; i.e. it is applied for fabric to be dyed in dark shades (black, brown, dark marine or turquoise etc.). “Light scouring” is also called “alkali pre-washing”; a precise definition is not available.

Usually bleaching is only applied for full bleach qualities which are not dyed subsequently or which are dyed in light and medium shades. However, because of logistics some mills bleach all kind of qualities. In the case of continuous processes bleaching is usually performed in a single stage. There are exceptional cases in which the combined bleaching process with peracetic acid/hydrogen peroxide/optical brightener is applied.

In many cases so-called combination bleaching, consisting of a two-stage bleaching with sodium hypochlorite and hydrogen peroxide has been replaced by two-stage hydrogen peroxide bleaching and one-stage bleaching with reducing agents. An acidic pretreatment, which requires a lower dosage of complexing agents in the subsequent bleaching stage is usually carried out in one-stage, similarly to woven cotton fabric or cotton blends.

The consumption of chemicals for pretreatment of knitted fabric is similar to that for woven fabric.

Neutral/acetic demineralisation

Table 11.8: Standard recipe for neutral/acidic demineralisation of knitted fabric consisting of CO and CO blends

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganic or organic acid</td>
<td>0 - 2</td>
<td></td>
</tr>
<tr>
<td>Complexing agents</td>
<td>1 - 3</td>
<td>The same chemicals are applied as for scouring of woven fabric (see Table 4)</td>
</tr>
<tr>
<td>Surfactant</td>
<td>1 - 3</td>
<td>The same chemicals are applied as for desizing of water-soluble sizing agents (see Table 3)</td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>

“Light scouring” process (alkali pre-wash)

Table 11.9: Standard recipe for “light scouring” of knitted fabric consisting of CO and CO blends

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soda or NaOH (as 100 %)</td>
<td>ca. 50</td>
<td>There is a wide range of alkali quantities applied</td>
</tr>
<tr>
<td>Surfactant</td>
<td>1 - 3</td>
<td></td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>
Annexes

Bleaching with hypochlorite

Table 11.10: Standard recipe for bleaching with hypochlorite of knitted fabric consisting of CO and CO blends

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Continuous and optimised process</th>
<th>Discontinuous process</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOCl (as active chlorine)</td>
<td>5 – 6</td>
<td>ca. 30</td>
<td></td>
</tr>
<tr>
<td>NaOH (100 %)</td>
<td>1 – 3</td>
<td>5 - 15</td>
<td></td>
</tr>
<tr>
<td>Surfactant</td>
<td>2 – 5</td>
<td>2 - 10</td>
<td></td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>n.d.</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>

Bleaching with hydrogen peroxide

Table 11.11: Standard recipe for bleaching with hydrogen peroxide of knitted fabric consisting of CO and CO Blends

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Continuous and optimised process</th>
<th>Discontinuous process</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O₂ (100 %)</td>
<td>5 - 15</td>
<td>5 – 15</td>
<td></td>
</tr>
<tr>
<td>NaOH (100 %)</td>
<td>4 – 10</td>
<td>4 - 30</td>
<td>Usually the lower dosage is applied because for knitted fabric seed shells are already removed to a high extent</td>
</tr>
<tr>
<td>Complexing agents</td>
<td>0 - 2</td>
<td>0 - 2</td>
<td>See Table 5</td>
</tr>
<tr>
<td>Organic stabiliser</td>
<td>0 – 10</td>
<td>0 - 20</td>
<td>See Table 5</td>
</tr>
<tr>
<td>Surfactant</td>
<td>2 – 5</td>
<td>2 - 10</td>
<td>See Table 5</td>
</tr>
<tr>
<td>Sodium silicate</td>
<td>8 – 20</td>
<td>0 - 20</td>
<td>See Table 5</td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>n.d.</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>

11.1.2 Viscose

WOVEN FABRIC

Usually viscose is treated with alkali. Only exceptionally is subsequent bleaching with hydrogen peroxide carried out. Thereby the applied quantities of chemicals are lower than for cotton because viscose does not contain natural by-products which need to be removed.

Alkali treatment

Table 11.12: Standard recipe for alkali treatment of woven fabric consisting of viscose

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOH (100 %)</td>
<td>40 – 60</td>
<td>Normally strength of applied caustic soda lye is 6°Bé</td>
</tr>
<tr>
<td>Surfactant</td>
<td>3 – 20</td>
<td></td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>
Scouring

Table 11.13: Standard recipe for scouring of woven fabric consisting of viscose

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOH (100 %)</td>
<td>ca. 30</td>
<td>When the scouring process is applied as a single stage</td>
</tr>
<tr>
<td>Surfactant</td>
<td>3 - 20</td>
<td></td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>ca. 10</td>
<td></td>
</tr>
</tbody>
</table>

KNITTED FABRIC

Knitted fabric consisting of viscose is not a common product. The standard recipe for bleaching concerns cotton. However the dosage of caustic soda and hydrogen peroxide is reduced to 40 - 70 %.

11.1.3 Man-made fibres (woven and knitted fabric)

Woven fabric and knitted fabric consisting of man-made fibres are usually washed in order to remove sizing agents and preparation agents which are normally water-soluble. Scouring is not carried out. The application of bleaching of PES and PAN with chlorite is no longer common.

STANDARD RECIPES FOR WASHING (CONTINUOUS AND DISCONTINUOUS PROCESSES)

Woven fabric

Table 11.14: Standard recipe for washing of woven fabric consisting of man-made fibres

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkali</td>
<td>0 – 2</td>
<td>For pH-adjustment depending on the kind of sizing agents; normally NaOH, soda or ammonia hydroxide are used, seldom sodium phosphate</td>
</tr>
<tr>
<td>Complexing agents</td>
<td>0.5 – 15</td>
<td></td>
</tr>
<tr>
<td>Surfactant</td>
<td>0.5 – 30</td>
<td></td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>4 – 8</td>
<td>In case of micro fibres up to 60 l/kg</td>
</tr>
</tbody>
</table>

Knitted fabric

Table 11.15: Standard recipe for washing of knitted fabric consisting of man-made fibres

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexing agents</td>
<td>0 – 10</td>
<td>Polyacrylates are predominantly applied, less often polyphosphates</td>
</tr>
<tr>
<td>Surfactant</td>
<td>2 – 20</td>
<td></td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>
BLEACHING

Reductive bleaching of polyamide

Table 11.16: Standard recipe for reductive bleaching and optical brightening of polyamide

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium dithionite containing formulation</td>
<td>10 – 30</td>
<td></td>
</tr>
<tr>
<td>Optical brightener</td>
<td>5 – 15</td>
<td></td>
</tr>
<tr>
<td>Surfactant</td>
<td>1 – 2</td>
<td></td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>

Bleaching of PES or PAN with sodium chlorite

Table 11.17: Standard recipe for the bleaching of PES and PAN with sodium chlorite

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaClO₂ (100 %)</td>
<td>5 – 15</td>
<td></td>
</tr>
<tr>
<td>Formic acid pH 2.5 – 3.5 or oxalic acid pH 2.5</td>
<td>n.d.</td>
<td>Additionally contains buffer salts and stabilisers</td>
</tr>
<tr>
<td>Corrosion inhibitor (Chemistry = ?)</td>
<td>10 – 20</td>
<td></td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>

11.1.4 Wool

Raw wool scouring

Table 11.18: Standard recipe for the raw wool scouring

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soda</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>Surfactant</td>
<td>n.d.</td>
<td>Non-ionic types</td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>ca. 4</td>
<td>For optimised continuous process</td>
</tr>
</tbody>
</table>

Carbonising

Table 11.19: Standard recipe for wool carbonising

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂SO₄ (100 %)</td>
<td>35 – 70</td>
<td></td>
</tr>
<tr>
<td>Surfactant</td>
<td>1 - 3</td>
<td></td>
</tr>
<tr>
<td>Water consumption (l/kg textile substrate)</td>
<td>ca. 3</td>
<td>For optimised continuous process</td>
</tr>
</tbody>
</table>
Washing and felting

Table 11.20: Standard recipe for wool washing and felting

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soda or ammonia (100 %)</td>
<td>0 – 5</td>
<td></td>
</tr>
<tr>
<td>Surfactant</td>
<td>3 – 20</td>
<td></td>
</tr>
<tr>
<td>Water consumption</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>

Bleaching

For full bleach qualities, the standard process for wool bleaching is the application of a combination of oxidation (hydrogen peroxide) with subsequent reductive bleaching (3 g/l reducing agent, e.g. stabilised sodium dithionite and 0.5 g/l surfactant). For wool pre-bleaching either hydrogen peroxide or reducing agents can be used. With regard to the standard recipe for wool bleaching it has to be stressed that the dosage of chemicals can vary considerably depending on time and temperature of the process.

Table 11.21: Standard recipe for bleaching of wool

<table>
<thead>
<tr>
<th>Chemical</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O₂ (100 %)</td>
<td>50 - 75</td>
<td>Because of high dosage the process is often carried out on standing bath</td>
</tr>
<tr>
<td>Complexing agents (stabiliser)</td>
<td>5 - 30</td>
<td></td>
</tr>
<tr>
<td>Ammonia (100 %)</td>
<td>0 - 20</td>
<td>pH 8 – 9 with buffer system (usually on base of sodium tripolyphosphate)</td>
</tr>
<tr>
<td>Water consumption</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>

In some cases acidic hydrogen peroxide bleaching is applied. Then an activator instead of a stabiliser is used. After bleaching rinsing takes place and reductive bleaching (40 – 80 g reducing agents/kg wool) at 60 °C for 30 minutes is carried out. Finally optical brighteners can be added.

In general, especially for bleaching of yarn and knitted fabric with hydrogen peroxide, stabilisers based on protein derivates and modified phosphoric esters (lecithin types) are used. These stabilisers also act as dispersing agents. Also fatty acid amides are in use; they do no stabilise the bleaching bath only but also serve as a softening agent.
Hercosett-anti-felt-finishing

Table 11.22: Standard recipe for Hercosett-anti-felt-finishing of wool

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOCl (as active chlorine)</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>H₂SO₄ (100 %)</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>Surfactant</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>Soda</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>Na₂SO₃</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>Polyamide resin</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>Softening agent</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>NaHCO₃</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>Water consumption</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>

Pretreatment for printing

Pretreatment with chlorine-containing substances

Table 11.23: Standard recipe for the pretreatment for printing of wool with chlorine-containing substances

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dichloroisocyanurate</td>
<td>20 - 60</td>
<td></td>
</tr>
<tr>
<td>(1.2 – 3.8 % active chlorine)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formic/acetic/sulphuric acid</td>
<td>10 - 30</td>
<td></td>
</tr>
<tr>
<td>Sodium disulphites or dithionite</td>
<td>20 – 40</td>
<td></td>
</tr>
<tr>
<td>Surfactant</td>
<td>2 – 5</td>
<td></td>
</tr>
<tr>
<td>Polymers (100 %)</td>
<td>10 – 30</td>
<td>Mainly cationic products</td>
</tr>
<tr>
<td>Water consumption</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>

Pretreatment without chlorine-containing substances

Table 11.24: Standard recipe for the pretreatment for printing of wool without chlorine-containing substances

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>(g Telquel/kg textile substrate)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peroxomonosulphates</td>
<td>20 - 60</td>
<td>Mainly cationic but padding with anionic polymers is also common. Cationic and anionic polymers are also applied without pre-oxidation</td>
</tr>
<tr>
<td>Sodium sulphite or dithionite</td>
<td>20 - 60</td>
<td></td>
</tr>
<tr>
<td>Surfactant</td>
<td>2 - 5</td>
<td></td>
</tr>
<tr>
<td>Polymers (100 %)</td>
<td>10 – 30</td>
<td></td>
</tr>
<tr>
<td>Water consumption</td>
<td>n.d.</td>
<td></td>
</tr>
</tbody>
</table>
### 11.2 Dyeing

#### Table 11.25: Typical recipe for padding liquors for cold pad-batch dyeing of cellulosic fibres (CO and CV) with reactive dyestuffs

<table>
<thead>
<tr>
<th>Component</th>
<th>(ml/l)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive dyestuffs</td>
<td>x (g/l)</td>
<td></td>
</tr>
<tr>
<td>NaOH 38°Bé</td>
<td>20 - 40</td>
<td></td>
</tr>
<tr>
<td>Water glass 37/40° Bé</td>
<td>30 - 50</td>
<td>Today, there are recipes available without water glass, using alkali only</td>
</tr>
<tr>
<td>Wetting agent</td>
<td>1 - 2</td>
<td></td>
</tr>
<tr>
<td>Complexing and sequestering agents</td>
<td>1 - 3</td>
<td>Mainly phosphonates and polyacrylates in order to minimise silicate deposits</td>
</tr>
<tr>
<td>Urea (45 %)</td>
<td>about 200 g/l</td>
<td>Applied for reactive dyestuffs with comparatively low water solubility</td>
</tr>
</tbody>
</table>

#### Table 11.26: Typical recipe for padding liquors for the application of sulphur dyestuffs (for dyeing of cellulosics (CO and CV))

<table>
<thead>
<tr>
<th>Component</th>
<th>(g/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur dyestuffs</td>
<td>x</td>
</tr>
<tr>
<td>NaOH 38°Bé</td>
<td>20 - 30</td>
</tr>
<tr>
<td>Anti-foaming agent</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Wetting agent</td>
<td>1.5 - 3</td>
</tr>
<tr>
<td>Reducing agent (liquid)</td>
<td>20 - 30</td>
</tr>
</tbody>
</table>

#### Table 11.27: Typical recipe for padding liquors for the application of vat dyestuffs (for dyeing of cellulosics (CO and CV))

<table>
<thead>
<tr>
<th>Component</th>
<th>(g/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vat dyestuffs</td>
<td>x</td>
</tr>
<tr>
<td>Wetting agent</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Sequestering agents</td>
<td>1 - 3</td>
</tr>
<tr>
<td>Anti-migration agent</td>
<td>10 - 15</td>
</tr>
<tr>
<td>For reduction</td>
<td></td>
</tr>
<tr>
<td>NaOH 38°Bé</td>
<td>60 - 120</td>
</tr>
<tr>
<td>Na-dithionite</td>
<td>60 - 100</td>
</tr>
<tr>
<td>Wetting agent</td>
<td>1 - 2</td>
</tr>
</tbody>
</table>

#### Table 11.28: Typical recipe for padding liquors for the application of vat and disperse dyestuffs (for dyeing of cellulosics/PES blends with one padding liquor)

<table>
<thead>
<tr>
<th>Component</th>
<th>(g/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vat and disperse dyestuffs</td>
<td>x</td>
</tr>
<tr>
<td>Wetting agent</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Sequestering agents</td>
<td>1 - 3</td>
</tr>
<tr>
<td>Anti-migration agent</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Acetic acid (60 %)</td>
<td>0.5 - 1</td>
</tr>
</tbody>
</table>
## 11.3 Printing

### Table 11.29: Typical composition of printing pastes with reactive dyestuffs (COD: ca. 55000 g/kg)

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive dyestuff liquid</td>
<td>7</td>
</tr>
<tr>
<td>Alginate thickener</td>
<td>2</td>
</tr>
<tr>
<td>Ludigol</td>
<td>1</td>
</tr>
<tr>
<td>NaHCO₃</td>
<td>3</td>
</tr>
<tr>
<td>Water</td>
<td>88</td>
</tr>
</tbody>
</table>

### Table 11.30: Typical composition of printing pastes with vat dyestuffs (COD: ca. 160000 g/kg)

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vat dyestuff liquid</td>
<td>4.3</td>
</tr>
<tr>
<td>Thickener</td>
<td>5.0</td>
</tr>
<tr>
<td>Rongalit C</td>
<td>10.6</td>
</tr>
<tr>
<td>K₂CO₃</td>
<td>11</td>
</tr>
<tr>
<td>Urea</td>
<td>2</td>
</tr>
<tr>
<td>Sorbit</td>
<td>5</td>
</tr>
<tr>
<td>De-aerating agent</td>
<td>0.2</td>
</tr>
<tr>
<td>Water</td>
<td>61.9</td>
</tr>
</tbody>
</table>

### Table 11.31: Typical composition of pigment printing pastes (COD: ca. 300000 g/kg)

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pigment dough</td>
<td>4</td>
</tr>
<tr>
<td>Acrylate thickener</td>
<td>3</td>
</tr>
<tr>
<td>Emulsifier</td>
<td>1</td>
</tr>
<tr>
<td>Binder</td>
<td>12</td>
</tr>
<tr>
<td>Cross-linking agent</td>
<td>1</td>
</tr>
<tr>
<td>Softening agent</td>
<td>1</td>
</tr>
<tr>
<td>Water</td>
<td>78</td>
</tr>
</tbody>
</table>

### Table 11.32: Typical composition of printing pastes with disperse dyestuffs

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disperse dyestuff</td>
<td>2.6</td>
</tr>
<tr>
<td>Tamarinds thickener</td>
<td>7.0</td>
</tr>
<tr>
<td>Dispersing agents</td>
<td>0.5</td>
</tr>
<tr>
<td>Monosodium phosphate</td>
<td>2.8</td>
</tr>
<tr>
<td>Water</td>
<td>87.1</td>
</tr>
</tbody>
</table>
11.4 Finishing

Typical recipes for padding liquors in textile finishing are summarised in Table 1, while Table 2 to Table 17 report the substrate emission factors to air for some common auxiliary formulations listed in the “Textile Auxiliaries Buyers’Guide” ([65, TEGEWA, 2000]).

Table 11.33: Typical recipes in textile finishing

<table>
<thead>
<tr>
<th>Effect</th>
<th>Substrate</th>
<th>Process temperature (°C)</th>
<th>Recipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softening</td>
<td>PES/CV/CO</td>
<td>150</td>
<td>Softening agent: 130 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Foaming agent: 15 g/l</td>
</tr>
<tr>
<td>Softening</td>
<td>PES</td>
<td>170</td>
<td>Softening agent: 40 g/l</td>
</tr>
<tr>
<td>Softening</td>
<td>CO/PES</td>
<td>160</td>
<td>Softening agent: 20 g/l</td>
</tr>
<tr>
<td>Softening</td>
<td>PES/WO</td>
<td>130</td>
<td>Softening agent: 5 g/l</td>
</tr>
<tr>
<td>Softening, optical brightener,</td>
<td>PES</td>
<td>185</td>
<td>Softening agent: 5 g/l</td>
</tr>
<tr>
<td>antielectrostatic</td>
<td></td>
<td></td>
<td>Optical brightener: 19 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Antielectrostatic agent: 6 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wetting agent: 2 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Levelling agent: 2 g/l</td>
</tr>
<tr>
<td>Softening, stiffening</td>
<td>CO</td>
<td>120</td>
<td>Starch: 50 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Softening agent 1: 30 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Softening agent 2: 15 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wetting agent: 2 g/l</td>
</tr>
<tr>
<td>Hydrophobic, conditioning</td>
<td>PES</td>
<td>160 - 190</td>
<td>Hydrophobic agent: 52 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conditioning agent: 27 g/l</td>
</tr>
<tr>
<td>Hydrophobic</td>
<td>PES</td>
<td>160 - 190</td>
<td>Hydrophobic agent: 90 g/l</td>
</tr>
<tr>
<td>Hydrophobic</td>
<td>PAC/PES</td>
<td>180</td>
<td>Hydrophobic agent: 40 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Acetic acid: 2 g/l</td>
</tr>
<tr>
<td>Non-slip</td>
<td>PAC</td>
<td>160</td>
<td>Non-slip agent: 50 g/l</td>
</tr>
<tr>
<td>Non-slip</td>
<td>PES/WO</td>
<td>130</td>
<td>Non-slip agent: 30 g/l</td>
</tr>
<tr>
<td>Easycare</td>
<td>CO/PES</td>
<td>130 - 170</td>
<td>Crosslinking agent: 50 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Catalyst: 7 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Acid: 0.5 g/l</td>
</tr>
<tr>
<td>Easycare</td>
<td>PES</td>
<td>155</td>
<td>Non-creasing agent (formaldehyde-free): 25 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Additive for easycare: 10 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dispersing agent: 1 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Levelling agent: 5 g/l</td>
</tr>
<tr>
<td>Easycare, softening,</td>
<td>CO</td>
<td>100 - 150</td>
<td>Softening agent: 35 g/l</td>
</tr>
<tr>
<td>optical brightening</td>
<td></td>
<td></td>
<td>Condition agent: 10 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Optical brightener: 25 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Crosslinking agent: 50 g/l</td>
</tr>
<tr>
<td>Easycare, softening,</td>
<td>CO/EL</td>
<td>170</td>
<td>Softening agent: 30 g/l</td>
</tr>
<tr>
<td>dyeing after-treatment</td>
<td></td>
<td></td>
<td>Crosslinking agent: 50 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dyeing after-treatment: 10 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Catalyst: 8 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Acetic acid: 1 g/l</td>
</tr>
<tr>
<td>Easycare, softening,</td>
<td>CO</td>
<td>150</td>
<td>Crosslinking agent: 100 g/l</td>
</tr>
<tr>
<td>optical brightening</td>
<td></td>
<td></td>
<td>Softening agent 1: 40 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Softening agent 2: 40 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Catalyst 1: 30 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Catalyst 2: 5 mg/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Optical brightener: 2 g/l</td>
</tr>
<tr>
<td>Easycare, softening</td>
<td>CV/PA 6</td>
<td>180</td>
<td>Crosslinking agent: 65 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Catalyst 1: 20 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Catalyst 2: 0.2 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Softening agent 1: 50 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Softening agent 2: 15 g/l</td>
</tr>
<tr>
<td>Easycare, softening,</td>
<td>LI/CO</td>
<td>180</td>
<td>Crosslinking agent: 70 g/l</td>
</tr>
<tr>
<td>anti-slip</td>
<td></td>
<td></td>
<td>Catalyst: 40 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Anti-slip agent: 35 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Softening agent 1: 10 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Softening agent 2: 40 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Desaturation agent: 2 g/l</td>
</tr>
<tr>
<td>Anti-electrostatic, anti-slip</td>
<td>PES</td>
<td>100</td>
<td>Anti-slip agent: 90 g/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Anti-electrostatic agent: 5 g/l</td>
</tr>
<tr>
<td>Effect</td>
<td>Substrate</td>
<td>Process temperature (°C)</td>
<td>Recipe</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>-----------</td>
<td>--------------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>Anti-electrostatic, optical brightening</td>
<td>PES</td>
<td>190</td>
<td>Optical brightener: 9 g/l Anti-electrostatic agent: 7 g/l</td>
</tr>
<tr>
<td>Flame retardant</td>
<td>CO</td>
<td>145</td>
<td>Flame retarder: 160 g/l</td>
</tr>
</tbody>
</table>

