EUROPEAN COMMISSION

Integrated Pollution Prevention and Control

Reference Document on
Best Available Techniques for the

Waste Treatments Industries

August 2006

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

Reference Document on Best Available Techniques . . .	**Code**
Large Combustion Plants	LCP
Mineral Oil and Gas Refineries	REF
Production of Iron and Steel	I&S
Ferrous Metals Processing Industry	FMP
Non Ferrous Metals Industries	NFM
Smitheries and Foundries Industry	SF
Surface Treatment of Metals and Plastics	STM
Cement and Lime Manufacturing Industries	CL
Glass Manufacturing Industry	GLS
Ceramic Manufacturing Industry	CER
Large Volume Organic Chemical Industry	LVOC
Manufacture of Organic Fine Chemicals	OFC
Production of Polymers	POL
Chlor – Alkali Manufacturing Industry	CAK
Large Volume Inorganic Chemicals - Ammonia, Acids and Fertilisers Industries	LVIC-AAF
Large Volume Inorganic Chemicals - Solid and Others industry	LVIC-S
Production of Speciality Inorganic Chemicals	SIC
Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector	CWW
Waste Treatments Industries	WT
Waste Incineration	WI
Management of Tailings and Waste-Rock in Mining Activities	MTWR
Pulp and Paper Industry	PP
Textiles Industry	TXT
Tanning of Hides and Skins	TAN
Slaughterhouses and Animals By-products Industries	SA
Food, Drink and Milk Industries	FDM
Intensive Rearing of Poultry and Pigs	ILF
Surface Treatment Using Organic Solvents	STS
Industrial Cooling Systems	CV
Emissions from Storage	ESB
Reference Document . . .	
General Principles of Monitoring	MON
Economics and Cross-Media Effects	ECM
Energy Efficiency Techniques	ENE

EXECUTIVE SUMMARY

The BAT (Best Available Techniques) Reference Document (BREF), entitled 'Waste Treatments Industries' reflects an information exchange carried out under Article 16(2) of Council Directive 96/61/EC (IPPC Directive). This executive summary describes the main findings, a summary of the principal BAT conclusions and the associated emission/consumption levels. It should be read in conjunction with the preface, which explains this document's objectives; how it is intended to be used and legal terms.

This executive summary can be read and understood as a standalone document but, as a summary, it does not present all the complexities of this full document. It is therefore not intended as a substitute for this full document as a tool in BAT decision making.

Scope of this document

This document, together with other BREFs in the series, is intended to cover the activities described in Section 5 of Annex I of the IPPC Directive, namely 'waste management'. Another BREF covers waste incineration and some thermal waste treatments such as pyrolysis and gasification (point 5.2 of Annex I of the Directive). Although point 5.4 of Annex I includes waste landfills, this document does not cover BAT for landfills.

The Recovery (R) and Disposal (D) (R/D) codes of Annexes II A and II B of Directive 75/442/EEC which refer to the IPPC Directive changed according to the Commission Decision 96/350/EC. Because this last amendment corresponds to the most recent classification of R/D operation codes, the following table reflects, in agreement with the view of the IEF and TWG and following the aim of the IPPC Directive, the type of waste operation codes that are covered in this document.

Waste treatment activity	R/D code 96/350/EC
Use of waste principally as a fuel or other means to generate energy	R1
Solvent reclamation/regeneration	R2
Recycling/reclamation of other inorganic materials (excluding metals and metal compounds covered in other recovery treatments (namely R4)	R5
Regeneration of acids or bases	R6
Recovery of components used for pollution abatement	R7
Recovery of components from catalysts	R8
Oil re-refining or other uses of oil	R9
Exchange of wastes for submission to some recovery operations (numbered R1 to R11)	R12
Storage of wastes pending some recovery operations (numbered R1 to R12) (excluding temporary storage, pending collection, on the site where it is produced)	R13
Biological treatment not specified elsewhere in Annex II of 96/350/EC which results in final compounds or mixtures which are discarded by means of some of the disposal operations (numbered D1 to D12)	D8
Physico-chemical treatment not specified elsewhere in Annex II of 96/350/EC which results in final compounds or mixtures which are discarded by means of some of the disposal operation (numbered D1 to D12) (e.g. evaporation, drying, calcination, etc.)	D9
Blending or mixing prior to submission to some disposal operations (numbered D1 to D12)	D13
Repacking prior to submission to some disposal operations (numbered D1 to D13)	D14
Storage pending any of the disposal operations (numbered D1 to D14) (excluding temporary storage, pending collection, on the site where it is produced)	D15