Table 11.34: Textile substrate specific emission factors of different compounds in preparation agents at certain conditions

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic-C (g/kg)</th>
<th>Testing conditions (Curing temperature (°C); Curing time (min)); Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  Mineral oils</td>
<td>500 - 800</td>
<td>190 °C; 2 min (PES)</td>
</tr>
<tr>
<td>B  Conventional fatty acid esters</td>
<td>100 - 250</td>
<td>190 °C; 2 min (PES)</td>
</tr>
<tr>
<td>C  Steric hindered fatty acid esters</td>
<td>50 - 100</td>
<td>190 °C; 2 min (PES)</td>
</tr>
<tr>
<td>D  Polyolesters</td>
<td>20 - 200</td>
<td>190 °C; 2 min (PES)</td>
</tr>
<tr>
<td>E  Polyester/polyethercarbontes</td>
<td>10 - 50</td>
<td>190 °C; 2 min (PES)</td>
</tr>
</tbody>
</table>

Table 11.35: Substance specific emission factors to air (organic carbon and formaldehyde) of easy-care finishing agents based on dimethyloldihydroxyethen urea derivatives

<table>
<thead>
<tr>
<th>Organic-C (g/kg)</th>
<th>Formaldehyde (g/kg)</th>
<th>Testing conditions (Curing temperature (°C); Curing time (min)); Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  14</td>
<td>4</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>B  15</td>
<td>5</td>
<td>170 °C; 3 min (CO/PES)</td>
</tr>
<tr>
<td>C  2</td>
<td>6</td>
<td>180 °C; 1.5 min (CO)</td>
</tr>
<tr>
<td>D  15</td>
<td>4</td>
<td>170 °C; 3 min (CO/PES)</td>
</tr>
<tr>
<td>E  20</td>
<td>4</td>
<td>170 °C; 3 min (CO)</td>
</tr>
<tr>
<td>F  5</td>
<td>15</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>G  23</td>
<td>3</td>
<td>150 °C; 2 min (CO)</td>
</tr>
<tr>
<td>H  5</td>
<td>3</td>
<td>170 °C; 3 min (CO)</td>
</tr>
</tbody>
</table>

Table 11.36: Substance specific emission factors to air (organic carbon and formaldehyde) of easy-care finishing agents based on melamine derivatives

<table>
<thead>
<tr>
<th>Organic-C (g/kg)</th>
<th>Formaldehyde (g/kg)</th>
<th>Testing conditions (Curing temperature (°C); Curing time (min)); Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  13</td>
<td>6</td>
<td>160 °C; 1 min (PES)</td>
</tr>
<tr>
<td>B  33</td>
<td>19</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>C  24</td>
<td>31</td>
<td>170 °C; 1.5 min (CO)</td>
</tr>
<tr>
<td>D  21</td>
<td>51</td>
<td>170 °C; 3 min (CO)</td>
</tr>
<tr>
<td>E  7</td>
<td>5</td>
<td>150 °C; 3 min (CO)</td>
</tr>
<tr>
<td>F  11</td>
<td>4</td>
<td>170 °C; 3 min (CO)</td>
</tr>
</tbody>
</table>
Table 11.37: Substance specific emission factors to air of anti-foaming agents

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic-C (g/kg)</th>
<th>Curing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Curing temperature (°C); Curing time (min); Substrate</td>
</tr>
<tr>
<td>A  Fatty acid ethoxylate, hydrocarbons</td>
<td>112</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>B  Silicone</td>
<td>22</td>
<td>160 °C; 2 min (PES)</td>
</tr>
<tr>
<td>C  Hydrocarbons (80 %)</td>
<td>573</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>D  Hydrocarbons</td>
<td>737</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
</tbody>
</table>

Table 11.38: Substance specific emission factors to air of wetting agents

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic-C (g/kg)</th>
<th>Curing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Curing temperature (°C); Curing time (min); Substrate</td>
</tr>
<tr>
<td>A  Fatty alcohol ethoxylate</td>
<td>64</td>
<td>150 °C; 2 min (WO)</td>
</tr>
<tr>
<td>B  Fatty alcohol derivative</td>
<td>31</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>C  Tributylphosphate</td>
<td>239</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>D  Tributylphosphate</td>
<td>228</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>E  Tributylphosphate</td>
<td>335</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>F  Phosphoric acid esters</td>
<td>45</td>
<td>170 °C; 4 min (BW)</td>
</tr>
<tr>
<td>G  Fatty alcohol ethoxylate</td>
<td>81</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>H  Fatty alcohol ethoxylate</td>
<td>294</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>I  Alkansulphonates</td>
<td>142</td>
<td>150 °C; 1.5 min (PES)</td>
</tr>
</tbody>
</table>

Table 11.39: Substance specific emission factors to air of softening agents

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic-C (g/kg)</th>
<th>Curing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Curing temperature (°C); Curing time (min); Substrate</td>
</tr>
<tr>
<td>A  Polysiloxane</td>
<td>19</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>B  Polysiloxane</td>
<td>10</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>C  Polysiloxane</td>
<td>3</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>D  Polysiloxane</td>
<td>17</td>
<td>160 °C; 0.5 min (CO)</td>
</tr>
<tr>
<td>E  Polysiloxane-polylethylene</td>
<td>0.6</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>F  Polysiloxan</td>
<td>17</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>G  Fatty acid derivative</td>
<td>1.9</td>
<td>170 °C; 3 min (CO)</td>
</tr>
<tr>
<td>H  Fatty acid derivative</td>
<td>4</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>I  Fatty acid derivative</td>
<td>5</td>
<td>170 °C; 2 min (CO)</td>
</tr>
<tr>
<td>K  Fatty acid derivative</td>
<td>2</td>
<td>170 °C; 3 min (CO)</td>
</tr>
<tr>
<td>L  Fatty acid derivative</td>
<td>1</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>M  Fatty acid derivative, waxes</td>
<td>38</td>
<td>180 °C; 1.5 min (PES)</td>
</tr>
</tbody>
</table>
### Table 11.40: Substance specific emission factors to air of carriers

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic-C (g/kg)</th>
<th>Testing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Aromatic carboxylic acid derivative</td>
<td>357</td>
<td>Curing temperature (°C); Curing time (min); Substrate</td>
</tr>
<tr>
<td>B Aromatic esters</td>
<td>219</td>
<td>190 °C; 1 min (PES)</td>
</tr>
<tr>
<td>C o-phenylphenol</td>
<td>354</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
</tbody>
</table>

### Table 11.41: Substance specific emission factors to air of flame-retardants

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic-C (g/kg)</th>
<th>Testing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Phosphonic acid derivative</td>
<td>124</td>
<td>Curing temperature (°C); Curing time (min); Substrate</td>
</tr>
<tr>
<td>B Phosphonic acid derivative</td>
<td>37</td>
<td>100 °C; 1 min (PES)</td>
</tr>
<tr>
<td>C Inorganic salts</td>
<td>2</td>
<td>170 °C; 3 min (CO)</td>
</tr>
<tr>
<td>D Organic-P-compound</td>
<td>19;</td>
<td>formaldehyde: 30 g/kg</td>
</tr>
<tr>
<td>E Organic P-compound</td>
<td>0.2;</td>
<td>formaldehyde: 3.6 g/kg</td>
</tr>
<tr>
<td>F Alkylphosphate</td>
<td>109</td>
<td>150 °C; 2 min (PES)</td>
</tr>
<tr>
<td>G Inorganic/organic salts</td>
<td>12</td>
<td>110 °C; 2 min (PES)</td>
</tr>
<tr>
<td>H Organic P-compound</td>
<td>24</td>
<td>175 °C; 1 min (PES)</td>
</tr>
<tr>
<td>I N-and P-containing compound</td>
<td>0.2;</td>
<td></td>
</tr>
<tr>
<td>K Inorganic/organic salts</td>
<td>3</td>
<td>110 °C; 2 min (PES)</td>
</tr>
<tr>
<td>L N-and P-containing compound</td>
<td>30</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
</tbody>
</table>

### Table 11.42: Substance specific emission factors to air of repellents

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic-C (g/kg)</th>
<th>Testing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Fluorocarbon resin</td>
<td>43</td>
<td>Curing temperature (°C); Curing time (min); Substrate</td>
</tr>
<tr>
<td>B Fluorocarbon resin</td>
<td>42</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>C Fluorocarbon resin</td>
<td>23</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>D Fluorocarbon resin</td>
<td>19; 9</td>
<td>150 °C; 3 min (CO)</td>
</tr>
<tr>
<td>E Fluorocarbon resin</td>
<td>22</td>
<td>150 °C; 3 min (PES)</td>
</tr>
<tr>
<td>G Various. Fluorocarbon resins (same producer)</td>
<td>13; 15; 5; 7 22; 8; 13; 37</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>H Paraffin, inorganic salt</td>
<td>43</td>
<td>120 °C; 2 min (CO)</td>
</tr>
<tr>
<td>I Paraffin, Zr-salt</td>
<td>15</td>
<td>150 °C; 4 min (CO)</td>
</tr>
<tr>
<td>K Paraffin</td>
<td>29</td>
<td>170 °C; 3 min (CO)</td>
</tr>
<tr>
<td>L Polysiloxane</td>
<td>37</td>
<td>150 °C; 3 min (CO)</td>
</tr>
<tr>
<td>M Polyurethane derivative</td>
<td>25</td>
<td>170 °C; 3 min (CO)</td>
</tr>
<tr>
<td>N Melamine derivative</td>
<td>19;</td>
<td>formaldehyde: 2 g/kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>140 °C; 4 min (CO)</td>
</tr>
</tbody>
</table>
### Table 11.43: Substance specific emission factors to air of conditioning agents

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic-C (g/kg)</th>
<th>Testing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  Paraffin, polyethylene</td>
<td>75</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>B  Fatty acid ester</td>
<td>13</td>
<td>170 °C; 4 min (CO)</td>
</tr>
<tr>
<td>C  Wax</td>
<td>67</td>
<td>190 °C; 1.5 min (PS)</td>
</tr>
<tr>
<td>D  Paraffin</td>
<td>79</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>E  Wax</td>
<td>172</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>F  Fatty acid derivative</td>
<td>5</td>
<td>170 °C; 1.5 min (CO)</td>
</tr>
<tr>
<td>G  Fatty acid derivative</td>
<td>2</td>
<td>140 °C; 2 min (CO)</td>
</tr>
<tr>
<td>H  Fatty acid derivative</td>
<td>3</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
</tbody>
</table>

### Table 11.44: Substance specific emission factors to air of optical brighteners

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic-C (g/kg)</th>
<th>Testing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  Diaminostilbene disulphonic acid</td>
<td>2</td>
<td>170 °C; 3 min (BW)</td>
</tr>
<tr>
<td>B  Pyrazoline derivative</td>
<td>32</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>C  Diaminostilbene disulphonic acid</td>
<td>3</td>
<td>170 °C; 3 min (BW)</td>
</tr>
<tr>
<td>D  Benzoazol derivative</td>
<td>2</td>
<td>190 °C; 1.5 min (PS)</td>
</tr>
<tr>
<td>E  Distyrylbenzene derivtive</td>
<td>18</td>
<td>190 °C; 1.5 min (PS)</td>
</tr>
<tr>
<td>F  Pyrene and oxazol derivatives</td>
<td>22</td>
<td>190 °C; 1.5 min (PS)</td>
</tr>
<tr>
<td>G  Benzoazol derivative</td>
<td>11</td>
<td>190 °C; 1.5 min (PS)</td>
</tr>
</tbody>
</table>

### Table 11.45: Substance specific emission factors to air of anti-electrostatic agents

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic-C (g/kg)</th>
<th>Testing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  Org. salt</td>
<td>72</td>
<td>150 °C; 3 min (PES)</td>
</tr>
<tr>
<td>B  Alkylphosphate</td>
<td>27</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>C  Polyglykolether</td>
<td>7</td>
<td>150 °C; 3 min (PES)</td>
</tr>
<tr>
<td>D  Org. P-compound</td>
<td>14</td>
<td>170 °C; 1 min (PES)</td>
</tr>
<tr>
<td>E  Quaternary ammonium compound</td>
<td>4</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>F  Alkylphosphate</td>
<td>5</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
<tr>
<td>G  Quaternary ammonium compound</td>
<td>24</td>
<td>190 °C; 1.5 min (PES)</td>
</tr>
</tbody>
</table>
### Table 11.46: Substance specific emission factors to air of filling and stiffening agents

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic C (g/kg)</th>
<th>Testing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Curing temperature (°C); Curing time (min); Substrate</td>
</tr>
<tr>
<td>A Polyvinyl alcohol</td>
<td>3</td>
<td>170 ºC; 1.5 min (CO)</td>
</tr>
<tr>
<td>B Starch derivative</td>
<td>1</td>
<td>160 ºC; 4 min (CO)</td>
</tr>
<tr>
<td>C Polyacrylate</td>
<td>2</td>
<td>170 ºC; 1.5 min (CO)</td>
</tr>
</tbody>
</table>

### Table 11.47: Substance specific emission factors to air of after-treatment agents for fastness improvement

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic C (g/kg)</th>
<th>Testing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Curing temperature (°C); Curing time (min); Substrate</td>
</tr>
<tr>
<td>A Quaternary ammonia compound</td>
<td>3</td>
<td>170 ºC; 1.5 min (CO)</td>
</tr>
<tr>
<td>B Quaternary ammonia compound</td>
<td>3</td>
<td>170 ºC; 4 min (CO)</td>
</tr>
<tr>
<td>C Quaternary ammonia compound</td>
<td>&lt; 1</td>
<td>180 ºC; 1 min (CO)</td>
</tr>
<tr>
<td>C Quaternary ammonia compound</td>
<td>17</td>
<td>190 ºC; 1.5 min (PES)</td>
</tr>
</tbody>
</table>

### Table 11.48: Substance specific emission factors to air of antimicrobtics

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic C (g/kg)</th>
<th>Testing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Curing temperature (°C); Curing time (min); Substrate</td>
</tr>
<tr>
<td>A Heterocyclic compounds</td>
<td>5</td>
<td>170 ºC; 4 min (CO)</td>
</tr>
<tr>
<td>B Aromatic compounds</td>
<td>47/241</td>
<td>170 ºC; 4 min (CO) 190 ºC; 1.5 min (PES)</td>
</tr>
<tr>
<td>C Isothiazolinone</td>
<td>55</td>
<td>190 ºC; 1.5 min (PES)</td>
</tr>
<tr>
<td>D Isothiazolinone</td>
<td>46/302</td>
<td>170 ºC; 4 min (CO) 190 ºC; 1 min (pES)</td>
</tr>
</tbody>
</table>

### Table 11.49: Substance specific emission factors to air of non-slip, ladder-proof agents

<table>
<thead>
<tr>
<th>Active ingredients</th>
<th>Organic C (g/kg)</th>
<th>Testing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Curing temperature (°C); Curing time (min); Substrate</td>
</tr>
<tr>
<td>A Silicic acid</td>
<td>0.6/3.7</td>
<td>100 ºC; 0.5 min (CO) 170 ºC; 3 min (PES)</td>
</tr>
<tr>
<td>B Silicic acid</td>
<td>1.3/2.8</td>
<td>170 ºC; 3 min (CO)</td>
</tr>
</tbody>
</table>

WORKING DRAFT IN PROGRESS
Note to the TWG: this Annex has not been reviewed. It has not been edited and formatted either. Please provide information to update this Annex.

12 ANNEX V: TYPICAL POLLUTANTS (AND POTENTIAL SOURCES) IN AIR EMISSIONS FROM TEXTILE PROCESSES

Table 12.1: Chemical compounds with less dangerous properties which may be present in waste gas

<table>
<thead>
<tr>
<th>Substance</th>
<th>Possible Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aliphatic hydrocarbons (C1-C40)</td>
<td>Preparation agents, wetting agents, printing</td>
</tr>
<tr>
<td>Aromatic hydrocarbons</td>
<td>Carriers, Machine cleaning</td>
</tr>
<tr>
<td>Ketones</td>
<td>Various products</td>
</tr>
<tr>
<td>Alcohols (low molecular)</td>
<td>Various products</td>
</tr>
<tr>
<td>Esters (low molecular)</td>
<td>Various products</td>
</tr>
<tr>
<td>Siloxanes</td>
<td>Softening agents</td>
</tr>
<tr>
<td>Carboxylic acids (e.g. acetic acid)</td>
<td>pH-adjustment</td>
</tr>
<tr>
<td>Fatty acids</td>
<td>By-product in surfactants</td>
</tr>
<tr>
<td>Fatty alcohols</td>
<td>By-product in surfactants</td>
</tr>
<tr>
<td>Fatty esters</td>
<td>By-product in surfactants</td>
</tr>
<tr>
<td>Fatty amines</td>
<td>By-product in surfactants</td>
</tr>
<tr>
<td>Aminoalcohols</td>
<td>By-product in surfactants</td>
</tr>
<tr>
<td>Dioles, polyoles</td>
<td>By-product in surfactants</td>
</tr>
<tr>
<td>Glycolether</td>
<td>By-product in surfactants</td>
</tr>
<tr>
<td>Aliphatic, aromatic ethers</td>
<td>Various products</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]
Table 12.2: Substances with more dangerous properties which may be present in waste gas