Waste treatment activities covered in this document

A full 'life cycle assessment' applied to a certain waste can consider all the links in the waste chain as well as the impact of the final product/waste on the environment. IPPC is not intended to address these analyses but focuses instead on installations. For example, minimisation of the amount and/or toxicity of the waste produced at source in industrial installations is intrinsic to IPPC and is covered by each industrial sector BREF (see list on the reverse of the title page of this document). Another example shows that waste management also covers strategic decisions on what type of waste is dealt with in each available waste treatment/process/option or what treatment is given to such a waste. This decision depends on the waste treatment options available at local, regional, national or international level, which also depends on the location where the waste is produced.

Scope of this document should not be interpreted as any attempt to interpret IPPC Directive or any waste legislation.

General information on the waste treatment sector

The waste sector is highly regulated in the EU. For this reason, many legal definitions of terms commonly used in this sector are available. Waste treatment installations contain operations for the recovery or disposal of waste. Waste treatment installations are considered to provide services to society to handle their waste materials and sometimes these treatments generate products. As it is shown in the next table, more than 14000 waste treatment installations exist in the EU. It is clear from the table that the physico-chemical installations represent the majority of WT installations.

Waste treatment	Number of known installations
Physico-chemical treatments	9907
Waste transfer	2905
Biological treatments	615
Preparation and use of waste oil as fuel	274
Waste fuel preparation	266
Inorganic waste treatment (excluding metals)	126
Waste solvent treatment	106
Re-refining of waste oil	35
Activated carbon treatment	20
Recovery of pollution abatement	20
Waste catalyst treatment	20
Waste acid/base treatment	13
TOTAL	**14307**
Note: Figures in this table may be different to actual numbers mainly due to two reasons: On the one hand, these figures underestimate the number of installations in Europe because some EU countries have not reported their number of installations. On the other side, these numbers typically include all capacities so the number of installations falling under IPPC may be lower.	

Reported waste treatment installations in the EU

Applied techniques, emissions and consumptions in the waste treatment sector

This document provides an updated picture of the technical and environmental situation of the waste treatment sector covered. It contains a brief technical description of the activities and processes found in the sector and is complemented by the actual emissions and consumptions found in the installations. More concretely, the information in this document describes:

- commonly applied techniques such as generic management of installations, reception, acceptance, traceability, quality assurance, storage and handling, energy systems
- biological treatments such as anaerobic and aerobic digestion and off-site biotreatment of soil
- physico-chemical treatments applied to waste waters, waste solids and sludges
- recovery of materials from waste such as regeneration of acids and bases, catalysts, activated carbon, solvents and resins as well as re-refining of waste oils
- preparation solid/liquid waste fuel from non-hazardous and hazardous waste
- emission abatement treatments to air, waste water and residues generated in the WT installations).

This document also identifies the key environmental issues for the waste treatment sector. These are related with air emissions, emission to water, waste and soil contamination. However, due to the variety of waste treatments and types of waste involved, not all types of emissions are relevant for all waste treatments. For example, the emissions from the physico-chemical treatment of waste water are mainly related to waste water and the regeneration of activated carbon is mainly related to air emissions. These types of specifities are shown in this document and can guide the reader to recognise the main environmental issues for each type of installation.

Techniques to consider in the determination of BAT

940 techniques are actually included and considered in the determination of BAT. Some other techniques may not been included simply because information has not been provided. The techniques included have been analysed following the same outline. Such an analysis is reported for each technique with a brief description, the achieved environmental benefits, the cross-media effects, the operational data, the applicability and economics. In some cases, the driving force for implementation has been explored and examples of WT installations using such techniques are reported. The analysis of the techniques ends with the reference literature supporting the data in Chapter 4. The techniques have been structured in eight sections. The first one is related to generic techniques and the last three are related to end-of-pipe techniques applied in the sector. The four middle sections refer to different specific waste treatments.

Due to the high number and variety of techniques considered in the determination of BAT, it is challenging to provide a short summary. The following table was constructed in order to give a snapshot of the techniques considered in the determination of BAT within this document. The table shows for each type of waste treatment identified in this document, the number of different types of techniques. Four different categories have been identified. The first category relates to techniques for the improvement of the environmental performance of the waste treatment itself, or techniques for the prevention of contamination or the management of the waste treatment facility. The other three categories relate to a) techniques for the abatement of air emissions, b) techniques for the abatement of water emissions and c) treatment of solid residues generated during the waste treatment process as well as techniques for the control and prevention of soil contamination. In many cases, it is difficult to include some techniques in one specific category. The number of techniques in the next table do not relate with the number of sections within a section. There are many cases in this document where more than one technique is included in one section.