<table>
<thead>
<tr>
<th>Substance</th>
<th>Possible source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td>Polyvinylacetate, acetic acid</td>
</tr>
<tr>
<td>Acroleine</td>
<td>Decomposition of glycerol</td>
</tr>
<tr>
<td>Acrylic acid</td>
<td>Coating agents and binders for non-wovens</td>
</tr>
<tr>
<td>Aliphatic amines</td>
<td>Polymers, thickeners</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Foaming agents, thickeners</td>
</tr>
<tr>
<td>2- aminoethanol</td>
<td>Wetting agents, softeners</td>
</tr>
<tr>
<td>Benzylalcohol</td>
<td>Carriers</td>
</tr>
<tr>
<td>Biphenyl</td>
<td>Carriers</td>
</tr>
<tr>
<td>Bis (2-aminoethyl)-1,2-ethanediamine, N, N</td>
<td>Softeners</td>
</tr>
<tr>
<td>Butine-1,4 diol</td>
<td>Fluorocarbon resins</td>
</tr>
<tr>
<td>Caprolactam</td>
<td>Polyamide 6 powder/textes</td>
</tr>
<tr>
<td>Chloromethane (methylchloride)</td>
<td>Quaternary ammonium compounds</td>
</tr>
<tr>
<td>Chlorinated aromatic hydrocarbons</td>
<td>Carriers</td>
</tr>
<tr>
<td>Chloroethanol</td>
<td>Decomposition of flameretardants (chlorinated P-ester)</td>
</tr>
<tr>
<td>Chloroparaffins</td>
<td>Flame-retardants</td>
</tr>
<tr>
<td>Dichloroethane</td>
<td>Polyvinylidenechloride</td>
</tr>
<tr>
<td>Dichloromethane</td>
<td>Solvent cleaning</td>
</tr>
<tr>
<td>Diethylenetriamine</td>
<td>Softeners</td>
</tr>
<tr>
<td>Dipropylene diamine</td>
<td>Dyeing auxiliaries/polymerdispersinons</td>
</tr>
<tr>
<td>Epoxy-1-propanol, 2,3-</td>
<td>Some antistatics</td>
</tr>
<tr>
<td>Acetic acid-(2-ethoxyiethyl)-ester</td>
<td>Softeners/fluorocarbon resins</td>
</tr>
<tr>
<td>Ethoxyethanol</td>
<td>Softeners/fluorocarbon resins</td>
</tr>
<tr>
<td>Ethanedialdehyde (glyoxal)</td>
<td>Crosslinkers</td>
</tr>
<tr>
<td>Ethylenediamine</td>
<td>Softeners</td>
</tr>
<tr>
<td>Fluoroorganics, low molecular</td>
<td>Fluorocarbon resins</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>Crosslinkers, conservation agent, stenter off-gas</td>
</tr>
<tr>
<td>Formic acid</td>
<td>Various recipes</td>
</tr>
<tr>
<td>Hexamethylenediamine</td>
<td>Polycondensation products</td>
</tr>
<tr>
<td>Hexamethylenediisocyanate</td>
<td>Fluorocarbon resins, polyurethane</td>
</tr>
<tr>
<td>Hexanone, 2-</td>
<td>Fluorocarbon resins</td>
</tr>
<tr>
<td>Hydrogen chloride</td>
<td>Catalyst</td>
</tr>
<tr>
<td>Isocyanatomethyl-3,5,5-trimethyclohexyl-isocyanate,3</td>
<td>Fluorocarbon resins, polyurethane</td>
</tr>
<tr>
<td>Methoxy-1-propanol, 2-</td>
<td>Rare</td>
</tr>
<tr>
<td>Methoxypropylacetate</td>
<td>Rare</td>
</tr>
<tr>
<td>Monochloroacetic acid, Na-salt</td>
<td>Rare</td>
</tr>
<tr>
<td>Monochloroacetic acid, 1-methylestester</td>
<td>Rare</td>
</tr>
<tr>
<td>Monochloroacetic acid, ethylester</td>
<td>Rare</td>
</tr>
<tr>
<td>Monochloroacetic acid, methylester</td>
<td>Rare</td>
</tr>
<tr>
<td>N-alkylmorpholine</td>
<td>Non wovens coating</td>
</tr>
<tr>
<td>Sodiumtrichloroacetate</td>
<td>Rare</td>
</tr>
<tr>
<td>Oxalic acid</td>
<td>Bleaching auxiliary</td>
</tr>
<tr>
<td>Tetrachloroethene</td>
<td>Dry cleaning</td>
</tr>
<tr>
<td>Thiourea</td>
<td>Dyeing auxiliary</td>
</tr>
<tr>
<td>Trichloroacetic acid</td>
<td>Rare</td>
</tr>
<tr>
<td>Triethylamine</td>
<td>Special crosslinkers</td>
</tr>
<tr>
<td>Trikresylphosphate (ooo, oom, oop, opp)</td>
<td>Flame-retardants</td>
</tr>
<tr>
<td>Substance</td>
<td>Possible source</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>-----------------------------------------------------------------</td>
</tr>
<tr>
<td>Polycyclic aromatic hydrocarbons</td>
<td>Crackproducts in off-gass (very low)</td>
</tr>
<tr>
<td>PCDD/PCDF (Br, Cl, F)</td>
<td>Crackproducts in off-gass (very low)</td>
</tr>
<tr>
<td>Bischloromethylether</td>
<td>Strongest synthetic carcinogenic, spontaneous formation when working with formaldehyde and hydrogenchloride (very low)</td>
</tr>
<tr>
<td>Arsenictrioxide/antimonytrioxide</td>
<td>Flame-retardants</td>
</tr>
<tr>
<td>Dimethylsulphate</td>
<td>Quaternary ammonium compounds</td>
</tr>
<tr>
<td>Ethylenimine</td>
<td>Flame-retardants</td>
</tr>
<tr>
<td>Acrylonitrile</td>
<td>Polymer dispersions</td>
</tr>
<tr>
<td>1,3-butadiene</td>
<td>Polymer dispersions</td>
</tr>
<tr>
<td>2-vinylcyclohexen</td>
<td>Polymer dispersions</td>
</tr>
<tr>
<td>Epichlorohydrin</td>
<td>Polycondensation products</td>
</tr>
<tr>
<td>1,2-epoxypropane (propyleneoxide)</td>
<td>Surfactants (propoxilate)</td>
</tr>
<tr>
<td>Ethylenoxide</td>
<td>Surfactants (ethoxilate)</td>
</tr>
<tr>
<td>Vinylchloride</td>
<td>Polymer dispersions (PVC)</td>
</tr>
<tr>
<td>Acrylamide</td>
<td>Reactive polymers, flame-retardants</td>
</tr>
<tr>
<td>Butanoneoxime</td>
<td>Fluorocarbon resins, polyurethanes</td>
</tr>
<tr>
<td>Pentachlorophenol</td>
<td>Pesticide</td>
</tr>
<tr>
<td>Propyleneimine</td>
<td>Flame-retardant and polyurethane crosslinker</td>
</tr>
<tr>
<td>N-vinylpyrrolidon</td>
<td>Polyvinylpyrrolidone dispensions</td>
</tr>
</tbody>
</table>

Source: [179, UBA, 2001]
13 ANNEX VI: AUXILIARIES CLASSIFICATION TOOLS

13.1 Tegewa scheme

The "Method of classification of textile auxiliaries according to their waste water relevance" provides a logic system for the classification of textile auxiliaries in 3 classes of relevance:

- **Class I**: Minor relevance to waste water
- **Class II**: Relevant to waste water
- **Class III**: High relevance to waste water

The main criteria for the classification are the content of certain harmful (including bioaccumulative) substances, biological degradation or elimination and aquatic toxicity of the sold products (see scheme on next page).

The introduction of the classification concept rests essentially on the following pillars:

- Classification by producers on their own responsibility, guided by the association of textile auxiliaries suppliers, called TEGEWA (TEGEWA = Verband der TExtilhilfsmittel-, Lederhilfsmittel-, GErbstoff- und WAscrholstoff-Industrie e.V., D-60329 Frankfurt)
- Screening of correct classification of textile auxiliaries in the three classes by an expert.
- A monitoring report on the effectiveness of the voluntary commitment which will be communicated to the authorities. For this purpose numbers and quantities of textile auxiliaries classified in classes I, II and III and sold in Europe are collected by a neutral consultant from the manufacturers.
- The triggering of market mechanisms towards the development of environmentally sounder products.

It is not claimed that the classification concept allows a differentiated ecotoxicological evaluation of textile auxiliaries. The purpose of the classification concept is rather to allow users to select textile auxiliaries also from ecological aspects. Ecological competition is intended to trigger a trend towards the development of environmentally more compatible textile auxiliaries. The German Association of the Textile Finishing Industry (TVI-Verband, D-Eschborn) is officially supporting this concept and has signed and published a self-commitment to recommend the textile finishing industries to use classified products only and preferably such of classes I and II ("TVI-Verband, 1997").

A classification of the textile auxiliary is possible both on the basis of data of the preparation and on the basis of data of the ingredients by calculating mean values for the ingredients. For data to be newly determined, it is recommended to determine those data on the basis of the ingredients.
Accumul. Substances Contained ≥ 5%

Textile auxiliaries aquatic toxicity ≥ 1 mg/l

Textile auxiliaries readily biodegradable

Problematic substances contained

Accumul. Substan. Biodegradable / bioeliminable

Textile aux. readily biodegradable

Textile auxiliaries with minor relevance to waste water

II. Textile auxiliaries with relevant to waste water

III. Textile auxiliaries with high relevance to waste water

Figure 13.1: Method of classification of textile auxiliaries according to their waste water relevance
Footnotes mentioned in the classification scheme:

1. Problematic substances are
   1.1 CMR substances which are - according to Annex I to Directive 67/548/EEC -
       • classified as "carcinogenic" cat. 1 or cat. 2 and labelled with R45 (May cause cancer) or R49 (May cause cancer by inhalation),
       • classified as "mutagenic" cat. 1 or cat. 2 and labelled with R46 (May cause heritable genetic damage) or R60 (May impair fertility),
       • classified as "toxic for reproduction" cat. 1 or cat. 2 and labelled with R61 (May cause harm to the unborn child).
   1.2 Ingredients which have an aquatic toxicity (definition see footnote 4) of < 0.1 mg/l and are not readily biodegradable (definition see footnote 3),
   1.3 Low-molecular halogen hydrocarbons (halogen share > 5 %, chain length C1 - C12),
   1.4 Arsenic and arsenic compounds,
   1.5 Lead and lead compounds,
   1.6 Cadmium and cadmium compounds,
   1.7 Tri- and tetra-organotin compounds,
   1.8 Mercury and mercury compounds,
   1.9 APEO,
   1.10 EDTA, DTPA.

2. In connection with classifications made within this voluntary commitment, substances shall be considered "accumulative" which are labelled either with R-phrase 53 "May cause long-term adverse effects in the aquatic environment" alone, or with R53 in combination with other R-phrases.

3. Readily biodegradable = OECD tests 301 A-F with > 60 % BOD/COD or CO₂ formation, respectively, or > 70 % DOC reduction in 28 days.

4. Aquatic toxicity of textile auxiliaries = LC 50 daphnia (if not available to be substituted by fish).

5. Biodegradable/eliminable = OECD test 302 B: > 70 % DOC reduction in 28 days, or OECD test 302 C: > 60 % O₂ consumption, or Proof of a > 70 % reduction in precipitation typical of sewage treatment plants.

Note:
For textile auxiliaries the evaluation "readily biodegradable (3)", "aquatic toxicity" (4), and "biodegradable/bioeliminable" (5) can be made not only on the basis of test data of the ready-for-use preparation but also on the basis of valid data obtained by calculating mean values for the various ingredients.
13.2 SCORE System

1. SUMMARY

The score system is an administrative method of sorting chemicals on the basis of information especially from the chemical supplier's specification sheets. The sorting permits a priority selection of chemicals which, because of actual consumption and information on environmental behaviour, should be subject to closer examination.

The score system is based on the parameters usually considered to be the most interesting in connection with characterisation of substances injurious to the environment of industrial sewage. The parameter A is a score on the estimated amount of chemical, which is discharged into the environment as waste water. B is a score on biodegradability, and C is a score on bioaccumulation. The structure of the score system appears from the table in Chapter 2.

Together, A, B and C indicate the potential presence of the substance in the environment; (exposure); how much of, how long and how is the substance present in the aquatic environment. A influences the effect of B and C, while B influences the effect of C. The total score, which is obtained by multiplying the score for A, B and C, is called the exposure score.

Effects of chemical exposure depend on the toxicity of the chemical. The toxicity (D) should be evaluated concurrently in proportion to the exposure.

Each parameter is given a numerical value between 1 and 4 with 4 indicating the most critical environmental impact. Missing information involves highest score. The result is that each substance can be given a score as to exposure (A x B x C), and independent of this, a score as to toxicity (D). Subsequently, it will be possible to make a ranking of the chemicals.

Application of the system implies that the system is worked into the waste water permits or environmental approvals of the companies. Hereafter, the companies should send in information on consumption of chemicals as well as environmental data. The first time, information on all chemicals employed should be submitted, but following, reporting of new chemicals may take place concurrently with the employment of these. At least once a year, the statement of consumption should be updated.

The Federation of Danish Textile and Clothing Industries is prepared to act as "consultant" for the individual companies, and it has established a data base management system for storing of information on chemicals and calculation of score. By means of the data base facilities, it will thus be possible to print out a list of the employed chemicals and the calculated score (a Score Report) specifically for each company. This list could subsequently be supplemented with a detailed analysis of the chemicals, which were given a high score.

The information now available should form the basis of the environmental authority's (municipality/county) evaluation as to possible "interventions".

2. DESCRIPTION OF THE SCORE SYSTEM

The score system is an administrative method of sorting chemicals on the basis of information especially from the chemical supplier's specification sheets. The sorting permits a priority selection of those chemicals, which should be subject to closer examination because of actual consumption and environmental behaviour.

The score system is based on the parameters usually considered to be the most interesting in connection with characterisation of substances injurious to the environment of industrial sewage.
A-score is based on estimated amount of chemical, which is discharged into environment as waste water. B-score is based on biodegradability and C-score on bioaccumulation.

Together the parameters A, B and C indicate the potential presence of the substance (exposure) in the environment; how much of, how long and where is the substance present in the aquatic environment. A influences the effect of B and C, while B influences the effect of C. Thus,

**exposure score** is obtained by multiplying A, B and C.

The effect of presence of a substance in the environment depends on its toxicity (D). The **toxicity score** should be evaluated concurrently and independently in proportion to the exposure score.

The exposure score (AxBxC) and toxicity score (D) are estimated for each chemical. Subsequently it will be possible to make a ranking of the chemicals.

**How to use the score system?**

On basis of information from especially the chemical supplier's specification sheets each parameter is given a numerical value between 1 and 4 with 4 indicating the most critical environmental impact. Missing information involves highest score.

It is advisable that the data used as score basis have been obtained according to internationally approved methods of examination.

Within the parameters B and C and D, data on different levels are used. The highest level represents data generated on basis of examination conditions, which are most comparable with a natural aquatic environment. As regards the parameter C, data obtained from standardised bioaccumulation tests with fish are thus more realistic than data from examinations based on determination of the distribution of the substance in a two-phased mixture of octanol and water (Pow-data). However, Pow has a more direct correlation with bioaccumulation than solubility data.
EXPOSURE SCORE (AxBxC)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SCORE FIGURE:</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Discharged amount of substance</td>
<td>kg/week</td>
<td>&lt; 1</td>
<td>1 - 10</td>
<td>&gt; 10 - 100</td>
<td>&gt; 100</td>
</tr>
<tr>
<td></td>
<td>kg/year</td>
<td>&lt; 50</td>
<td>50 - 500</td>
<td>&gt; 500 - 5000</td>
<td>&gt; 5000</td>
</tr>
<tr>
<td>B Biodegradability</td>
<td>Surface water (%)</td>
<td>&gt; 60(50 - 100)</td>
<td>10 - 60</td>
<td>&lt; 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sludge culture (%)</td>
<td>&gt; 70</td>
<td>20 - 70</td>
<td>&lt; 20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BOD/COD ratio</td>
<td>&gt; 0.5</td>
<td>≤ 0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Bioaccumulation</td>
<td>Bioconcentration Factor (BCF)</td>
<td>&lt; 100</td>
<td>≥ 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Or C1, C2, C3</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C1 if MW &gt; 1000 g/mol</td>
<td>Pow data</td>
<td>&lt; 1000</td>
<td>≥ 1000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water solubility g/litre</td>
<td>&gt; 10</td>
<td>10 - 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C2 if 500 = or &lt; MW = or &lt; 1000 g/mol</td>
<td>Pow data</td>
<td>&lt; 1000</td>
<td>≥ 1000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water solubility g/litre</td>
<td>&gt; 10</td>
<td>10 - 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C3 if MW &lt; 500 g/mol</td>
<td>Pow data</td>
<td>&lt; 1000</td>
<td>≥ 1000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water solubility g/litre</td>
<td>&gt; 100</td>
<td>100 - 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No information</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TOXICITY SCORE (D)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SCORE FIGURE:</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>D Effect concentration divided by effluent concentration</td>
<td>&gt; 1000</td>
<td>1000 - 101</td>
<td>100 - 10</td>
<td>&lt; 10</td>
<td></td>
</tr>
</tbody>
</table>

Implementation

Application of the system implies that the system is worked into the waste water permits or environmental approvals of the companies. Hereafter the companies should send in information on consumption of chemicals as well as environmental data. The first time, information on all chemicals employed should be submitted, but following, reporting of new chemicals may take place concurrently with the employment of these. At least once a year, the statement of consumption should be updated.

The Federation of Danish Textile and Clothing is prepared to act as "consultant" for the individual companies, and it has established a data base management system for storing of information on chemicals and calculation of score. By means of the data base facilities, it will thus be possible to print out a list of the employed chemicals and the calculated score (a Score Report) specifically for each company. This list could subsequently be supplemented with a detailed analysis of the chemicals, which were given a high score.

The Score Report forms the basis of the environmental authority’s (municipality and county) dialog with the companies and evaluation as to possible interventions.
Information

The Score System is worked out by a working group representing the municipalities in Ringkøbing County, Ringkøbing County and Federation of Danish Textile and Clothing in Denmark.

The Score System was implemented in 1992 in Ringkøbing County, it was worked into the waste water permits or environmental approvals of the companies. The reader is wellcome to contact Ringkøbing County, Damstræde 2, 6950 Ringkøbing, Denmark for further information about the system and experiences from the use of the system.

Information including The Compendium with Guidelines to the Sorting System for sorting af Chemicals can also be found on the web site.
13.3 Dutch General Policy Scheme

Summary

The lead-up to the grant of a permit under the Dutch Pollution of Surface Waters Act comprises three phases: information provision, establishing measures to be taken to control emissions, and assessing any residual emissions. The assessment of substances and preparations relates mainly to the ‘information provision’ phase. However, the data required to assess a substance or preparation are equally relevant to the assessment of residual emissions (immission assessment).

The implementation of the Pollution of Surface Waters Act demands an understanding of the toxicity of individual substances and preparations to the aquatic environment.

This report describes both the general method of assessment and the procedure for informing the competent authority (via the user) of the water toxicity of individual substances and preparations. The general method of assessment is designed to apply to direct and indirect discharges under the Pollution of Surface Waters Act, but can also be used to assess substances and preparations involved in indirect discharges falling under the Environmental Protection Act.

The method employs parameters and criteria which comply with European regulations regarding the classification and characteristics of substances and preparations, but couples to the properties of substances a set level of effort to limit pollution at source. The method can be used wherever it is necessary to determine the water toxicity of substances and preparations.

This means that companies can use it if they need to supply information on substances and preparations to competent authorities in relation to permit or licence applications under the two aforementioned Acts or, for example, to demonstrate that a decision to use a particular substance or preparation will contribute to the on-going reduction of pressure on the environment.

It should be remembered that the general assessment method is a means of using various properties of substances to categorise them with regard to their toxicity to the aquatic environment. It will not indicate what measures should be taken in a specific case to prevent or reduce emissions. Nor can it be used to assess residual emissions.

With regard to the procedure, it should be stressed that responsibility for supplying information to the competent authority still lies with the applicant for a permit or licence under the relevant Acts. This is a blanket rule and therefore also applies to information about any basic or auxiliary substance, and any intermediate or final product which may find its way into waste water.

However, producers wishing to preserve confidentiality regarding the composition of their preparations do not always provide complete information to users. This means that users are in turn unable to pass it on to the competent authority.

For this reason, and for the sake of efficiency, producers are expected to use the general method of assessment to assess substances and preparations and to supply wholesalers and users with the results of the assessment, together with information about the relevant substances and preparations. The procedure is in line with the widely supported programmes of ‘responsible care’ and ‘product stewardship’ within the chemical industry. The private sector is launching international programmes to identify the missing data necessary for the assessment of the toxicity of a large number of substances.

The procedure described in this report can be used to resolve the dilemma between the need of applicants for permits under the Pollution of Surface Waters Act to supply information on the toxicity of preparations and the desire of producers to protect information on the composition of their preparations. The description of the procedure is accompanied by a discussion of possible means of monitoring and enforcement.
In addition to describing the general method of assessment and the procedure, the report focuses on points relevant to their application. It ends with conclusions and recommendations.

13.3.1 Procedure

Assessment of substances and preparations within the context of the implementation of the water discharge policy.

This chapter deals with the procedure for providing the authorities with information about substances and preparations by means of the user.

Key issues are the information that must be provided, the verifiability of this information and the enforceability of the procedure.

13.3.1.1 Introduction

The Pollution of Surface Waters Act prescribes that anyone applying for a permit under this act is obliged to provide information to enable the competent authorities to review the application. This obligation also applies to information about raw and auxiliary materials and partly processed and finished products that are used by companies and may be discharged into the surface water. Due to the confidentiality of information about the composition of preparations, producers and suppliers are not always willing to provide this information. In this situation, the customer does not have the exact information. A request to observe secrecy with regard to part of the permit applications by the user does not solve this problem, because in the confidential section of the application the water quality manager cannot be provided with any information about the preparation.