Type of waste treatment	Number of techniques applied to				TOTAL
	waste treatment, prevention and management	air emissions	waste water	solid residues	
Common techniques	296	26	16	31	**369**
Biological treatments	41	58	3	4	**106**
Physico-chemical treatments	133	17	4	6	**160**
Recovery of materials	44	44	19	7	**114**
Preparation of waste fuel	39	16	0	0	**55**
Air abatement treatments		57			**57**
Waste water treatments			52		**52**
Residue management				27	**27**
TOTAL	**553**	**218**	**94**	**75**	**940**

Techniques to consider in the determination of BAT

From the table above it can be easily calculated that more than half of the techniques are related to the improvement of the environmental performance of waste treatments, prevention or management techniques. The rest of the techniques are mainly devoted to the abatement of air emissions representing close to a quarter, and the rest more or less equally distributed between treatment of waste water and treatment of solid residues. From the other perspective, it can be calculated that more than a third of the techniques are considered common techniques. For the four different type of specific treatment identified, physico-chemical treatment is the section which contains the most techniques.

Best available techniques for the waste treatment sector

This document contains the determined Best Available Techniques (BAT) for the waste treatment sector. These relate to the most relevant environmental issues and typically relate to emissions from normal operation. In some situations, BAT conclusions on emissions from incidents and (major) accidents are also reported.

The BAT identified are summarised in the following table. This table cannot be properly understood if the full BAT section is not read and then cannot be used as a decision making tool. The main reason is that each BAT conclusion contains numerous details mainly relating to when the BAT conclusion is applicable. Consequently, it is essential to consult the entire BAT chapter. Some facts can be extracted from the BAT chapter:

- BAT conclusions for the waste treatment sector are set out at two levels. One level deals with generic BAT conclusions, i.e. they are generally applicable to the whole sector. The other level contains more specific BAT conclusions, e.g. those for the various types of specific processes and activities identified in the scope. So, the BAT for any specific type of waste treatment installation are a combination of the ‘generic’ elements generally applied and the ‘activity specific’ elements applicable to the particular case. In some cases, other BREF documents can give guidance and then form part of the list of documents that need to be considered when analysing a specific installation. As an example, BAT for re-refining waste oil contains the BAT elements numbered from 1 to 64 plus 95 to 104. On top of that, it may be considered that other BREF documents related to the issue may give extra guidance. Another example is that BAT for liquid waste fuels from hazardous waste contain the BAT elements from 1 to 64, 117 to 121 and 129 to 130
- some of the BATs are based on concrete techniques or technologies
- some BATs have been identified to be related to hazardous waste. Such techniques have been highlighted following a similar strategy to that used in the European waste list of the waste framework Directive
- in the determination of BAT in this sector, some associated emission levels following the use of BAT have been identified. These relate to emissions of volatile organic compounds and particulate matter to air, and water parameters such as chemical oxygen demand, biological oxygen demand and heavy metals. Moreover, emissions to air of odour and ammonia have been identified for mechanical biological treatment and emissions to water of hydrocarbons and phenols have been identified for waste oil treatment.

Category	Identified BAT elements on
Generic BAT	
Environmental management	1. environmental management systems 2. provision of full details of the activities carried out on-site 3. having a good housekeeping procedure in place 4. having a close relationship with the waste producer/customer 5. the availability of qualified staff
Improve the knowledge of the waste input	6. having a concrete knowledge of the waste input 7. implementing a pre-acceptance procedure 8. implementing an acceptance procedure 9. implementing different sampling procedures 10. having a reception facility
Waste output	11. analysing the waste output
Management systems	12. the traceability in waste treatment 13. mixing/blending rules 14. segregation and compatibility procedures 15. the efficiency of waste treatment 16. accident management plan 17. incident diary 18. noise and vibration management plans 19. decommissioning
Utilities and raw material management	20. energy consumption and generation 21. energy efficiency 22. internal benchmarking 23. the use of waste as a raw material
Storage and handling	24. generic storage techniques 25. bunding 26. pipework labelling 27. storage/accumulation of waste 28. generic handling techniques 29. bulking/mixing techniques of packaged waste 30. the segregation guide for storage 31. the techniques to handle containerised waste
Other common techniques not mentioned before	32. using extractive vents during crushing, shredding and sieving operations 33. encapsulating the crushing and shredding of special waste 34. washing processes
Air emission treatments	35. the use of open topped tanks, vessels and pits 36. enclosing systems with extraction to suitable abatement plants 37. sized extraction systems for some storage and treatments 38. the operation and maintainance of the abatement equipment 39. scrubber systems for major inorganic gaseous releases 40. leak detection and repair procedures 41. reducing emissions of volatile organic compounds and particulate matter to the air