To solve this bottleneck, a procedure has been designed to help users, authorities and third parties to gain sufficient insight into the aquatic harmfulness of a substance or preparation, while guaranteeing the confidentiality of the information vis-à-vis the producer or supplier.

Producers and suppliers of substances and preparations play an important part in the provision of information and the assessment of substances and preparations in accordance with the GAM. The working group dealing with the effects on the market of the deregulation of legislation concerning permits granted under the Pollution of Surface Waters Act has recommended to encourage that in consultation with the corporate sector a system is set up within certain branches, which will make all standard information about raw and auxiliary materials relating to the permit-application procedure accessible to all parties involved. This working group has proposed to link up with the initiatives taken by the Integrated Water Management Committee. The Dutch cabinet has adopted this recommendation.

13.3.1.2 Procedure

Producers of substances and preparations play an important part in the procedure. In fact, if there are any details available about substances and preparations, it is most likely the producers who have this information. Besides, it is not efficient to have numerous users collect the data of properties of the same substances and preparations. The most obvious approach is to have the producer/supplier collect the data and assess the substances. This is in line with Directive 86/609/EEC, which deals with the protection of animals used for experimental and other scientific purposes. The procedure distinguishes between the submission of a basic set and a full set of information about substances and preparations.

The following figure represents the proposed procedure in diagram form.
13.3.1.2.1 **Full data set**

The full data set for assessing substances and preparations contains the answers to the questions below, plus the results of the assessment. This information must be made available through the commercial chain to the user, who can pass this on to the authorities dealing with the permits.

**Substances**

The details of each substance required to carry out the GAM are:

- Is the substance carcinogenic (R-45), insofar as is known?
- Is the substance mutagenic (R-46), insofar as is known?
- What is the acute toxicity to water organisms (LC50), preferably for four trophic levels, but in any case for crustaceans or fish.
- What is the degree of biodegradability?
- What is the Log Pow?
- What is the BCF? (optional)
- What is the water solubility if the acute toxicity to water organisms cannot be determined.

**Preparations**

For preparations, the results of the GAM must be given, as well as the exact composition of the preparation and information about the substances of each component.
Basic set should not be confused with Base-set according to Annex 7 of the Substances Directive. Assessment of substances and preparations within the context of the implementation of the water discharge policy.

13.3.1.2.2 Basic data set

Producers may provide only a basic set of information about substances or the composition of a preparation, if the substance or preparation is assessed in accordance with the GAM.

Substances

If the producer/supplier assesses the substance and provides only a basic set of information, then it is in principle enough to indicate its aquatic harmfulness and the place at which the substance file is available for inspection by the (verifying) authorities. In this case, the authorities will apply a worst-case approach to the water quality test (i.e. assessment of residual discharge after introduction of btm/bpm), based on the most harmful properties that have resulted to this category. In other words: if a substance falls into category 6 of aquatic harmfulness according to the GAM, it is assumed that the substance has an acute toxicity to water organisms of 1 mg/l and is persistent. If this results in additional decontamination measures, then a more accurate water quality test may be carried out if the producer provides more exact data about the properties of the substance.

Preparations

In principle, users must be provided with the following basic data set for preparations:

- results of assessment of the preparation in accordance with the GAM
- components in the category of aquatic harmfulness of 'black-list substance, may cause hereditary damage and/or cancer', as well as the rough quantities of the components that make up the preparation
- components with abatement effort A and the rough quantities of these components in the preparation
- the place at which the product file is available for inspection by the (verifying) authorities.

The exact composition of the preparation is only known to the producer or supplier.

In the case of preparations, too, the authorities will base the water quality test on the most harmful properties, which have led to the category of aquatic harmfulness, if the producer fails to state the exact composition.

If this results in additional measures, then the producer may ensure that a more accurate water quality test is carried out by providing more exact data about the composition of the preparation.

13.3.1.3 Verifiability

To assess substances and preparations, information is necessary. But it is impossible to verify whether all the information provided is correct.

Users and authorities must be able to trust that the assessment is based on the correct information and that the assessment itself has been carried out correctly. Those who carry out the assessment, the producers of substances and preparations, are responsible for this. The details of properties of substances may be determined by or under the authority of the producer.
For many existing substances, the information stored in databases may be used. In both cases, the details are preferably verified by certified laboratories (Good Laboratory Practice) in accordance with standardised methods. Any information about properties or substances that may have been assessed before standard test methods and the GLP came into force, may be used if valid conclusions can be drawn on the basis of this information. This is dealt with by the technical guidelines in Directive 93/67/EEC and Regulation 1488/94 for risk assessment of new and existing substances.

To reduce the risk of errors in the assessment, a software application has been made of the GAM. However, both the corporate sector and the government value a form of verification, which may be carried out in various ways.

13.3.1.3.1 Verification by authorities

In case of doubt (but also simply as a random test), the authorities must be able to verify whether the information provided is correct and whether the assessment is carried out correctly. It is proposed to use the same procedure as that used in the verification of information for the assessment of effects on humans and the environment. In other words, the authorities (for example, in the shape of the Inspectorate for the Environment) will be permitted to inspect the product file, at their request. Of course, the user and the authorities must know by whom and where the product file is kept. This file must also contain the information that has been used for the assessment of preparations.

13.3.1.3.2 Verification by the corporate sector

Apart from the authorities, the corporate sector may organise the verification themselves. For example, an independent, certified body may be designated to carry out or verify the assessment. The assessment may also form part of a section of the business operations that may be certified. This means that in environmental audits within the scope of the certification, the auditor will then verify whether the assessment has been carried out correctly. But the protocols for this will have to be set up first.

13.3.1.3.3 Product liability

Apart from this, the producer is at all times responsible for the correctness of information provided. On the other hand, the customer must also verify whether the information is correct, for example, by comparing the properties to those of other products. In this way, the user of a hazardous product that has been incorrectly categorised by the producer may prevent the incorrect use of the product.

However, if the user of a product has been misled by its supplier and the user could not reasonably have known this, then the producer can be held liable. According to criminal law, the user will always be liable. But based on product liability, the user is able to recover any damage from the producer in civil proceedings.

In the Netherlands, the Environment Inspectorate verifies whether the information provided is correct. If misleading information has been provided, steps can be taken. The EU member countries have entered into agreements in the event that companies from EU countries are involved.
13.3.1.4 Enforceability

In the permit-application procedure, the information provided must be verified; usually, the body that grants the permits (competent authorities) verifies the information itself. After that, the manner in which the permit is formulated determines its enforceability. For example, the wording of the conditions must provide clear legal grounds to allow for measures to be taken if other substances are discharged than those mentioned in the permit. In enforcing the permit conditions, special attention may be paid, for instance, to the availability of information about raw and auxiliary materials, as well as partly processed and finished products that are used by a company and may be discharged into the waste water.

Enforcers also ought to be alert if the permit allows the holder, for example, to change any raw or auxiliary materials, provided that the authorities are notified, whether in advance or afterwards.
Table B.4.1: Hazard identification test for substances

Figure 13.3 Hazard identification test for substances
### Table 13.1: General Assessment Methodology for preparations

<table>
<thead>
<tr>
<th>Category of substance</th>
<th>Classification of preparation (category of aquatic harmingness and decommissioning effort)</th>
<th>A</th>
<th>A</th>
<th>A</th>
<th>B</th>
<th>A</th>
<th>A</th>
<th>B</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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<td></td>
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<td></td>
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<tr>
<td>(1) Blank test substance</td>
<td></td>
<td>≥ 61%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) May cause moderate genetic damage</td>
<td></td>
<td>&lt; 0.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(3) May cause severe genetic damage</td>
<td></td>
<td>&lt; 0.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(4) Very toxic to aquatic organisms, toxic to cause long-term adverse effects in the aquatic environment</td>
<td></td>
<td>≥ 25%</td>
<td>&lt; 25%</td>
<td>&lt; 25%</td>
<td></td>
<td>&lt; 25%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) Very toxic to aquatic organisms, toxic to cause acute effects in the aquatic environment (in combination with (3))</td>
<td></td>
<td>≥ 25%</td>
<td>&lt; 25%</td>
<td>&lt; 25%</td>
<td></td>
<td>&lt; 25%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(6) Toxic to aquatic organisms and may cause long-term adverse effects in the aquatic environment (in combination with (4))</td>
<td></td>
<td>≥ 25%</td>
<td>&lt; 25%</td>
<td>&lt; 25%</td>
<td></td>
<td>&lt; 25%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(7) Toxic to aquatic organisms and may cause acute effects in the aquatic environment (in combination with (5))</td>
<td></td>
<td>≥ 25%</td>
<td>&lt; 25%</td>
<td>&lt; 25%</td>
<td></td>
<td>&lt; 25%</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>(8) Harmful to aquatic organisms, toxic to cause long-term adverse effects in the aquatic environment (in combination with (4) and (6))</td>
<td></td>
<td>≥ 25%</td>
<td>&lt; 25%</td>
<td>&lt; 25%</td>
<td></td>
<td>&lt; 25%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(9) Harmful to aquatic organisms, toxic to cause acute effects in the aquatic environment (in combination with (5) and (7))</td>
<td></td>
<td>≥ 25%</td>
<td>&lt; 25%</td>
<td>&lt; 25%</td>
<td></td>
<td>&lt; 25%</td>
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<tr>
<td>(10) Slightly harmful to aquatic organisms</td>
<td></td>
<td>≥ 25%</td>
<td>&lt; 25%</td>
<td></td>
<td></td>
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<tr>
<td>(11) Slightly harmful to aquatic organisms</td>
<td></td>
<td>&lt; 25%</td>
<td></td>
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<tr>
<td>(12) Slightly harmful to aquatic organisms; natural occurrence in surface water</td>
<td></td>
<td>&lt; 25%</td>
<td></td>
<td></td>
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<td></td>
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WORKING DRAFT IN PROGRESS
14 [ADVANCED OXIDATION PROCESSES (FENTON REACTION)]

The Fenton reaction involves an advanced oxidation process. Advanced oxidation processes (which are a particular case of chemical oxidation processes) are oxidation processes that produce active oxygen species that react as powerful and clean oxidants.

The Fenton process is based on the redox oxidation of hydrogen peroxide to produce the \(\text{OH}^*\) radical. Other methods to produce the \(\text{OH}^*\) radical from \(\text{H}_2\text{O}_2\) are, for example, \(\text{H}_2\text{O}_2\) and UV, ozone/\(\text{H}_2\text{O}_2\) and ozone/UV.

The Fenton reaction is based on \(\text{H}_2\text{O}_2\) and \(\text{Fe}^{2+}\) at pH 3. At pH 3, the first hydrolysed form of ferric ion (\(\text{Fe(OH)}^{++}\)) is in equilibrium with water, thereby controlling the rate of production of free \(\text{OH}^*\) radical from the decomposition of \(\text{H}_2\text{O}_2\).

There is evidence from recent research in advanced oxidation processes to assume the following pathway: \(\text{Fe}^{2+} + \text{HO}^- \rightarrow \text{Fe(OH)}^{++} + \text{OH}^*\).

In the absence of organics, the generated \(\text{OH}^*\) radical slowly further reacts consuming hydrogen peroxide. However, in the presence of organics (\(\text{R-H}\)) the following reaction takes place:

1. \(\text{R-H} + \text{OH}^* \rightarrow \text{R}^* + \text{H}_2\text{O}\)

Organic radicals are formed that react further by complex chain mechanisms or become terminated by deactivation and radical-radical combination. This process may occur in the absence or presence of oxygen gas (\(\text{O}_2\)). In the presence of oxygen gas, the alkyl radicals (\(\text{R}^*\)) produced by advanced oxidation, react very rapidly and the formation of the peroxyl radical occurs:

2. \(\text{R}^* + \text{O}_2 \rightarrow \text{ROO}^*\)

(Ground state molecular oxygen is consumed instead of the oxygen from the more expensive hydrogen peroxide).

The peroxyl radical may or may not be stable (which can slow down the oxidation process). In any case, oxygen is chemically introduced into the organic molecule and thus consumed, leading to the oxidation of organic molecules to more hydrophilic and usually more biodegradable intermediates. This is known as a clean route (unlike chlorination where chlorine atoms are introduced into the organic molecule).

The \(\text{OH}^*\) radical is (after fluorine) the most powerful oxidant in nature and reacts in an aspecific way with any substance containing at least one hydrogen atom.

With the Fenton reaction there is no risk of an accumulation of oxygen. Therefore potentially dangerous reactions in the presence of VOCs cannot occur. Moreover as the \(\text{H}_2\text{O}_2\) is present in very low concentrations (about 0.1 %) it should never be possible to reach explosive mixtures. On the contrary \(\text{O}_2\) is consumed by the reaction in the above-mentioned conditions.

It was stated earlier that \(\text{OH}^*\) is a very powerful oxidant. However, there are some dyes or groups that react more slowly than other groups (e.g. antraquinone dyes react 100 times more slowly than azo dyes because the product of the degradation is regenerated into the original one). However, what is interesting about Fenton is that the dyes that react slowly or not efficiently with the \(\text{OH}^*\) radical are often removable by precipitation or complexation with iron (III), which is a reaction product of the Fenton process. As a result less iron (II) is consumed for nothing!
Moreover, in the enhanced system (the Enhanced Thermal Fenton ETF and the Enhanced Photo Fenton) the intention is to concentrate the reactants and to reactivate the iron(III) by reduction (thermally, via radiation UV-VIS, or via electrochemistry).

In conclusion, the Fenton reaction is a very efficient process for treating highly-loaded segregated streams with a high concentration of non readily biodegradable substances.
## ANNEX VII PLANTS HAVING TAKEN PART IN THE DATA COLLECTION

<table>
<thead>
<tr>
<th>Plant code</th>
<th>Name of the textile plant</th>
<th>City</th>
<th>Country</th>
<th>Process carried out</th>
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<td>AT001</td>
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This Annex gives more details about the traditional loose stock dyeing route and the yarn dyeing route as introduced in Section 2.13.5.

16.1 Carpet loose fibre dye-house

Fibre is conventionally dyed in loose form (loose stock) when a large quantity of yarn is required to be of precisely the same shade, for example in a large solid shade (plain coloured) carpet where subtle variations in colour would be visible in service. Single colour batches may be made up of a number of individual dyeings, the dyer adjusting the dye addition to each dyeing in order to achieve the desired final shade of the yarn. Thorough mixing of the individual dyeings in a batch is achieved in a specific mechanical blending operation and during carding. Loose fibre dyeing, therefore, need not be as level as, for example, yarn dyeing, where there is no possibility of levelling the colour by further mechanical processing.

Dyed loose fibre is also used to achieve multicoloured effects in some yarns. In this process fibre dyed to different shades is blended together to produce a large range of designs, such as the “heather” styles in fashion at the present time. Such blends may contain dyed and undyed natural fibre and undyed and pigmented synthetic fibre.

Where the final yarn will contain a blend of wool and synthetic fibres (typically 80 % wool and 20 % polyamide) the required weights of the two components are normally dyed separately to optimise application conditions and dyestuff selection for each fibre type.

Loose-fibre dyeing processes

Scoured wool and new synthetic fibre are presented to the dye-house in a “clean” state and usually require no further treatment to remove contaminants before dyeing. If purchased from outside sources, fibrous raw materials normally arrive on site in the press-packed bales used universally by the textile industry to transport raw fibre.

Within an integrated manufacturing site, for example, one with its own wool scouring facilities, loose fibre may be transferred between the scouring department and blending department or loose fibre dyehouse by pneumatic conveyer or as individual low-density bales from intermediate warehousing.

Special opening machinery is not usually necessary when dealing with previously scoured wool and with new synthetic fibre. Bales are, therefore, often simply weighed and then brought into the dyehouse, opened at the side of the dyeing machine and the required quantity of (dry) fibre loaded manually into the dyeing vessel. Alternatively, fibre may be wet prior to packing in order to facilitate more even more machine loading.

Various types of machines are used for dyeing wool and synthetic fibres in loose form. These include conical pan, pear shaped and radial flow machines (see Chapter 10). Loose fibre is typically packed into these machines manually.

Dyestuffs are dissolved in hot water before being added to the circulating bath. Typical dyestuffs and chemicals for wool and wool-blends are employed (see Sections 2.7.4 and 2.7.6).
In the majority of cases all chemical and dyestuff additions are made manually to the open dyeing machine. Less frequently, or if “pressure” dyeing machinery is being utilised (for synthetic fibres, because wool is normally dyed at atmospheric pressure), pre-dissolved chemicals and dye are introduced to the circulating dye bath from special addition tanks.

The dye bath is typically run for 10 - 15 minutes to ensure even penetration of the liquor through the fibre pack before commencing the heating cycle, raising the temperature of the dye liquor to 98 ºC at a rate of 1 – 2 ºC per minute. On reaching top temperature, dyeing may continue for up to 60 minutes, during which time the dye bath pH may be checked and adjusted by adding further acid to achieve maximum dye uptake. Progress of the dyeing is normally judged by eye and fibre samples are then removed for comparison with a standard.

A dyeing which is judged to be on shade will be terminated and the machine drained. A dyeing which is not of the required colour may have further additions of one or more dyestuffs, the dye bath being returned to the boiler after each addition. Because of the blending operation which follows loose fibre dyeing, it is uncommon for there to be more than one shade addition unless the machine load is the only fibre in a batch.

Dyeing is followed by rinsing with cold water, to remove any surface-bound dyestuff and to cool the dyepack before manual unloading. The machine may be filled with cold water and then run for 10 - 15 minutes before draining. The use of “flood rinsing” in which the dye bath is allowed to refill and then run continuously to drain during the rinsing operation is now much less common due to increases in water charges and effluent disposal costs.

Liquor from both the dyeing and rinsing process may be recycled for further use. In this case the machine must be fitted with an external holding tank. The dye bath may be recycled if a number of dyeings of the same shade are being performed to make up a bigger dye lot. In this case the dye bath is pumped to the reserve tank and dropped back to the dyeing vessel when required for the next dyeing. There are, however, severe limitations to the use of this process because dye uptake is temperature-dependent and starting the dyeing at too high a temperature can result in an unacceptable rate of strike and unlevel application. The selection of dyestuffs and dyeing conditions which promote maximum uptake of dye are required for the successful operation of this process.

In such circumstances it is more usual to recycle the rinse liquor, as the temperature of this liquor is lower and more compatible with dyeing start temperatures. Depending on the design of the machine a reserve tank may not be required for the operation of this process, as the fibre carrier can often be removed with the dyeing vessel full. Both these alternatives conserve water, and to a lesser degree, thermal energy (see also Section 4.5.1.7).

**Application of functional finishes**

A number of functional finishes may be applied to the loose fibre, either during the dyeing process itself or by application from an additional bath following dyeing/rinsing. This is particularly relevant in the “dry spinning” route where there will be no further wet processing after yarn formation. Finishes applied at the loose fibre stage include insect-resist treatments, antistatic treatments, anti-soiling treatments and treatments to counteract yarn/carpet colour change due to light exposure in service (see Section 8.8).

For expediency these finishes are combined with dyeing whenever possible, after-treatments only being used when the chemistry of the two finishes is incompatible or if they require widely differing conditions of temperature and pH. Co-application with the dyes is simply accomplished by adding the product to the dye bath, usually with the dyeing auxiliaries.

After-treatments may require a fresh bath of clean water, or alternatively the rinse bath may be clean enough for reuse.
Specific techniques have been devised to minimise the concentration of mothproofing agents present in the spent liquors from loose fibre dyeing. The formulated commercial product is added at the beginning of the dyeing cycle and dyeing carried out as normal. At the end of the dyeing cycle the pH of the dye bath is lowered with the addition of formic acid and boiling is continued for a further 20 - 30 minutes. These strongly acidic conditions promote uptake of any active ingredient not adsorbed by the wool fibre under normal dyeing conditions and residual concentration can be reduced by up to 98%.

Rinsing the fibre at moderate temperatures is known to cause desorption of mothproofer bound on or close to the surface of the wool fibre. Active ingredient concentrations in the spent rinse bath may consequently be significantly higher than those present in the dye bath. Techniques to minimise the impact of rinse desorption have been developed, in which the rinse bath is recycled, forming the next dye bath, thus eliminating all residues from the rinse liquor and reducing overall water consumption by 50% (see Section 4.7.7 for further details).

Fibre in a drained carrier will contain up to 2 litres/kg of residual water (dry fibre weight). This is initially reduced by either centrifugal extraction or by mangling before evaporative drying in a hot air dryer.
16.2 Carpet yarn dye-house

On integrated sites the spun undyed yarn may be held in a bulk store as either hanks, wound onto cones or wound onto the special centres compatible with package dyeing equipment. Batches of suitable size are drawn from this material to fill individual orders. Commission yarn processors generally receive hanks baled in conventional wool bales.

In hank-based processes the bales are normally brought into the dyehouse and opened at the side of the scouring or dyeing machine ready for manual loading.

Yarn scouring

Scouring is generally carried out as a semi-continuous process in which batches of yarn are transported through a series of aqueous baths containing detergent and alkali or rinsing water. As shown in Figure 2.49, scouring can be carried out both on dyed and undyed yarn. To prevent cross contamination with dyestuffs, integrated yarn manufacturers may operate two scouring machines, one being reserved for scouring white yarn prior to dyeing and the second for the scouring of coloured yarn.

Yarn may be scoured using either hank scouring or package to package (sometimes referred to as single end) processing machinery.

In tape scouring machines (Figure 16.1) hanks are transported through the machine trapped between an upper and lower set of nylon tapes which run in an endless belt through each bowl and mangle set, guided by intermediate rollers in the bottom of each bowl. Bowl working volume is typically between 1 200 and 1 800 litres. Throughput capacity typically ranges from 500 to 1 500 kg/hour. Residence time in each bowl varies between 20 and 45 seconds. Heating is provided by either closed coils in the base of the machine or live steam injection.

![Schematic layout of a hank-scouring machine](image)

Source: [32, ENco, 2001]

Figure 16.1: Schematic layout of a hank-scouring machine
Each bowl is initially charged with the required chemicals and further additions are made during processing, either manually or with a metering device. In machines used only for scouring, the process liquor may flow from bowl four towards bowl one, thus providing a simple countercurrent extraction system. Specific water consumption varies widely, depending on the quantity of yarn processed through the machine before dropping the liquor for cleaning and the extent of any flowdown to drain from the scouring bowls. Values between 2 and 7 litres of water per kg yarn are common.

"Package to package" scouring machines (Figure 16.2) are less common and are of more recent design. With this machinery the whole process may be automated, including drying. Coiling devices take yarn from a number of individual cones and form this into an endless blanket of overlaid coils, laid down automatically onto a moving conveyer belt. The conveyer passes through each of the scouring and rinse bowls. The yarn is transferred to a second conveyer, which then passes through the dryer. The yarn blanket is then uncoiled and the yarn finally rewound onto cones.

![Diagram of a "Package to Package" yarn scouring installation](source: [32, ENco, 2001])

Figure 16.2: Schematic diagram of a "Package to Package" yarn scouring installation

The scouring bowls are of larger volume (3 500 litres) than tape scouring machines and heating may be by direct gas firing. Most machines are equipped with dual yarn coilers, giving an overall capacity of up to 500 kg/hour.

Both hank and single end machines may be utilised only for scouring or the process may be modified to include simultaneous chemical setting of yarn twist and the application of insect-resist (IR) agents.

**Scouring to remove lubricant**
When the machines are operated only to remove lubricant, the first two bowls are charged with detergent and alkali and operate at 50 – 60 °C, while the remaining bowls serve to rinse the yarn with clean water at 20 – 30 °C. Chemical additions are made initially to set the bath concentration at a predetermined level, which is then maintained by further additions during processing.

**Scouring and insect-resist treatment**

Four-bowl machines are normally used if the scouring process is to incorporate a simultaneous insect-resist (IR) treatment. Bowls 1 & 2 are charged as above for scouring, bowl 3 contains clean water for rinsing, and bowl 4 is adapted for insect-resist application. Bowl 4 may be of the low volume type (100 - 200 litres), designed specifically for the treatment of yarn with insect-resist agent in order to minimise the volume of the process liquor and the resulting emissions.

In these installations, insect-resist agent is applied by a process of “continuous exhaustion” rather than physical impregnation and the active substance is stripped from the bath by the yarn, equilibrium bath concentration being maintained by continuous chemical metering at a rate proportional to yarn throughput.

Application is carried out at 50 – 60 °C under acidic conditions (approximately pH 4.5 by either formic or acetic acid) to promote rapid uptake of the active substance in the short yarn residence times available.

The insecticide content of the bowl is such that it cannot be discharged to drain and therefore storage tanks are used to retain the liquor between treatment cycles. Heavy contamination of the liquor with dyestuff removed from the yarn would lead to a change of shade in subsequent yarn lots and so a simple adsorptive filter system may be used to remove dyestuff before storage. This consists of a quantity of wool fibre packed into a filter housing and through which the liquor can be circulated. The liquor is preheated to a minimum of 70 °C to assist effective dyestuff removal. Operating with this liquor renovation system permits reuse of the liquor without the need to discharge to drain.

In the absence of these abatement systems the spent treatment liquor can be pumped from the scouring machine and added to a dark shade dyeing, where uptake at the high dyeing temperatures minimises emissions of active substance. Both loose fibre and yarn dyeing can be done in this way.

A third abatement option uses chemical hydrolysis of the active ingredient to destroy residual insecticide. Spent liquor is pumped from the machine and treated in a separate tank at 98 °C with sodium hydroxide (4g/l) for 60 minutes. The ester and cyano-ester linkages in permethrin and cyfluthrin undergo rapid hydrolysis under these conditions and more than 98 % abatement is achieved. The primary degradation products are at least one order of magnitude less toxic to aquatic invertebrates when compared to the parent molecule. Liquors treated in this way are normally discharged to drain, where the high alkali-content is neutralised by acids from dyeing processes.

More information about these techniques is reported in Section 4.7.7.

**Chemical twist setting**

Five-bowl machines are normally employed if chemical twist setting is to be carried out at the same time as scouring. In this mode Bowls 1 and 2 contain sodium metabisulphite (10 to 20 g/l) in addition to detergent and alkali and Bowl 4 may be charged with hydrogen peroxide (5 to 10g/l) to neutralise any residual bisulphite. In all other respects the process is similar to that described above.
Hanks leave the final mangle of the scouring line with a moisture content of approximately 0.8 litres per kg (dry weight). If the material is to receive no further wet processing, this residual moisture is further reduced by centrifugal extraction before evaporative drying in a hot air dryer.

Scouring in hank form may also be carried out using batch solvent processing equipment, although this practice is now less common. Perchloroethylene is the solvent of choice, and these machines operate on the totally enclosed principle, washing, rinsing and drying being accomplished sequentially within a horizontal drum. All machines are fitted with solvent recovery systems to distil used solvent and recover solvent vapour during drying.

**Hank and package dyeing processes**

Traditionally, carpet yarn dyeing is carried out in hank form, where liquor circulation in the dyeing machine produces a yarn with a characteristic physical property, often described as loft or fullness. Hank dyeing machines are mostly of the Hussong type.

In other sectors of the textile industry it is common to dye yarn in package form – wound onto a perforated centre, through which dye liquor can be circulated under pressure. This process has considerable cost advantage over hank dyeing in that it requires no reeling operation to form the hank and consequently no winding of the hank back onto cones in preparation for weaving or tufting. With wool and wool-blend yarns the extension applied during package winding results in the yarn being set in a “lean” condition and the resultant yarn does not have the required physical characteristics for carpet manufacture. There are, however, a number of ways of overcoming these objections and package dyeing is slowly gaining credence in the carpet yarn dyeing industry. Three basic types of machines may be used for package dyeing wool yarns: horizontal or vertical spindle machines or tube type machines.

Although the machinery employed in hank and package-dyeing processes is different, the dyeing procedures and techniques are essentially the same and are described together.

Considerable care is required to obtain a level (even) dyeing on yarn as there are no opportunities to even up the colour by mechanical blending, as is the case with loose fibre dyeing. Faulty dyeings must be corrected by manipulation in the dye bath, by either removing or adding colour to achieve the final shade. This process can add significantly to the resources consumed in yarn dyeing.

In comparison to synthetic fibres, the rate of dyeing and the extent of dye uptake is less predictable when dyeing wool, as natural variations in the physical and chemical composition of the fibre have a marked effect on these important parameters.

The dyeing of carpet yarns predominantly composed of a blend of wool and polyamide fibre further compromises the dyer because the two fibres have markedly different dyeing properties and special dyeing auxiliaries must be used to achieve a commercially acceptable product. Problems associated with level dyeing are further compounded by the fact that very few shades can be achieved with one single dyestuff; most shades require the simultaneous application of a number of colours in various proportions and which may have different rates of uptake.

The usual approach is to carry out trial laboratory dyeing on a sample of the particular fibre blend and then to apply 5 – 10% less dye in the full scale dyeing, the final shade being achieved by adding additional dye in small portions to achieve the final shade. Depending on the dyestuffs, it may be necessary to cool the dye bath for each of these additions in order to promote even migration of the added dye.

Dyeings which are “overshade” can be corrected by stripping dyestuff from the fibre using an excess of levelling agent or reducing conditions, and then adding further colour to achieve the correct shade. This is a practice of last resort in most dyehouses.
This shade matching procedure is an essential part of the dyeing processes as most dyeing is carried out to an agreed standard, either for internal use in the case of an integrated site or by agreement with the customer. Shade matching is predominantly carried out by eye, the dyer comparing the dyed material with a reference pattern under standard illumination.

In other sectors of the textile industry it is common to use colour matching spectrophotometers to determine the reflectance spectra of the dyed material for comparison with a numerical standard. In some instances these measurements may also be used to generate the dyeing recipe from the standard. These techniques are less successful with carpet yarn because a sample of yarn prepared to represent the cut pile of a carpet, viewed end on, must be used for the result to be meaningful. Despite these difficulties a number of manufacturers do use this technology, claiming significant improvements in batch-to-batch matching and subsequent reductions in material wastage.

Hank dyeing machines may be loaded with either dry or wet yarn. In the latter case the yarn may be carrying moisture from the scouring operation or may have been deliberately wetted out to facilitate even packing. This technique is often applied when loading large hanks of yarn with a high twist factor. Package dyeing machines are loaded dry.

Dyestuffs and chemicals typical of wool and polyamide fibres are employed (see Sections 2.7.4 and 2.7.6.1). Preparation for dyeing normally consists of filling the machine with water at 15 - 30 ºC and adding acids, salts and dyeing auxiliaries as required by the recipe. With hank dyeing machines it is conventional to raise the lid and yarn from the dye bath before adding pre-dissolved dyestuffs. In closed package dyeing machines dyestuffs are added from linked transfer tanks.

The dye liquor is circulated for 10 - 15 minutes at 15 – 30 ºC before commencing the heating programme, raising the temperature of the dye bath, according to the dyeing programme in order to maximise exhaustion.

At this stage the dyer will obtain a sample of the dyed yarn for comparison with a standard, in the case of hank dyeing by raising the load from the dye bath, or with package dyeing equipment, through a sampling port in the machine case. A dyeing which is judged to be on shade at this stage is terminated and the dye bath drained. If further additions of dyestuff are required the dye bath may be cooled, in the case of hank dyeing machines by partial draining and refilling with cold water or in package dyeing machines by circulating cooling water through an internal heat exchange core.

Following addition of dyestuff, the dye bath will be returned to the boil and boiled for 30 - 60 minutes before a further yarn sample is taken for shade matching. This operation may be repeated several times before the dyer is satisfied that the bulk material matches the standard. The spent dye bath is then drained and the yarn rinsed in clean water at 15 – 30 ºC for 10 - 20 minutes before finally being allowed to drain, ready for unloading.

In some instances the spent rinse bath may contain little or no residual colour. As the temperature of this liquor is compatible with dyeing start temperatures, it may be retained in the dyeing machine and used for a subsequent dyeing. This practice reduces water usage by up to 50 %.

**Application of functional finishes**

A number of functional finishes may be applied, either with the dyestuffs or from additional baths of clean water following dyeing. These include insect-resist treatments, flame-retardant treatments and antistatic treatments.

**Insect-Resist treatments**
Traditionally formulated insecticides, based on synthetic pyrethroids or Sulcofuron, were added to the dyeing with the dyestuffs. To minimise residues and control fugitive emissions this basic procedure has been modified. The formulated product is now added to the dyeing at a later stage; to avoid the spillages that occur during yarn lowering and dyeing, auxiliaries are selected which do not interfere with exhaustion. Emissions from dyeings carried out under acidic conditions are normally within permitted limits, but experience has shown that these standards cannot be met when dyeing under more neutral conditions. In this case, the insect-resist agent is applied from a blank after-treatment bath in the presence of formic acid at a temperature of 70 - 80 °C (see also Section 4.7.7).

**Antistatic treatments**

Antistatic finish applied to the pile yarn is mainly based on a cationic surfactant system, which is readily applied to the fibre under mildly alkali conditions. Cationic compounds are not compatible with anionic dyestuffs and these materials cannot, therefore, be incorporated in the dye bath, but must instead be applied as after-treatments. The process consists of preparing a fresh bath of clean water, adjusting the pH and adding the required quantity of the proprietary product. The liquor is raised to 60 °C and run at this temperature for 20 - 30 minutes, followed by rinsing in clean water.

**Flame-retardant treatments**

Potassium salts of fluoro complexes of zirconium (potassium hexafluorozirconate) are typically used for wool and wool-blend fibres. Typical application conditions for carpet wool yarn are as follows:

- rinsing is required to remove interfering sulphate and phosphate ions, if present;
- bath set up at 20 – 30 °C, pH 3 with hydrochloric acid (10 % o.w.f.) or formic acid (15 % o.w.f.) and citric acid (4 % o.w.f.);
- addition of potassium hexafluorozirconate (3 to 8 % o.w.f. depending on the final specification to be achieved and the substrate) dissolved in 10 times its weight of hot water;
- temperature raised at 1 – 2 °C per minute to 60 °C and held at this temperature for 30 minutes;
- rinsing in cold water for 10 - 20 minutes.

**Other treatments**

In addition to application of the above functional finishes, which are all invariably carried out in conjunction with colouration, yarn dyeing equipment may be used for other specific yarn preparation or treatment procedures, principally bleaching and twist setting. These are described separately below.

**Bleaching**

The industry favours the neutral white colour obtained by an oxidation bleach, followed by a reductive bleach. Typical processing conditions would be:

- at 40 °C, run yarn in liquor containing 3 % o.w.f. proprietary stabiliser, 1.5 % o.w.f. sodium tri-polyphosphate, 20 % o.w.f. hydrogen peroxide (35 %). Raise liquor to 70 °C, circulate 40 minutes and drain.
- run in a fresh bath containing 0.2 % o.w.f. formic acid (85 %) and 0.75 % o.w.f. sodium hydrosulphite. Raise to 50 °C, circulate 20 minutes, drain and rinse in cold water.

**Yarn (dye bath) twist setting**

This process is not always carried out as a separate treatment. In fact, during the hank dyeing of wool yarns the twist inserted during spinning is stabilised by chemical changes within the fibre at the temperatures reached by the boiling dye bath.
Yarn may, however, be twist set in hank form using conventional hank dyeing equipment. Typical processing conditions would be:

- raise dye bath to 80 °C, add 5 % on the weight of yarn sodium metabisulphite, immerse yarn, circulate liquor for 15 minutes, drain machine.
- rinse cold with liquor containing 0.8 % o.w.f. hydrogen peroxide (35 %) for 15 minutes.
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 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. Definitions
### ISO country codes

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<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Member States (*)</strong></td>
<td></td>
</tr>
<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>FR</td>
<td>France</td>
</tr>
<tr>
<td>IT</td>
<td>Italy</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>
<tr>
<td><strong>Non-member countries</strong></td>
<td></td>
</tr>
<tr>
<td>NO</td>
<td>Norway</td>
</tr>
<tr>
<td>US</td>
<td>United States</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).
## Monetary units

<table>
<thead>
<tr>
<th>Code</th>
<th>Country/territory</th>
<th>Currency</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUR</td>
<td>Euro area (2)</td>
<td>euro (pl. euros)</td>
</tr>
<tr>
<td>DKK</td>
<td>Denmark</td>
<td>Danish krone (pl. kroner)</td>
</tr>
<tr>
<td>SEK</td>
<td>Sweden</td>
<td>Swedish krona (pl. kronor)</td>
</tr>
</tbody>
</table>

### Member State currencies

<table>
<thead>
<tr>
<th>Code</th>
<th>Country/territory</th>
<th>Currency</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUR</td>
<td>Euro area (2)</td>
<td>euro (pl. euros)</td>
</tr>
<tr>
<td>DKK</td>
<td>Denmark</td>
<td>Danish krone (pl. kroner)</td>
</tr>
<tr>
<td>SEK</td>
<td>Sweden</td>
<td>Swedish krona (pl. kronor)</td>
</tr>
</tbody>
</table>

### Other currencies

<table>
<thead>
<tr>
<th>Code</th>
<th>Country/territory</th>
<th>Currency</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUD</td>
<td>Australia</td>
<td>Australian dollar</td>
</tr>
<tr>
<td>USD</td>
<td>United States</td>
<td>US dollar</td>
</tr>
</tbody>
</table>

(1) ISO 4217 codes.
(2) Includes Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Portugal, Slovakia, Slovenia and Spain.
Glossary

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 – is the notation used to indicate approximation.

The symbol $\Delta$ is the notation used to indicate a difference.

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>G</td>
<td>giga</td>
<td>$10^9$</td>
<td>Billion</td>
<td>1 000 000 000</td>
</tr>
<tr>
<td>M</td>
<td>mega</td>
<td>$10^6$</td>
<td>Million</td>
<td>1 000 000</td>
</tr>
<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>
<tr>
<td>µ</td>
<td>micro</td>
<td>$10^{-6}$</td>
<td>Millionth</td>
<td>0.000 001</td>
</tr>
<tr>
<td>n</td>
<td>nano</td>
<td>$10^{-9}$</td>
<td>Billionth</td>
<td>0.000 000 001</td>
</tr>
</tbody>
</table>
# Units and measures

<table>
<thead>
<tr>
<th>Unit symbol</th>
<th>Unit name</th>
<th>Measure name (measure symbol)</th>
<th>Conversion and comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>atm</td>
<td>normal atmosphere</td>
<td>Pressure (P)</td>
<td>1 atm = 101 325 N/m²</td>
</tr>
<tr>
<td>bar</td>
<td>bar</td>
<td>Pressure (P)</td>
<td>1.013 bar = 100 kPa = 1 atm</td>
</tr>
<tr>
<td>°C</td>
<td>degree Celsius</td>
<td>Temperature (T)</td>
<td>temperature difference (ΔT)</td>
</tr>
<tr>
<td>d</td>
<td>day</td>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>gram</td>
<td>Weight</td>
<td></td>
</tr>
<tr>
<td>h</td>
<td>hour</td>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>Hz</td>
<td>hertz</td>
<td>Frequency (f)</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>joule</td>
<td>Energy</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Kelvin</td>
<td>Temperature (T)</td>
<td>0 °C = 273.15 K</td>
</tr>
<tr>
<td>kcal</td>
<td>kilocalorie</td>
<td>Energy</td>
<td>1 kcal = 4.1868 kJ</td>
</tr>
<tr>
<td>kg</td>
<td>kilogram</td>
<td>Weight</td>
<td></td>
</tr>
<tr>
<td>kJ</td>
<td>kilojoule</td>
<td>Energy</td>
<td></td>
</tr>
<tr>
<td>kPa</td>
<td>kilopascal</td>
<td>Pressure</td>
<td></td>
</tr>
<tr>
<td>kWh</td>
<td>kilowatt-hour</td>
<td>Energy</td>
<td>1 kWh = 3 600 kJ</td>
</tr>
<tr>
<td>l</td>
<td>litre</td>
<td>Volume</td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>metre</td>
<td>Length</td>
<td></td>
</tr>
<tr>
<td>m²</td>
<td>square metre</td>
<td>Area</td>
<td></td>
</tr>
<tr>
<td>m³</td>
<td>cubic metre</td>
<td>Volume</td>
<td></td>
</tr>
<tr>
<td>mg</td>
<td>milligram</td>
<td>Weight</td>
<td>1 mg = 10⁻³ g</td>
</tr>
<tr>
<td>mm</td>
<td>millimetre</td>
<td>Weight</td>
<td>1 mm = 10⁻³ m</td>
</tr>
<tr>
<td>min</td>
<td>minute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MWₑ</td>
<td>megawatts electric (energy)</td>
<td>Electric energy</td>
<td></td>
</tr>
<tr>
<td>MW₉h</td>
<td>megawatts thermal (energy)</td>
<td>Thermal energy</td>
<td>Heat</td>
</tr>
<tr>
<td>nm</td>
<td>nanometre</td>
<td></td>
<td>1 nm = 10⁻⁹ m</td>
</tr>
<tr>
<td>Nm³</td>
<td>normal cubic metre</td>
<td>Volume</td>
<td>at 101.325 kPa, 273.15 K</td>
</tr>
<tr>
<td>ouE</td>
<td>European odour unit</td>
<td>Odour</td>
<td></td>
</tr>
<tr>
<td>Pa</td>
<td>pascal</td>
<td></td>
<td>1 Pa = 1 N/m²</td>
</tr>
<tr>
<td>ppm</td>
<td>parts per million</td>
<td>Composition of mixtures</td>
<td>1 ppm = 10⁻⁹</td>
</tr>
<tr>
<td>ppmw</td>
<td>parts per million by weight</td>
<td>Composition of mixtures</td>
<td></td>
</tr>
<tr>
<td>ppmv</td>
<td>parts per million by volume</td>
<td>Composition of mixtures</td>
<td></td>
</tr>
<tr>
<td>rpm RPM</td>
<td>Revolutions per minute</td>
<td>Rotational speed, frequency</td>
<td></td>
</tr>
<tr>
<td>s</td>
<td>second</td>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>t</td>
<td>metric tonne</td>
<td>Weight</td>
<td>1 t = 1 000 kg or 10⁶ g</td>
</tr>
<tr>
<td>t/d</td>
<td>tonnes per day</td>
<td>Mass flow</td>
<td>Materials consumption</td>
</tr>
<tr>
<td>t/yr</td>
<td>tonnes per year</td>
<td>Mass flow</td>
<td>Materials consumption</td>
</tr>
<tr>
<td>vol-% % v/v</td>
<td>percentage by volume</td>
<td>Composition of mixtures</td>
<td></td>
</tr>
</tbody>
</table>
### Glossary