Category	Identified BAT elements on
Waste water management	42. water use and the contamination of water 43. effluent specification being suitable for the on-site effluent treatment system or discharge criteria 44. avoiding the effluent by-passing the treatment plant systems 45. collectioning waste waters 46. segregrating waste waters 47. having a full concrete base in all the treatment areas 48. collecting rainwater 49. re-using treated waste waters and rainwater 50. daily checking on the effluent management system and maintainance of a log 51. identifing the main hazardous constituents of the treated effluent 52. the appropriate WW treatment techniques for each type of waste water 53. increasing the reliability of control and abatement performance to waste waters 54. the main constituents of treated waste water 55. discharging of the waste water 56. the emission levels on chemical and biological oxygen demand and heavy metals associated to the use of BAT
Management of the process generated residues	57. residue management planning 58. using re-usable packaging 59. re-using drums 60. having an inventory of the waste on-site 61. re-using waste
Soil contamination	62. providing and maintaining the surface of operational areas 63. the impermeable base and drainage 64. minimising site and underground equipment
BAT for specific types of waste treatments	
Biological treatments	65. the storage and handling in biological systems 66. waste types and separation processes 67. techniques for anaerobic digestion 68. reducing the air emissions of dust, nitrogen oxides, sulphur oxides, carbon monoxide, hydrogen sulphide and volatile organic compounds when using biogas as fuel 69. the techniques for mechanical biological treatments 70. reducing the emissions of odour, ammonia, nitrous oxide and mercury from mechanical biological treatments 71. reducing the emissions to water of total nitrogen, ammonia, nitrate and nitrite
Physico-chemical treatments of waste waters	72. the techniques in physico-chemical reactors 73. additional waste water parameters needing to be identified 74. neutralisation process 75. the precipitation of the metals 76. the break-up of emulsions 77. oxidation/reduction 78. waste waters containing cyanides 79. waste waters containing chromium (VI) compounds 80. waste waters containing nitrites 81. waste waters containing ammonia 82. air abatement during filtration and dewatering processes 83. flocculation and evaporation 84. cleaning of sieving processes
Physico-chemical treatment of solid wastes	85. the insolubilisation of amphoteric metals 86. the leachability of inorganic compounds 87. restricting the acceptance of wastes to be treated by solidification/immobilisation 88. enclosed systems 89. abatement systems in charging and unloading 90. solid wastes to be landfilled

Category	Identified BAT elements on
Physico-chemical treatment of contaminated soil	91. the control of excavations 92. determining the suitability of the process to be applied 93. collecting and controlling equipment 94. the efficiency achieved during the processes
Re-refining of waste oils	95. controling of incoming materials 96. checking chlorinated solvents and polychlorinated biphenyls 97. condensation for the gas phase of the flash distillation units 98. abatement during the loading and unloading of vehicles 99. different abatements when chlorinated species are present 100. thermal oxidation 101. vacuum systems 102. using the residues from vacuum distillation or thin film evaporators 103. highly efficient re-refining processes of waste oil 104. waste water emission values for hydrocarbon and phenols
Regeneration of waste solvents	105. controlling of incoming materials 106. evaporating the residue
Regeneration of waste catalysts	107. using bag filters 108. using sulphur oxide abatement systems
Regeneration of waste activated carbons	109. quality control procedures 110. the origin of the waste activated carbons 111. using a kiln for the treatment of industrial carbons 112. using an afterburner for the regeneration of industrial carbons 113. using an afterburner for the regeneration of potable water and food grade active carbons 114. using a flue-gas treatment train 115. scrubbing systems 116. waste water treatment plants
Preparation of waste to be used as fuel	117. transferring the knowledge of the waste fuel composition prepared 118. quality assurance systems 119. manufacturing different type of waste fuels 120. waste water treatments 121. safety aspects
Preparation of solid waste fuels from non-hazardous waste	122. visually inspecting the incoming wastes 123. using magnetic ferrous and non ferrous metal separators 124. using near-infrared techniques 125. the preparation of the waste fuel at the correct size
Preparation of solid waste fuels from hazardous waste	126. drying or heating operations 127. mixing and blending operations 128. the abatement of particulates
Preparation of liquid waste fuels from hazardous waste	129. using heat-exchange units external to the vessel 130. the homogeneity of the liquid fuel