<table>
<thead>
<tr>
<th>Unit symbol</th>
<th>Unit name</th>
<th>Measure name (measure symbol)</th>
<th>Conversion and comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>wt-%</td>
<td>percentage by weight</td>
<td>Composition of mixtures</td>
<td></td>
</tr>
<tr>
<td>% w/w</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>watt</td>
<td>Power</td>
<td>1 W = 1 J/s</td>
</tr>
<tr>
<td>yr</td>
<td>year</td>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>μm</td>
<td>micrometre</td>
<td>Length</td>
<td>1 μm = 10⁻⁶ m</td>
</tr>
</tbody>
</table>
## Chemical elements

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Symbol</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>Silver</td>
<td>He</td>
<td>Helium</td>
</tr>
<tr>
<td>Al</td>
<td>Aluminium</td>
<td>Hg</td>
<td>Mercury</td>
</tr>
<tr>
<td>Ar</td>
<td>Argon</td>
<td>I</td>
<td>Iodine</td>
</tr>
<tr>
<td>As</td>
<td>Arsenic</td>
<td>K</td>
<td>Potassium</td>
</tr>
<tr>
<td>B</td>
<td>Boron</td>
<td>Mg</td>
<td>Magnesium</td>
</tr>
<tr>
<td>Ba</td>
<td>Barium</td>
<td>Mn</td>
<td>Manganese</td>
</tr>
<tr>
<td>Br</td>
<td>Bromine</td>
<td>N</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>C</td>
<td>Carbon</td>
<td>Na</td>
<td>Sodium</td>
</tr>
<tr>
<td>Ca</td>
<td>Calcium</td>
<td>Ni</td>
<td>Nickel</td>
</tr>
<tr>
<td>Cd</td>
<td>Cadmium</td>
<td>O</td>
<td>Oxygen</td>
</tr>
<tr>
<td>Cl</td>
<td>Chlorine</td>
<td>P</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>Co</td>
<td>Cobalt</td>
<td>Pb</td>
<td>Lead</td>
</tr>
<tr>
<td>Cr</td>
<td>Chromium</td>
<td>S</td>
<td>Sulphur</td>
</tr>
<tr>
<td>Cu</td>
<td>Copper</td>
<td>Sb</td>
<td>Antimony</td>
</tr>
<tr>
<td>F</td>
<td>Fluorine</td>
<td>Si</td>
<td>Silicon</td>
</tr>
<tr>
<td>Fe</td>
<td>Iron</td>
<td>Sn</td>
<td>Tin</td>
</tr>
<tr>
<td>H</td>
<td>Hydrogen</td>
<td>Ti</td>
<td>Titanium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zn</td>
<td>Zinc</td>
</tr>
</tbody>
</table>
# Chemical formulae commonly used in this document

<table>
<thead>
<tr>
<th>Chemical formula</th>
<th>Name (explanation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₂Cl₂</td>
<td>Dichloromethane or methylene chloride</td>
</tr>
<tr>
<td>Cl₂</td>
<td>Chlorine</td>
</tr>
<tr>
<td>ClO₂</td>
<td>Chlorine dioxide</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>H₂O₂</td>
<td>Hydrogen peroxide</td>
</tr>
<tr>
<td>H₂S</td>
<td>Hydrogen sulphide</td>
</tr>
<tr>
<td>H₂O</td>
<td>Water</td>
</tr>
<tr>
<td>H₂O₂</td>
<td>Hydrogen peroxide</td>
</tr>
<tr>
<td>H₂SO₄</td>
<td>Sulphuric acid</td>
</tr>
<tr>
<td>HCl</td>
<td>Hydrochloric acid</td>
</tr>
<tr>
<td>NaClO</td>
<td>Sodium hypochlorite</td>
</tr>
<tr>
<td>NaClO₂</td>
<td>Sodium chlorite</td>
</tr>
<tr>
<td>NaOH</td>
<td>Sodium hydroxide. Also called caustic soda</td>
</tr>
<tr>
<td>NH₃</td>
<td>Ammonia</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Nitrogen oxides (mixture of NO and NO₂)</td>
</tr>
<tr>
<td>O₂</td>
<td>Oxygen</td>
</tr>
<tr>
<td>SO₂</td>
<td>Sulphur dioxide</td>
</tr>
<tr>
<td>SbO₃</td>
<td>Antimony trioxide</td>
</tr>
<tr>
<td>TiO₂</td>
<td>Titanium dioxide</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full phrase</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>AE</td>
<td>Alcohol ethoxylates</td>
</tr>
<tr>
<td>AMS</td>
<td>Automated measuring system</td>
</tr>
<tr>
<td>APE</td>
<td>Alkyl phenol ethoxylates</td>
</tr>
<tr>
<td>APEO</td>
<td>Alkyl phenol ethoxylates</td>
</tr>
<tr>
<td>AOX</td>
<td>Adsorbable organically bound halogens</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>BAT</td>
<td>Best Available Techniques</td>
</tr>
<tr>
<td>BAT-AEL</td>
<td>Best Available Techniques - associated emission level</td>
</tr>
<tr>
<td>BAT-AEPL</td>
<td>Best Available Techniques - associated performance emission level</td>
</tr>
<tr>
<td>BFW</td>
<td>Boiler feed-water</td>
</tr>
<tr>
<td>BF</td>
<td>Bag filter</td>
</tr>
<tr>
<td>BOD</td>
<td>Biochemical oxygen demand</td>
</tr>
<tr>
<td>BREF</td>
<td>BAT reference document</td>
</tr>
<tr>
<td>BSI</td>
<td>British Standards Institution</td>
</tr>
<tr>
<td>BTEX</td>
<td>Benzene, toluene, ethylbenzene, xylene</td>
</tr>
<tr>
<td>BTX</td>
<td>Benzene, toluene, xylene</td>
</tr>
<tr>
<td>CAS</td>
<td>Chemical abstracts service (chemicals registry number)</td>
</tr>
<tr>
<td>CEFIC</td>
<td>Conseil Européen de l’Industrie Chimique (European Chemical Industry Council)</td>
</tr>
<tr>
<td>CEMS</td>
<td>Continuous emissions monitoring system</td>
</tr>
<tr>
<td>CEN</td>
<td>Comité Européen de Normalisation (European Committee for standardisation)</td>
</tr>
<tr>
<td>C.I.</td>
<td>Colour index</td>
</tr>
<tr>
<td>CMC</td>
<td>Carboxymethyl cellulose</td>
</tr>
<tr>
<td>CMR</td>
<td>Carcinogenic, mutagenic, reprotoxic</td>
</tr>
<tr>
<td>CMS</td>
<td>Chemicals management system</td>
</tr>
<tr>
<td>CO</td>
<td>Cotton</td>
</tr>
<tr>
<td>COD</td>
<td>Chemical oxygen demand</td>
</tr>
<tr>
<td>CPI</td>
<td>Corrugated plate interceptor</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
</tr>
<tr>
<td>CT</td>
<td>Cellulose triacetate</td>
</tr>
<tr>
<td>CTO</td>
<td>Catalytic thermal oxidiser</td>
</tr>
<tr>
<td>CU</td>
<td>Cupro</td>
</tr>
<tr>
<td>CV</td>
<td>Viscose</td>
</tr>
<tr>
<td>DAF</td>
<td>Dissolved air flotation</td>
</tr>
<tr>
<td>DEFRA</td>
<td>Department for Environment, Food and Rural Affairs (UK)</td>
</tr>
<tr>
<td>DIN</td>
<td>Deutsches Institut für Normung (German national organisation for standardisation)</td>
</tr>
<tr>
<td>DOC</td>
<td>Dissolved Organic Carbon</td>
</tr>
<tr>
<td>DTPA</td>
<td>Diethylenetriamine pentaacetae</td>
</tr>
<tr>
<td>DTPMP</td>
<td>Diethylenetriaminepentaacetic acid</td>
</tr>
<tr>
<td>EA</td>
<td>Environment Agency (England and Wales)</td>
</tr>
<tr>
<td>EDTA</td>
<td>Ethylenediaminetetraacetic acid</td>
</tr>
<tr>
<td>EDTMP</td>
<td>Ethylenediaminetetra(methylene phosphonic acid)</td>
</tr>
<tr>
<td>EEA</td>
<td>European Environment Agency</td>
</tr>
<tr>
<td>E-Fac</td>
<td>Emission factor</td>
</tr>
<tr>
<td>EFTA</td>
<td>European Free Trade Association (established on 3 May 1960)</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental impact assessment</td>
</tr>
<tr>
<td>EL</td>
<td>Elastane</td>
</tr>
<tr>
<td>ELV</td>
<td>Emission limit value</td>
</tr>
<tr>
<td>EMAS</td>
<td>Eco-Management and Audit Scheme (Council Regulation (EC) No 1221/2009)</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>EO/PO</td>
<td>Ethylene oxide/propylene oxide (group of copolymers)</td>
</tr>
<tr>
<td>EOP</td>
<td>End-of-pipe (measure)</td>
</tr>
<tr>
<td>EOX</td>
<td>Extractable organic halogens</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency (US)</td>
</tr>
<tr>
<td>ESP</td>
<td>Electrostatic precipitator</td>
</tr>
<tr>
<td>EQS</td>
<td>Environmental quality standard</td>
</tr>
<tr>
<td>ETAD</td>
<td>Ecological and Toxicological Association of the Dyes and Organic Pigments Manufacturers</td>
</tr>
<tr>
<td>EU-15</td>
<td>Member States of the European Union before 1 May 2004</td>
</tr>
<tr>
<td>EU-25</td>
<td>Member States of the European Union from 1 May 2004 until 31 December 2006</td>
</tr>
<tr>
<td>EU-27</td>
<td>Member States of the European Union from 1 January 2007 until 30 June 2013</td>
</tr>
<tr>
<td>EU-28</td>
<td>Member States of the European Union from 1 July 2013</td>
</tr>
<tr>
<td>EURATEX</td>
<td>The European Apparel and Textile Confederation</td>
</tr>
<tr>
<td>EVA</td>
<td>Ethylene vinylacetate</td>
</tr>
<tr>
<td>FID</td>
<td>Flame ionisation detector</td>
</tr>
<tr>
<td>FR</td>
<td>Flame retardant</td>
</tr>
<tr>
<td>HC</td>
<td>Hydrocarbons</td>
</tr>
<tr>
<td>HCH</td>
<td>Hexachlorocyclohexane (pesticide)</td>
</tr>
<tr>
<td>HP</td>
<td>High pressure</td>
</tr>
<tr>
<td>HT</td>
<td>High temperature (process, machine)</td>
</tr>
<tr>
<td>IED</td>
<td>Industrial Emissions Directive (2010/75/EU)</td>
</tr>
<tr>
<td>IGR</td>
<td>Insect growth regulators (group of pesticides)</td>
</tr>
<tr>
<td>IK</td>
<td>Indanthren cold (group of vat dyes)</td>
</tr>
<tr>
<td>IN</td>
<td>Indanthren normal (group of vat dyes)</td>
</tr>
<tr>
<td>IPPC</td>
<td>Integrated pollution prevention and control</td>
</tr>
<tr>
<td>IR</td>
<td>Infrared</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organisation for Standardisation</td>
</tr>
<tr>
<td>IWR</td>
<td>Indanthren warm (group of vat dyes)</td>
</tr>
<tr>
<td>LCP</td>
<td>Large combustion plant</td>
</tr>
<tr>
<td>LP</td>
<td>Low pressure</td>
</tr>
<tr>
<td>L.R.</td>
<td>Liquor ratio</td>
</tr>
<tr>
<td>MBR</td>
<td>Membrane bioreactor</td>
</tr>
<tr>
<td>MEL</td>
<td>Minimum Effect Level</td>
</tr>
<tr>
<td>MF</td>
<td>Microfiltration</td>
</tr>
<tr>
<td>MP</td>
<td>Medium pressure</td>
</tr>
<tr>
<td>MS</td>
<td>(European Union) Member State</td>
</tr>
<tr>
<td>MSW</td>
<td>Municipal solid waste</td>
</tr>
<tr>
<td>N</td>
<td>Normal – refers to volume of gases under normal operating conditions with a temperature of 273.15 K and pressure of 101.325 kPa</td>
</tr>
<tr>
<td>NA</td>
<td>Not applicable</td>
</tr>
<tr>
<td>ND</td>
<td>Not determined / Not detectable</td>
</tr>
<tr>
<td>NFR</td>
<td>Nitrogen flame-retardant</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-governmental organisation</td>
</tr>
<tr>
<td>NMVOC</td>
<td>Non-Methane Volatile Organic Compound</td>
</tr>
<tr>
<td>NOC</td>
<td>Normal operating conditions</td>
</tr>
<tr>
<td>NPE</td>
<td>Nonyl phenol ethoxylates</td>
</tr>
<tr>
<td>NRA</td>
<td>National Registration Authority (Australia)</td>
</tr>
<tr>
<td>NTA</td>
<td>Nitrilotriacetatic acid</td>
</tr>
<tr>
<td>OEC</td>
<td>Organochlorines (group of pesticides)</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation and Development</td>
</tr>
<tr>
<td>OEL</td>
<td>Observable Effect Level</td>
</tr>
<tr>
<td>OP</td>
<td>Organophosphates (group of pesticides)</td>
</tr>
<tr>
<td>OTNOC</td>
<td>Other than normal operating conditions</td>
</tr>
<tr>
<td>o.w.b</td>
<td>On the weight of the bath</td>
</tr>
<tr>
<td>o.w.f</td>
<td>On the weight of the fibre</td>
</tr>
<tr>
<td>PA</td>
<td>Polyamide fibres</td>
</tr>
<tr>
<td>PAC</td>
<td>Polycrylonitrile fibres</td>
</tr>
<tr>
<td>PAH</td>
<td>Polycyclic aromatic hydrocarbons</td>
</tr>
<tr>
<td>PAN</td>
<td>Acrylonitrile</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
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</tr>
<tr>
<td>PBT</td>
<td>Polybutylene terephthalate</td>
</tr>
<tr>
<td>PCDD/Fs</td>
<td>Polychlorinated dibenzodioxins/dibenzofurans</td>
</tr>
<tr>
<td>PCP</td>
<td>Pentachloro phenol</td>
</tr>
<tr>
<td>PE</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>PES</td>
<td>Polyester fibres</td>
</tr>
<tr>
<td>PET</td>
<td>Polyethylene terephthalate</td>
</tr>
<tr>
<td>PFC</td>
<td>Perfluorocarbon, containing 8 atoms of carbon (C8) or less (C6 or C4)</td>
</tr>
<tr>
<td>PFR</td>
<td>Phosphorus flame-retardant</td>
</tr>
<tr>
<td>ROI</td>
<td>Return on investment</td>
</tr>
<tr>
<td>PP</td>
<td>Polypropylene</td>
</tr>
<tr>
<td>PPE</td>
<td>Personal protective equipment</td>
</tr>
<tr>
<td>PTT</td>
<td>Polytrimethylene terephthalate</td>
</tr>
<tr>
<td>PU</td>
<td>Polyurethane</td>
</tr>
<tr>
<td>PVA</td>
<td>Polyvinyl alcohol</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl chloride</td>
</tr>
<tr>
<td>RTO</td>
<td>Regenerative thermal oxidiser</td>
</tr>
<tr>
<td>SBR</td>
<td>Styrene butadiene rubber</td>
</tr>
<tr>
<td>SEC</td>
<td>Specific energy consumption</td>
</tr>
<tr>
<td>SI</td>
<td>Silk</td>
</tr>
<tr>
<td>SP</td>
<td>Synthetic pyrethroids (group of pesticides)</td>
</tr>
<tr>
<td>SS</td>
<td>Suspended solids</td>
</tr>
<tr>
<td>TDS</td>
<td>Total dissolved solids</td>
</tr>
<tr>
<td>TEF</td>
<td>Toxic equivalency factor</td>
</tr>
<tr>
<td>TEGEWA</td>
<td>Verband der Textilhilfsmittel-, Lederhilfsmittel-, Gerbstoff- und Waschrohstoff-Industrie e.V. (Industry Association)</td>
</tr>
<tr>
<td>TEQ</td>
<td>Toxicity equivalents (iTEQ: international toxicity equivalents)</td>
</tr>
<tr>
<td>TFI</td>
<td>Textile finishing industry</td>
</tr>
<tr>
<td>THPC</td>
<td>Tetrakis(hydroxymethyl)phosphonium chloride</td>
</tr>
<tr>
<td>TKN</td>
<td>Total Kjeldahl nitrogen</td>
</tr>
<tr>
<td>TO</td>
<td>Thermal oxidiser</td>
</tr>
<tr>
<td>TOC</td>
<td>Total organic carbon</td>
</tr>
<tr>
<td>TS</td>
<td>Total solids</td>
</tr>
<tr>
<td>TSS</td>
<td>Total suspended solids</td>
</tr>
<tr>
<td>TVOC</td>
<td>Total volatile organic carbon</td>
</tr>
<tr>
<td>TWG</td>
<td>Technical Working Group</td>
</tr>
<tr>
<td>UF</td>
<td>Ultrafiltration</td>
</tr>
<tr>
<td>UBA</td>
<td>Umweltbundesamt – Federal Environment Agency, i.e. from Germany or Austria</td>
</tr>
<tr>
<td>ULLR</td>
<td>Ultra-Low Liquor Ratio</td>
</tr>
<tr>
<td>UV</td>
<td>Ultraviolet</td>
</tr>
<tr>
<td>UWWT(P)</td>
<td>Urban waste water treatment (plant)</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile organic compound</td>
</tr>
<tr>
<td>WEA</td>
<td>Whole effluent assessment</td>
</tr>
<tr>
<td>WESP</td>
<td>Wet electrostatic precipitator</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organisation</td>
</tr>
<tr>
<td>WO</td>
<td>Wool</td>
</tr>
<tr>
<td>WW</td>
<td>Waste water</td>
</tr>
<tr>
<td>WWT(P)</td>
<td>Waste water treatment (plant)</td>
</tr>
<tr>
<td>x-SBR</td>
<td>Carboxylated SBR</td>
</tr>
</tbody>
</table>
### Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Absorption</strong></td>
<td>A volume process in which one substance permeates another (soaking up).</td>
</tr>
<tr>
<td><strong>Accreditation</strong></td>
<td>Formal recognition that a testing laboratory is competent to carry out specific tests or specific types of tests. Laboratory accreditation uses criteria and procedures specifically developed to determine technical competence based on the international standard ISO/IEC 17025.</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>Associated with measured values. It is the degree of how close a measurement is to the actual (true) value.</td>
</tr>
<tr>
<td><strong>Acidification</strong></td>
<td>Raising the acidity (lowering the pH) of a fluid by the addition of an acid.</td>
</tr>
<tr>
<td><strong>Acidity</strong></td>
<td>Measure of the capacity of a solution to neutralise a strong base.</td>
</tr>
<tr>
<td><strong>Activated sludge process</strong></td>
<td>A biological process for treating municipal and industrial waste waters by the use of microorganisms under aerobic conditions.</td>
</tr>
<tr>
<td><strong>Acute effect</strong></td>
<td>An adverse effect on any living organism in which severe symptoms develop rapidly but often subside after the exposure stops.</td>
</tr>
<tr>
<td><strong>Acute pollution</strong></td>
<td>Pollution arising from infrequent events, unplanned events or accidents (see also: chronic pollution).</td>
</tr>
<tr>
<td><strong>Acute toxicity</strong></td>
<td>Toxicity which is severe enough to produce a response rapidly (typically a response observed in 48 or 96 hours). Acute toxicity studies in animals aim to assess the human risk from single exposure to high doses.</td>
</tr>
<tr>
<td><strong>Adsorption</strong></td>
<td>The adhesion of molecules of a gas, liquid or dissolved substance to a solid surface resulting in the formation of a thin film on the surface of the solid.</td>
</tr>
<tr>
<td><strong>Aerobic processes</strong></td>
<td>Biological processes that occur in the presence of oxygen.</td>
</tr>
<tr>
<td><strong>Alkalinity</strong></td>
<td>The acid-neutralising capacity of solutes in a water sample. This capacity is a result of carbonate, bicarbonate, hydroxide and occasionally borate, silicate and phosphate content of the water. It is equivalent to the stoichiometric sum of the basis in solution. It is expressed in milliequivalents per litre.</td>
</tr>
<tr>
<td><strong>Ammoniacal nitrogen</strong></td>
<td>Nitrogen present as ammonia and ammonium ions in liquid effluents.</td>
</tr>
<tr>
<td><strong>Anaerobic processes</strong></td>
<td>Biological processes that occur in the absence of oxygen and other electron-accepting substances except carbon dioxide/carbonate.</td>
</tr>
<tr>
<td><strong>Anodising</strong></td>
<td>Anodic oxidation – an electrolytic process in which the surface layer of a metal, such as aluminium, magnesium or zinc is converted to a coating, usually an oxide, having protective, decorative or functional properties.</td>
</tr>
<tr>
<td><strong>Anoxic denitrification</strong></td>
<td>Bacterial process by which nitrate nitrogen is converted to inert nitrogen gas in the absence of oxygen.</td>
</tr>
<tr>
<td><strong>A/O process</strong></td>
<td>Process used for combined carbon oxidation and phosphorus removal from waste waters. It is a suspended-growth system similar to the activated sludge process that combines anaerobic (10-20 % total reactor volume) and aerobic (oxic) sections in sequence.</td>
</tr>
<tr>
<td><strong>AOX</strong></td>
<td>Adsorbable organically bound halogens in water; the most frequently used measurement standard is EN ISO 9562. The AOX measurements are expressed in mg Cl/l of water or mg Cl/g of substance.</td>
</tr>
<tr>
<td><strong>Aquatic toxicity</strong></td>
<td>A measure of the adverse effects of a given pollutant on aquatic life. The most common parameters are given below. IC\textsubscript{10} – inhibition concentration of bacterial growth (10 % inhibition). Concentrations above the IC\textsubscript{10} value may strongly affect the efficiency of a biological treatment plant or even completely poison the activated sludge. LC\textsubscript{50} – lethal concentration (the concentration which is lethal to 50 % of the test organisms).</td>
</tr>
<tr>
<td>Glossary</td>
<td>Working Draft in Progress</td>
</tr>
<tr>
<td>----------</td>
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</tr>
<tr>
<td>Assimilative capacity</td>
<td>The capacity of a natural body of water to receive waste waters or toxic materials without harmful effects and without damage to aquatic life or humans who consume the water.</td>
</tr>
<tr>
<td>Base case</td>
<td>The existing situation. The projection of the base case is sometimes referred to as ‘business as usual’ or the ‘baseline’ scenario.</td>
</tr>
<tr>
<td>Base year</td>
<td>In the context of processing time-dependent data such as costs or emissions, the base year is the first of the years for which data have been assembled.</td>
</tr>
<tr>
<td>BFW</td>
<td>Boiler feed-water. Water used to supply (‘feed’) a boiler to generate steam or hot water.</td>
</tr>
<tr>
<td>BHF</td>
<td>Bag house filter. Also fabric filter (FF). Abatement equipment used for the removal of particulate matter from gases. The gases are forced to pass through removable filter bags, and the particulate matter collected by the bag filters is normally periodically removed by shaking or the application of a reverse airflow.</td>
</tr>
<tr>
<td>Biodegradability</td>
<td>A measure of the ease with which a substance will degrade as a result of biological metabolism.</td>
</tr>
<tr>
<td>Bioeliminability</td>
<td>A measure of the ability of an organic substance to be removed from the effluent as a consequence of all elimination mechanisms that can take place in a biological plant (including biodegradation). It is measured by the bio-elimination test OECD 302 B, which determines the total effect of all elimination mechanisms in a biological treatment plant: - biodegradation (measured over a long period - up to 28 days - in order to account for the biodegradation of substances that necessitate the development of specially acclimatised bacteria capable of digesting them); - adsorption on activated sludge; - stripping of volatile substances; - hydrolysis and precipitation processes. It is usually expressed in % (of the substance).</td>
</tr>
<tr>
<td>Biological nutrient removal</td>
<td>The removal of nitrogen and/or phosphorus from aqueous effluents in biological treatment processes.</td>
</tr>
<tr>
<td>Biomass</td>
<td>The biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste (Directive 2009/28/EC on the promotion of the use of energy from renewable sources).</td>
</tr>
<tr>
<td>Bioremediation</td>
<td>The use of living organisms, e.g. bacteria, to remove pollutants from contaminated sites.</td>
</tr>
<tr>
<td>Bleaching agent</td>
<td>The active substance providing the bleaching effect. The bleaching agent is formed/produced by activating the bleach.</td>
</tr>
<tr>
<td>Bleach</td>
<td>The formulation used in the bleaching process.</td>
</tr>
<tr>
<td>BOD</td>
<td>Biochemical oxygen demand – the quantity of dissolved oxygen required by microorganisms in order to decompose organic matter in a given water sample at a certain temperature over a specific time period. The unit of measurement is mg O₂/l. In Europe, BOD is usually measured after 3 (BOD₃), 5 (BOD₅) or 7 (BOD₇) days using EN 1899-1 and 1899-2.</td>
</tr>
<tr>
<td>By-product</td>
<td>A substance or object, resulting from a production process, the primary aim of which is not the production of that item and which is not regarded as being waste, and which meets the requirements of Article 5 of Directive 2008/98/EC on waste.</td>
</tr>
<tr>
<td>Cake</td>
<td>Solid or semisolid material remaining on a filter after pressure filtration.</td>
</tr>
<tr>
<td>Calibration</td>
<td>Set of operations that establishes, under specific conditions, the systematic difference that may exist between the values of a parameter to be measured and those indicated by a measuring system (with the corresponding values given in reference to a specific ‘reference’ system, including reference materials and their accepted values).</td>
</tr>
<tr>
<td>Glossary</td>
<td>Definition</td>
</tr>
<tr>
<td>---</td>
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</tr>
<tr>
<td>Campaign monitoring</td>
<td>(Also referred to as spot measurements): Measurements made in response to a need or an interest to obtain further fundamental information than that which routine/conventional monitoring provides. Examples are campaign monitoring during a special time period for estimating uncertainties, estimating variations in emissions patterns or for evaluating the chemical content or the ecotoxicological effects of the emissions by more advanced analyses.</td>
</tr>
<tr>
<td>Carcinogen</td>
<td>Any substance that is capable of causing cancer in humans or animals or a substance that promotes or aggravates cancer.</td>
</tr>
<tr>
<td>Carding</td>
<td>Reduction of entangled mass of fibres into a filmy web which is done by working between two closely spaced and relatively moving surface clothed with the sharp wire points.</td>
</tr>
<tr>
<td>CAS</td>
<td>Chemical abstracts service (registry number). A division of the American Chemical Society holds registries of chemical substances; providing a unique numerical identifier for chemical compounds, polymers, biological sequences, mixtures and alloys which designates only one substance.</td>
</tr>
<tr>
<td>Cellulosic materials</td>
<td>Cellulosic materials include cotton and viscose.</td>
</tr>
<tr>
<td>Certification</td>
<td>Procedure by which a third party gives written assurance that a product, process or service conforms to specified requirements. Certification can apply to instruments, equipment and/or personnel.</td>
</tr>
<tr>
<td>Chalk</td>
<td>Amorphous type of calcium carbonate.</td>
</tr>
<tr>
<td>Chamber filter press</td>
<td>Equipment for dewatering waste water or product sludges.</td>
</tr>
<tr>
<td>Channeled emissions</td>
<td>Emissions of pollutants to air through any kind of duct, pipe, stack, etc.</td>
</tr>
<tr>
<td>Chelating agent</td>
<td>A compound capable of chelation with metal ions.</td>
</tr>
<tr>
<td>Chelation</td>
<td>The formation of a closed ring of atoms by the attachment of compounds or radicals to a central polyvalent metal ion (occasionally non-metallic) (see also: sequestration, complexing agent).</td>
</tr>
<tr>
<td>Chronic pollution</td>
<td>Pollution occurring from regular or continuous events, such as effluent discharge (see also: acute pollution).</td>
</tr>
<tr>
<td>Chronic toxicity</td>
<td>The toxicity due to regular or continuous exposure over a long period of time, such as years, to a toxin that can have irreversible effects (see also: acute toxicity).</td>
</tr>
<tr>
<td>COD</td>
<td>Chemical oxygen demand - indicating the amount of organic matter in waste waters susceptible to oxidation by a strong chemical oxidant (normally referring to analysis with dichromate oxidation) according to ISO 15705:2002 (see ‘hard COD’).</td>
</tr>
<tr>
<td>Coagulation</td>
<td>A process in which dispersed colloidal particles agglomerate by the addition of a chemical reagent called a coagulant.</td>
</tr>
<tr>
<td>Combustible material</td>
<td>Solids, liquids and gases capable of igniting and burning in the presence of ignition source.</td>
</tr>
<tr>
<td>Comparability</td>
<td>A process for identifying and/or assessing differences and/or common characteristics between two (or more) samples, measurements, monitoring results, etc. Comparability is related to uncertainty, traceability to the specified reference, averaging time and frequency.</td>
</tr>
<tr>
<td>Complexing agent</td>
<td>See chelating agent.</td>
</tr>
<tr>
<td>Compliance assessment</td>
<td>Process to compare actual emissions of pollutants from an installation (manufacturing unit) with the permitted emission limit values, within a defined degree of confidence.</td>
</tr>
<tr>
<td>Component</td>
<td>Substance embedded in a mixture, e.g. in waste water, waste gas, solid waste.</td>
</tr>
<tr>
<td>Composite sample</td>
<td>Sample prepared by an operator or by an automatic device and that has been obtained by mixing several spot samples.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Containment, contained area</td>
<td>(Secondary) containment refers to additional protection against storage tank releases over and above the inherent protection provided by the tank container itself. There are two major types of secondary containment for leakages, namely those that are part of the tank construction, such as double tank bottoms (only for above-ground tanks), double skinned and double walled tanks; and impervious barriers which are placed upon the soil surface below the tanks. May also refer to remediation measures put in place in order to prevent contaminant spreading from primary sources of pollution.</td>
</tr>
<tr>
<td>Continuous measurement</td>
<td>Measurement with an automated measuring system (AMS) permanently installed on site.</td>
</tr>
<tr>
<td>Continuous monitoring</td>
<td>Two types of continuous monitoring techniques are considered: Fixed in-situ (or in-line) continuous reading instruments. The measuring cell is placed in the duct, pipe or stream itself. These instruments do not need to withdraw any sample to analyse it and are usually based on optical properties. Fixed on-line (or extractive) continuous reading instruments. This type of instrumentation extracts a sample of the emissions along a sampling line, which is driven to a measurement station, where the sample is then analysed continuously. The measurement station may be remote from the duct, and therefore care must be taken so that the sample integrity is maintained.</td>
</tr>
<tr>
<td>Continuous sampling</td>
<td>Sampling on a continuous basis, and without interruption, of a portion of an effluent, which itself can be continuous or discontinuous. An aliquot of the flow is taken at any time when there is a discharge. Two formats can be identified: continuous flow-proportional sampling - where a continuous sample is taken from a partial flow ratio of the sample volume to the effluent flow rate; continuous sampling at fixed time intervals - where equal volumes are taken at fixed time intervals.</td>
</tr>
<tr>
<td>Control of emissions</td>
<td>Techniques used to limit, reduce, minimise or prevent emissions.</td>
</tr>
<tr>
<td>Cooling water</td>
<td>Water used for energy transfer (heat removal from components and industrial equipment), which is kept in a network separated from industrial water and which can be released back to receiving waters without further treatment.</td>
</tr>
<tr>
<td>Co-product</td>
<td>Any of two or more products coming from the same unit process or product system.</td>
</tr>
<tr>
<td>Corrosion</td>
<td>Surface chemical reaction, especially on metals by the action of moisture, air or chemicals.</td>
</tr>
<tr>
<td>Corrosive material</td>
<td>A material that, in contact with the skin, can have a destructive effect on living tissue. Corrosives can also damage or even destroy metal.</td>
</tr>
<tr>
<td>CPI</td>
<td>Corrugated plate interceptor – oil/water separation device utilising inclined corrugated plates to separate free non-emulsified oil and water based on their density difference.</td>
</tr>
<tr>
<td>Decommissioning</td>
<td>The shutdown of an installation including decontamination and/or dismantling.</td>
</tr>
<tr>
<td>Denitrification</td>
<td>Biological process by which nitrite is converted to nitrogen through a series of intermediate gaseous nitrogen oxide products.</td>
</tr>
<tr>
<td>Diffuse emissions</td>
<td>Non-channelled emissions to air</td>
</tr>
<tr>
<td>Digestate</td>
<td>The solid residue remaining after anaerobic digestion.</td>
</tr>
<tr>
<td>Dilution factor</td>
<td>Final volume/aliquot volume (is the measure of subvolume of the original sample).</td>
</tr>
<tr>
<td>Dioxins</td>
<td>Polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs).</td>
</tr>
<tr>
<td>Direct discharge</td>
<td>Discharge to a receiving water body without further downstream waste water treatment.</td>
</tr>
<tr>
<td>Direct measurements</td>
<td>Specific quantitative determination of the emitted compounds at source.</td>
</tr>
<tr>
<td>Glossary</td>
<td>Definition</td>
</tr>
<tr>
<td>----------</td>
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</tr>
<tr>
<td>Discharge</td>
<td>Physical release of a pollutant through a defined outlet, (i.e. channelled), system, (e.g. sewer, stack, vent, curbing area, outfall).</td>
</tr>
<tr>
<td>Discrete</td>
<td>Not continuous, i.e. having gaps between all possible values.</td>
</tr>
<tr>
<td>Drainage</td>
<td>Natural or artificial removal of surface and subsurface water from an area, including surface streams and groundwater pathways.</td>
</tr>
<tr>