BATs for the waste treatment sector

Emerging techniques

This document also includes the techniques identified by the TWG that have not yet been commercially applied and are still in the research or development phase. However, because of the implications they may have in the waste treatment sector, they have been included here to raise awareness for any future revision of this document.

Concluding remarks

From the beginning of the information exchange process, it has been clear that there are different conceptions of what waste treatment installations should and should not be in this document. Moreover, it has been detected that some installations will be only partially affected by IPPC. Due mainly to these facts, a considerable amount of expert time has been dedicated to try to solve and understand these issues and, therefore, expert time dedicated to determination of BAT for the sector was restricted. This issue has probably restricted the amount of conclusions reached in the information exchange. Additionally, different views on the structure of this document were also discussed at the two plenary meetings (kick-off meeting and final meeting).

There are some views that the scope of this document should cover all waste treatment activities now available in the waste sector. Their view was based on three rationales: first, the technical characteristics of such additional treatments are very similar if not equal to some of the treatments covered in this document; secondly they maintain that such issues may benefit the competitiveness of some waste treatments not covered by IPPC because such installations may be allowed to operate at less stringent environmental standards than required by BAT; and third it may be interpreted that because these treatments are not covered, no BAT can be determined and that they cannot run under BAT conditions.

A high level of consensus was reached on the BAT chapter. However, there are some views on the coverage of this document claiming that the scope of this document needs to be enlarged to include other waste treatments not covered in this actual document.

In preparation for review of this document, all TWG members and interested parties should continue to collect data on the current consumption and emission levels and on the performance of techniques to be considered in the determination of BAT.

The EC is launching and supporting, through its RTD programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially these projects could provide a useful contribution to future reviews of this document. Readers are therefore invited to inform the EIPPCB of any research results which are relevant to the scope of this document (see also the preface of this document).

PREFACE

1. Status of this document

Unless otherwise stated, references to "the Directive" in this document means the Council Directive 96/61/EC on integrated pollution prevention and control. As the Directive applies without prejudice to Community provisions on health and safety at the workplace, so does 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 technique (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".

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, 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 worldwide 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.

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.

5. How to understand and use 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 chapter of this document.

Chapters 1 and 2 provide general information on the industrial sector concerned and on the applied processes and techniques used within the sector. Chapter 3 provides data and information concerning current consumption and emission levels reflecting the situation in existing installations at the time of writing.

Chapter 4 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 technique, 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 consumption and emission levels that are considered to be compatible with BAT in a general sense. The purpose is thus to provide general indications regarding the consumption and emission 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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Best Available Techniques Reference Document for the Waste Treatments Industry

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SCOPE

This document together with other BREFs in the series (see list on the reverse of the title page), are intended to cover the activities described in Section 5 of Annex I of the Directive, namely Waste Management. One BREF covers waste incineration and some thermal waste treatments such as pyrolysis and gasification (point 5.2 of Annex I of the Directive). Although point 5.4 of Annex I includes waste landfills, this document does not cover BAT for landfills. Thus, the scope of this document focuses on the following points of Annex I of the Directive:

- *installations for the disposal or recovery of hazardous waste as defined in the list referred to in Article 1 (4) of Directive 91/689/EEC, as defined in Annexes II A and II B (operations R1, R5, R6, R8 and R9) to Directive 75/442/EEC with a capacity exceeding 10 tonnes per day*
- *installations for the disposal of waste oils as defined in Council Directive 75/439/EEC of 16 June 1975 with a capacity exceeding 10 tonnes per day*
- *installations for the disposal of non-hazardous waste as defined in Annex II A to Directive 75/442/EEC under headings D8 and D9, with a capacity exceeding 50 tonnes per day.*

The Recovery (R) and Disposal (D) codes of Annexes II A and II B of Directive 75/442/EEC which refer to IPPC Directive changed according to the Commission Decision 96/350/EC. Because this last amendment corresponds to the most recent classification of R and D operation codes, the following table reflects, in agreement with the view of the IEF and TWG and following the aim of the IPPC Directive, the type of waste operation codes that are covered in this document.