<td>Draining</td>
<td>Emptying the liquid contents of a system to a collection system or other storage system, creating a possible liquid waste stream.</td>
</tr>
<tr>
<td>Dry cleaning</td>
<td>Cleaning of textile materials with an organic solvent.</td>
</tr>
<tr>
<td>Dry matter percentage</td>
<td>The ratio between the initial weight of a defined substance and the final (constant) weight, obtained after defining drying procedures.</td>
</tr>
<tr>
<td>Dust</td>
<td>Solid particles with a size ranging from submicroscopic to macroscopic of any shape, structure or density, dispersed in the gas phase. Also includes particulate matter (PM).</td>
</tr>
<tr>
<td>Dye</td>
<td>The formulation (commercial product) containing the dyestuff together with other dyeing auxiliaries.</td>
</tr>
<tr>
<td>Dyestuff</td>
<td>The colouring agent in the dye formulation: a planar molecule which contains chromophoric group(s) capable of interacting with light.</td>
</tr>
<tr>
<td>Emissions factor</td>
<td>The estimated average emissions rate of a given pollutant for a given source, relative to units of activity.</td>
</tr>
<tr>
<td>Emissions pattern</td>
<td>Type of variation of emissions over time: for example, emissions can be stable, cyclic, random peaking, random variable, erratic.</td>
</tr>
</tbody>
</table>
| Emissions to air | (1) Concentration: mass of emitted substance related to the volume of waste gas under standard conditions (273.15 K, 101.325 kPa), after deduction of water vapour content, expressed in the units g/Nm^3, mg/Nm^3, µg/Nm^3 or ng/Nm^3.  
(2) Mass flow: mass of emitted substances related to time, expressed in the units kg/yr, kg/h, g/h or mg/h.  
(3) Specific emission: ratio of mass of emitted substances to the mass of products generated or processed (consumption or emissions factors), expressed in the units kg/t, g/t or mg/t or µg/t. |
| Emissions to water | (1) Mass of emitted substances related to the volume of waste water, expressed in the units g/m3, g/l, mg/l or µg/l.  
(2) Mass flow: mass of emitted substances related to time, expressed in the units kg/yr, kg/h, g/h or mg/h.  
(3) Specific emission: ratio of mass of emitted substances to the mass of products generated or processed (consumption or emissions factors), expressed in the units kg/t, g/t or mg/t or µg/t. |
| EOP | (1) End-of-pipe, device or treatment system applied to waste water or channelled exhaust or flue gas at the outlet of a collection system prior to release into the environment.  
(2) Extraction bleaching stage using sodium hydroxide with the subsequent addition of oxygen and hydrogen peroxide solution as a reinforcing agent. |
| Eutrophication | The excessive growth of algae as a result of the pollution of a body of water by sewage, fertilisers washed from the land, or industrial wastes; containing plant nutrients (principally inorganic nitrates and phosphates). Dead algae decomposing reduce the oxygen content in the water and so kill animals with a high oxygen requirement. |
| EWL | European waste list from the European Waste Framework Directive (Directive 2008/98/EC on waste) – hierarchical list of waste descriptions. This list classifies waste materials and categorises them by:  
(a) the activity from which they are produced, and  
(b) their characteristics. |
<p>| Exhaust gas (or exhaust air) | Gas/air stream coming from a combustion or extraction process; it may contain gaseous or particulate components. There is no link to exhausting through a stack. (See also flue-gas, off-gas, waste gas.) |
| Existing plant | A plant that is not a new plant. |</p>
<table>
<thead>
<tr>
<th>Glossary Item</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finishing</td>
<td>This term can address both the sequence of wet treatments that are carried out to give the fibre the required colour and final properties, and any specific operation to apply functional finishes (easy-care, anti-felting, mothproofing agents, etc.). Physical and/or chemical treatment aiming at giving the textile materials end-use properties such as visual effect, handle characteristics, waterproofing or non-flammability.</td>
</tr>
<tr>
<td>Fixation rate</td>
<td>Ratio of the dye fixed on the fibre to the total dye applied.</td>
</tr>
<tr>
<td>Fixation efficiency</td>
<td>Ratio of the dye fixed on the fibre to the dye exhausted from the bath.</td>
</tr>
<tr>
<td>Flammable material</td>
<td>Any solid, liquid, vapour or gas material that will ignite easily and burn rapidly.</td>
</tr>
<tr>
<td>Flocculation</td>
<td>Agglomeration of destabilised particles into microfloc, and afterwards into bulky flocules which can be settled called floc. The addition of another reagent called a flocculant or a flocculant aid may promote the formation of the floc.</td>
</tr>
<tr>
<td>Flotation</td>
<td>A water treatment process that clarifies waste waters by the removal of suspended matter such as oil or solids; a specific example is dissolved air flotation (DAF).</td>
</tr>
<tr>
<td>Flue-gas</td>
<td>A mixture of combustion products and air leaving a combustion chamber and that is directed up a stack to be emitted.</td>
</tr>
<tr>
<td>Fouling</td>
<td>A process of becoming dusty or clogged, e.g. by undesirable foreign matter, such as dirt and other material, accumulating and clogging pores and coating surfaces.</td>
</tr>
<tr>
<td>Free CN</td>
<td>The cyanide not combined in complex ions, both the molecular HCN and the cyanide ion.</td>
</tr>
<tr>
<td>Fugitive emissions</td>
<td>Emissions that leave a process because of lack of containment, or failure of containment. Note: fugitive emissions are a subset of diffuse emissions.</td>
</tr>
<tr>
<td>Groundwater</td>
<td>All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil (Article 2 of Directive 2000/60/EC on establishing a framework for Community action in the field of water policy). Note: groundwater is distinct from surface water.</td>
</tr>
<tr>
<td>Halogenated organic compound</td>
<td>An organic compound which contains one or more halogen atoms of bromine, chlorine, fluorine or iodine per molecule.</td>
</tr>
<tr>
<td>Hard COD</td>
<td>Total residual COD, including the inert non-treatable fraction and that part beyond the capacity of a particular treatment (see COD).</td>
</tr>
<tr>
<td>Hazardous substances</td>
<td>A substance or a mixture that complies with criteria laid down in Parts 2 to 5 of Annex I to Regulation (EC) No 1272/2008 on the classification, labelling and packaging of substances and mixtures.</td>
</tr>
<tr>
<td>Hazardous waste</td>
<td>Hazardous waste as defined in point 2 of Article 3 of Directive 2008/98/EC.</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Metals with a density greater than 4.5 g/ml, according to the 1998 Aarhus Protocol on Heavy Metals.</td>
</tr>
<tr>
<td>Indirect discharge</td>
<td>Discharge which is not a direct discharge.</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>Leachate</td>
<td>Solution obtained by leaching. The solution consists of liquid that, in passing through matter, extracts solutes, suspended solids or any other component of the material through which it has passed.</td>
</tr>
<tr>
<td>Leakage</td>
<td>Gaseous or liquid spills out of system/equipment due to system/equipment failure.</td>
</tr>
<tr>
<td>Liquor ratio</td>
<td>Weight ratio between the total dry material and the total liquor within a batch machine. So, for example, a liquor ratio of 1:10 means 10 litres of water per 1 kg of textile material (or 10 l/kg). For a batch process, weight ratio between the dry textile materials and the process liquor used.</td>
</tr>
<tr>
<td>Major plant upgrade</td>
<td>A major change in the design or technology of a plant with major adjustments or replacements of the process and/or abatement technique(s) and associated equipment.</td>
</tr>
<tr>
<td>Make-up</td>
<td>Generic term used in the textile industry to name the different forms in which a textile material can exist. Examples are floc, yarn, woven and knitted fabric.</td>
</tr>
<tr>
<td>Make-up water</td>
<td>Water added to a process or a circuit to replace water that is lost by leakage or evaporation for example.</td>
</tr>
<tr>
<td>Mass flow</td>
<td>The mass of a given substance or parameter which is emitted over a defined period of time.</td>
</tr>
<tr>
<td>Measurement uncertainty</td>
<td>Non-negative parameter characterising the dispersion of the values attributed to a measured quantity. The uncertainty has a probabilistic basis and reflects incomplete knowledge of the quantity.</td>
</tr>
<tr>
<td>MF</td>
<td>Microfiltration (membrane process). A filtration process which removes contaminants from a liquid by passage through a microporous membrane (pore size 0.1-10 µm).</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Systematic surveillance of the variations of a certain chemical or physical characteristic of emissions, discharges, consumptions, equivalent parameters or technical measures, etc.</td>
</tr>
<tr>
<td>Mother liquor</td>
<td>Saturated solution remaining after crystallisation or precipitation.</td>
</tr>
<tr>
<td>Nanofiltration</td>
<td>A membrane filtration process using typical pore sizes of the membrane of about 1 nm.</td>
</tr>
<tr>
<td>Nanomaterial</td>
<td>A natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1-100 nm.</td>
</tr>
<tr>
<td>NCV</td>
<td>Net calorific value or lower heat value (LHV) (see also: UHV).</td>
</tr>
<tr>
<td>New plant</td>
<td>A plant first permitted at the site of the installation following the publication of the BAT conclusions or a complete replacement of a plant following the publication of the BAT conclusions.</td>
</tr>
<tr>
<td>Nitrification</td>
<td>A biological process by which ammonia is converted first to nitrite and then to nitrate.</td>
</tr>
<tr>
<td>Normal operating conditions (NOC)</td>
<td>Conditions during which the plant is operating normally and discharging emissions into the air and/or water, excluding other than normal operating conditions (see OTNOC below).</td>
</tr>
<tr>
<td>N-total or TN, total Nitrogen</td>
<td>The sum of organic nitrogen, ammonia, nitrite and nitrate in the chemical analysis of soil, water or waste water (see also TKN, total Kjeldahl nitrogen).</td>
</tr>
<tr>
<td>Nylon</td>
<td>Generic name for polyamide fibres.</td>
</tr>
<tr>
<td>O</td>
<td>Oxygen bleaching stage.</td>
</tr>
<tr>
<td>Odour concentration</td>
<td>Conventionally defined (EN 13725) as the dilution factor to be applied to an effluent in order to be no longer perceived as odorant by 50% of people in a sample of population.</td>
</tr>
<tr>
<td>Off-gas</td>
<td>General term for gas/air resulting from a process or operation (see exhaust gas, flue-gas, waste gas).</td>
</tr>
<tr>
<td>Organic solvent</td>
<td>Organic solvent as defined in Article 3(46) of Directive 2010/75/EU.</td>
</tr>
<tr>
<td>ORP</td>
<td>Oxidation reduction / redox potential. The electric potential required to transfer electrons from one compound or element (the oxidant) to another compound (the reductant).</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>Osmosis</td>
<td>The passage of a liquid from a weak solution to a more concentrated solution across a semipermeable membrane that allows passage of the solvent (water) but not the dissolved solids. See reverse osmosis technique.</td>
</tr>
<tr>
<td>Other than normal operating conditions (OTNOC)</td>
<td>Conditions other than normal operating conditions, such as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and definitive cessation of operations.</td>
</tr>
<tr>
<td>Oxidant</td>
<td>(1) One of the elements of the transfer of electrons to another (the reductant) in the oxidation reduction chemical reaction. (2) Some of the primary constituents of photochemical smog, leading to tropospheric ozone.</td>
</tr>
<tr>
<td>Oxidiser</td>
<td>An oxidising agent (e.g. peroxides) that can react highly exothermically when brought into contact with other materials, flammable in particular.</td>
</tr>
<tr>
<td>Ozone (O₃)</td>
<td>(1) Stratospheric ozone: natural form of oxygen that provides a protective layer shielding the earth from ultraviolet radiation. (2) Tropospheric ozone: produced through complex chemical reactions of nitrogen oxides, hydrocarbons and sunlight; can seriously impair the respiratory system.</td>
</tr>
<tr>
<td>PAH(s)</td>
<td>Polycyclic aromatic hydrocarbons. Group of fused aromatic ring compounds, of which napthalene is the simplest example. Regarding environmental impact and although individual health effects are not the same, 17 PAHs are considered as a group. Among them, benzo[a]pyrene was first listed as a carcinogen.</td>
</tr>
<tr>
<td>Particulate matter (PM)</td>
<td>Total particulate matter refers to all inorganic and organic solid and liquid materials (droplets and aerosols) that may be present in the flue-gas. Specific sizes of PM may be measured/distinguished, such as PM₁₀, PM₅.₅, PM₁, depending on the amount of particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 10 μm, 5 μm, 1 μm aerodynamic diameter, respectively. (See also dust.)</td>
</tr>
<tr>
<td>PBB</td>
<td>Polychlorinated biphenyl-polyhalogenated compounds whose chlorine analogues are the PCBs.</td>
</tr>
<tr>
<td>PCDD</td>
<td>Polychlorinated dibenzo-p-dioxins. Organic polyhalogenated compounds. Members of this group have been shown to bioaccumulate due to lipophilic properties and are known human carcinogens. Usually named dioxins.</td>
</tr>
<tr>
<td>PCDF</td>
<td>Polychlorinated dibenzofurans. Organic polyhalogenated compounds. Tend to co-occur with PCDD. Usually named furans.</td>
</tr>
<tr>
<td>Periodic measurement</td>
<td>Measurement at specified time intervals using manual or automated methods.</td>
</tr>
<tr>
<td>Periodic sampling</td>
<td>Discrete / individual / separate / discontinuous / grab / spot sampling - individual samples taken in batch, time or effluent-volume-dependent. Three formats can be identified: periodic time-dependent sampling – discrete samples of equal volume are taken at equal time intervals; periodic flow-proportional sampling – discrete samples are taken of variable volumes at equal time intervals; periodic samples taken at fixed flow intervals – discrete samples of equal volume are taken after the passage of a constant volume.</td>
</tr>
<tr>
<td>Pesticide</td>
<td>Biological, physical or chemical agent used to kill pests. The term pesticide is often applied only to chemical agents. Various pesticides are known as insecticides, nematicides, fungicides, herbicides and rodenticides. According to the Stockholm Convention on Persistent Organic Pollutants, 10 of the 12 most dangerous and persistent organic chemicals are pesticides.</td>
</tr>
<tr>
<td>PFC</td>
<td>Perfluorinated carbon or perfluorocarbons. Organofluorine compounds that contain only carbon and fluorine bonded together. They are potent greenhouse gases.</td>
</tr>
<tr>
<td>Glossary</td>
<td>Definition</td>
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</tr>
<tr>
<td><strong>Pick-up</strong></td>
<td>For a continuous process, weight ratio between the liquid taken up by the textile materials and the dry textile materials.</td>
</tr>
<tr>
<td><strong>PID</strong></td>
<td>Piping and instrumentation diagrams: diagrams which show the interconnection of process equipment and the instrumentation.</td>
</tr>
<tr>
<td><strong>Pigging</strong></td>
<td>In the maintenance of pipelines, the practice of using inspection gauges or ‘pigs’ to perform various operations on a pipeline without stopping the flow of the product in it. Operations include cleaning and inspection of the pipeline.</td>
</tr>
<tr>
<td><strong>PLC</strong></td>
<td>Programmable logic controller: digital computer used for the automation of industrial processes.</td>
</tr>
<tr>
<td><strong>PNEC</strong></td>
<td>Predicted no effect concentrations. Ecotoxicological measure for multiple species systems defined as the concentration below which a specified percentage of species in an ecosystem are expected to be protected.</td>
</tr>
<tr>
<td><strong>Pollution</strong></td>
<td>The direct or indirect introduction, as a result of human activity, of substances, vibrations, heat or noise into the air, water or land which may be harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment (Directive 2010/75/EU).</td>
</tr>
<tr>
<td><strong>Pollution source</strong></td>
<td>The emissions source. Pollution sources can be categorised as: point, or concentrated sources; dispersed sources; line sources, including mobile (transport) and stationary sources area sources.</td>
</tr>
<tr>
<td><strong>POPs</strong></td>
<td>Persistent organic pollutants, as defined by protocol to the UNEP LRTAP convention: they are organic substances that: possess toxic characteristics that are likely to cause significant adverse human health or environmental effects; are persistent, i.e. remain intact for exceptionally long periods of time (many years); bioaccumulate in the fatty tissue of living organisms including humans, and are found at higher concentrations at higher levels in the food chain; and are prone to long-range transboundary atmospheric transport and deposition, i.e. become widely distributed throughout the environment as a result of natural processes involving soil, water and air.</td>
</tr>
<tr>
<td><strong>Post-combustion</strong></td>
<td>Ignition and burning of exhaust gas through the injection of air or the use of a burner (e.g. in order to reduce the amount of CO or other pollutants).</td>
</tr>
<tr>
<td><strong>PPI</strong></td>
<td>Parallel plate interceptor. A decantation device made with a series of plates parallel to the longitudinal axis of a separator (plates form a ‘V’ viewed along the axis) used to separate sediments from a liquid. (See also API, CPI.)</td>
</tr>
<tr>
<td><strong>Precision</strong></td>
<td>Refers to the ability of a measurement to be consistently reproduced.</td>
</tr>
<tr>
<td><strong>Process chemicals</strong></td>
<td>Substances and/or mixtures as defined in Article 3 of regulation EC/1907/2006 and used in the process(es), including sizing chemicals, bleaching chemicals, dyes, printing pastes and finishing chemicals.</td>
</tr>
<tr>
<td><strong>Process liquor</strong></td>
<td>Solution and/or suspension containing process chemicals.</td>
</tr>
<tr>
<td><strong>Primary measure/technique</strong></td>
<td>A measure/technique that changes the way in which the core process operates thereby reducing raw emissions or consumption (see also the counterpart: end-of-pipe technique).</td>
</tr>
<tr>
<td><strong>Purging</strong></td>
<td>Replacement of the gaseous contents of a system by air or inert gases.</td>
</tr>
<tr>
<td><strong>Rayon</strong></td>
<td>A generic name for man-made continuous filament fibres, obtained from regenerated cellulose. The term rayon is used for fibres produced by both cupra-ammonium and viscose processes.</td>
</tr>
<tr>
<td><strong>Recovery</strong></td>
<td>Any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy (Waste Directive (2008/98/EC)).</td>
</tr>
<tr>
<td><strong>Recycling</strong></td>
<td>Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations (Waste Directive (2008/98/EC)).</td>
</tr>
<tr>
<td><strong>Reuse</strong></td>
<td>Any operation by which products or components that are not waste are used again for the same purpose for which they were conceived (Waste Directive (2008/98/EC)).</td>
</tr>
<tr>
<td><strong>Reference conditions</strong></td>
<td>Conditions that are specified, e.g. in connection with operating a process, collecting samples.</td>
</tr>
<tr>
<td><strong>Release</strong></td>
<td>Actual discharge (routine, usual or accidental) of emissions into the environment.</td>
</tr>
<tr>
<td><strong>Remediation</strong></td>
<td>The containment and/or decontamination of contaminated environmental media such as soil, groundwater, sediment, or surface water from a contaminated site intended for further use. The area of the site may be larger than the fenced area.</td>
</tr>
<tr>
<td><strong>Reporting</strong></td>
<td>A process of periodic transmission of information about environmental performance, including emissions and compliance with permit conditions, to authorities or to the internal management of the installation and other agencies, such as the general public.</td>
</tr>
<tr>
<td><strong>Residue</strong></td>
<td>A material that is not deliberately produced in a production process and may or may not be waste.</td>
</tr>
<tr>
<td><strong>Roving</strong></td>
<td>Prior to spinning, reduction of the sliver thickness by drafting.</td>
</tr>
<tr>
<td><strong>R-phrases</strong></td>
<td>R-phrases are standard phrases indicating the special risk arising from the dangers involved in using the dangerous substance. The wording of the R-phrases is laid down in Annex III to Directive 67/548/EEC on the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.</td>
</tr>
<tr>
<td><strong>Run-off</strong></td>
<td>Part of the precipitation and snowmelt that does not infiltrate but moves as overland flow.</td>
</tr>
<tr>
<td><strong>Sampling, sample</strong></td>
<td>Sampling is the process by which a portion of substance is collected to form a representative part (the sample) of the whole, for the purpose of examination of the substance or material under consideration. (See also continuous sampling, periodic sampling.)</td>
</tr>
<tr>
<td><strong>Sankey diagram</strong></td>
<td>A specific type of diagram used for displaying flows through a system, e.g. to show mass, energy, material, money flows.</td>
</tr>
<tr>
<td><strong>Scouring</strong></td>
<td>Removal of foreign impurities from textiles. In the case of wool, this term can address both the removal of the grease and dirt present on raw wool (wool scouring process) and the removal of spinning oils and residual contaminants from yarn or fabric in the wet treatments that are carried out before the dyeing process.</td>
</tr>
<tr>
<td><strong>Sequencing batch reactor</strong></td>
<td>A variation of the conventional activated sludge system to treat waste waters containing organic material whereby the aeration and settlement take place in the same vessel (no need for a secondary clarifier).</td>
</tr>
<tr>
<td><strong>Secondary measure/technique</strong></td>
<td>See EOP, end-of-pipe techniques.</td>
</tr>
<tr>
<td><strong>Slag</strong></td>
<td>A vitrified or partially vitrified residue.</td>
</tr>
<tr>
<td><strong>Sludge</strong></td>
<td>A suspension with a high solids content, such as the type precipitated by sewage treatment.</td>
</tr>
<tr>
<td><strong>Slurry</strong></td>
<td>A suspension of solid particles in a liquid but at a lower concentration than found in sludge.</td>
</tr>
<tr>
<td><strong>Specific emissions/consumption</strong></td>
<td>Emissions/consumption related to a reference basis, such as production capacity, or actual production.</td>
</tr>
<tr>
<td>Glossary</td>
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</tr>
<tr>
<td><strong>Spot measurement</strong></td>
<td>A measurement relating to a specific point in time – not a continuous measurement.</td>
</tr>
<tr>
<td><strong>Spot sample</strong></td>
<td>A sample related to a single point in time.</td>
</tr>
<tr>
<td><strong>Standard conditions</strong></td>
<td>Referring to a temperature of 273.15 K a pressure of 101.325 kPa and a specified oxygen content.</td>
</tr>
<tr>
<td><strong>Site</strong></td>
<td>Geographical area which may contain more than one installation, plant or facility.</td>
</tr>
<tr>
<td><strong>Sizing</strong></td>
<td>Impregnation of yarn with chemicals aiming to protect the yarn and provide lubrication during weaving.</td>
</tr>
<tr>
<td><strong>Sump</strong></td>
<td>A pit, well or hole used for collecting water or other liquid.</td>
</tr>
<tr>
<td><strong>Surrogate parameter</strong></td>
<td>Measurable or which can calculable quantities be closely related, directly or indirectly, to conventional direct measurements of pollutants, and which may therefore be monitored and used instead of the direct pollutant values for some practical purposes. Also called proxy parameter.</td>
</tr>
<tr>
<td><strong>Synthetic materials</strong></td>
<td>Synthetic materials include polyester, polyamide and acrylic.</td>
</tr>
<tr>
<td><strong>TA Luft</strong></td>
<td>Technical Instructions on Air Quality Control. German Federal Regulation for the control of pollution to air.</td>
</tr>
<tr>
<td><strong>TDS</strong></td>
<td>Total dissolved solids - the concentration in liquid of the solids that remain after the liquid has passed through a filter with a defined pore size.</td>
</tr>
<tr>
<td><strong>TEQ</strong></td>
<td>Toxicity equivalent (also called TE or iTEQ – international toxicity equivalent) - dioxins and furans. The last revision of the equivalency methodology (WHO-TEQDFP) now also includes PCBs.</td>
</tr>
<tr>
<td><strong>Textile materials</strong></td>
<td>Textile fibres and/or textiles.</td>
</tr>
<tr>
<td><strong>Texturised fibres</strong></td>
<td>Filament yarns that have undergone a special treatment aimed at giving the fibre a greater volume and surface interest than the conventional yarn of the same fibre.</td>
</tr>
<tr>
<td><strong>Thermal treatment</strong></td>
<td>Thermal treatment of textile materials includes drying, curing, fixing or heat-setting which is carried out as a process step of the activities covered by this document.</td>
</tr>
<tr>
<td><strong>Thickening</strong></td>
<td>Liquid-solid separation process to increase the concentration of a suspension by sedimentation, accompanied by the formation of a clear solid.</td>
</tr>
<tr>
<td><strong>TKN</strong></td>
<td>Total Kjeldahl nitrogen - the sum of organic nitrogen, ammonia (NH₃) and ammonium (NH₄⁺) in the chemical analysis of soil, water or waste water.</td>
</tr>
<tr>
<td><strong>TOC</strong></td>
<td>Total organic carbon. The concentration in water of all organic compounds, measured according to EN 1484. The term TOC is also used for carbon in air.</td>
</tr>
<tr>
<td><strong>Top</strong></td>
<td>A continuous untwisted strand or sliver of wool fibres.</td>
</tr>
<tr>
<td><strong>TS</strong></td>
<td>Total solids (content). The sum of TDS and TSS.</td>
</tr>
<tr>
<td><strong>TSS</strong></td>
<td>Total suspended solids. The concentration in any liquid, usually water, of suspended particles that are trapped by a filter with a defined pore size. (See also SS.)</td>
</tr>
<tr>
<td><strong>UF</strong></td>
<td>Ultrafiltration is a variety of membrane filtration in which hydrostatic pressure (typically 0.1-5 MPa) forces a liquid against a semi-permeable membrane (typical pore size of 2-10 nm).</td>
</tr>
<tr>
<td><strong>Unit</strong></td>
<td>A part of the plant in which a specific processing operation is conducted.</td>
</tr>
<tr>
<td><strong>Waste gas</strong></td>
<td>Any gas leaving a process which is not a product (includes exhaust gas, off-gas and flue-gas).</td>
</tr>
<tr>
<td><strong>Waste hierarchy</strong></td>
<td>Priority order in waste prevention and management legislation and policy: (a) prevention; (b) preparing for reuse; (c) recycling; (d) other recovery, e.g. energy recovery; and (e) disposal (Waste Directive (2008/98/EC)).</td>
</tr>
<tr>
<td><strong>Waste treatment</strong></td>
<td>Waste recovery or waste disposal operations, including preparation prior to recovery or disposal (Waste Directive (2008/98/EC)).</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
</tr>
<tr>
<td>WEA</td>
<td>Whole Effluent Assessment of the entire effluent using integrating parameters (e.g. acute and chronic toxicity, liability to bioaccumulate and to persist) in contrast to measuring individual substances.</td>
</tr>
<tr>
<td>WESP</td>
<td>Wet electrostatic precipitator A WESP or wet ESP is an electrostatic precipitator (ESP) operating with saturated air streams (100% relative humidity) which is often used to control particulate matter and acid mists and can provide incidental control of volatile organic compounds. Wet ESPs are used when the material to be collected is wet, sticky, flammable, explosive, or has a high resistivity.</td>
</tr>
<tr>
<td>Zeolites</td>
<td>Microporous, aluminosilicate minerals commonly used as commercial adsorbents.</td>
</tr>
</tbody>
</table>
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