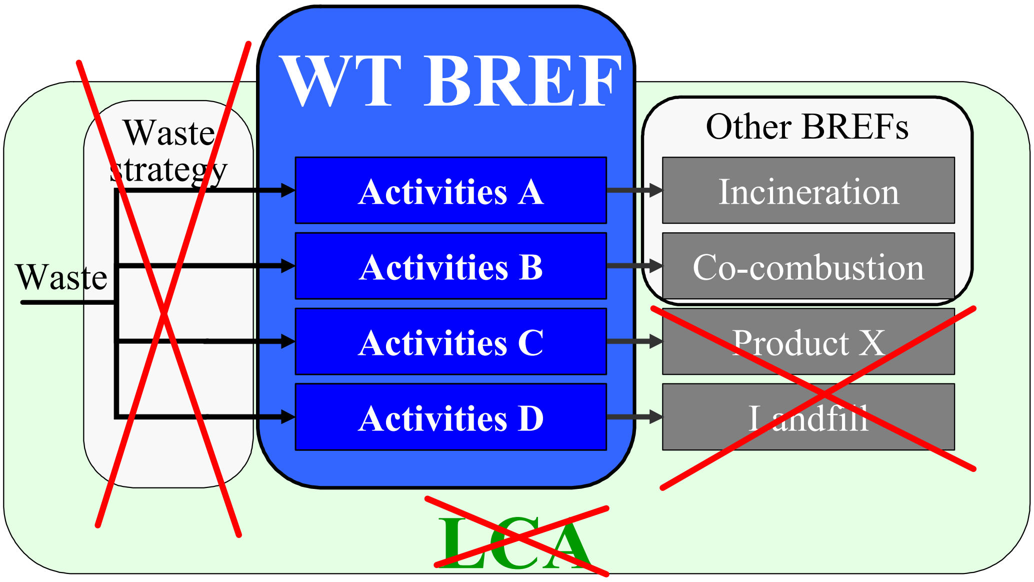
Waste treatment activity	R/D code 96/350/EC
Use of waste principally as a fuel or other means to generate energy	R1
Solvent reclamation/regeneration	R2
Recycling/reclamation of other inorganic materials (excluding metals and metal compounds covered in R4)	R5
Regeneration of acids or bases	R6
Recovery of components used for pollution abatement	R7
Recovery of components from catalysts	R8
Oil re-refining or other uses of oil	R9
Exchange of wastes for submission of any of the operations numbered R1 to R11	R12
Storage of wastes pending any of the operations numbered R1 to R12 (excluding temporary storage, pending collection, on the site where it is produced)	R13
Biological treatment not specified elsewhere in Annex II of 96/350/EC which results in final compounds or mixtures which are discarded by means of any of the operations numbered D1 to D12	D8
Physico-chemical treatment not specified elsewhere in Annex II of 96/350/EC which results in final compounds or mixtures which are discarded by means of any of the operations numbered D1 to D12 (e.g. evaporation, drying, calcination, etc.)	D9
Blending or mixing prior to submission to any of the operations numbered D1 to D12	D13
Repacking prior to submission to any of the operations numbered D1 to D13	D14
Storage pending any of the operations numbered D1 to D14 (excluding temporary storage, pending collection, on the site where it is produced)	D15

Waste treatment activities covered in this document

The remainder of this chapter seeks to clarify what activities of the whole waste management chain are included in this document.

The waste management sector and the Waste Treatment (WT) document

The chain of activities involved in waste management is long and extends outside the scope of the IPPC Directive. The following figure tries to summarise what activities from the waste management sector are covered in the series of BREFs.



Waste management and Waste Treatment BREF
Note: crossed out areas means not covered in this document

A full Life Cycle Assessment (LCA) applied to a certain waste can consider all the links in the waste chain as well as the impact of the final product/waste on the environment. IPPC is not intended to address these analyses but instead focuses on installations. For example, minimisation of the amount and/or toxicity of the waste produced at source in industrial installations is intrinsic to IPPC and is covered by each Industrial Sector BREF (see list in the reverse of the front page of this document). Another example shows that waste management also covers strategic decisions on what type of waste is dealt with in each available waste treatment/process/option or what treatment is given to such a waste. This decision depends on the waste treatment options available at local, regional, national or international level, which also depends on the location where the waste is produced.

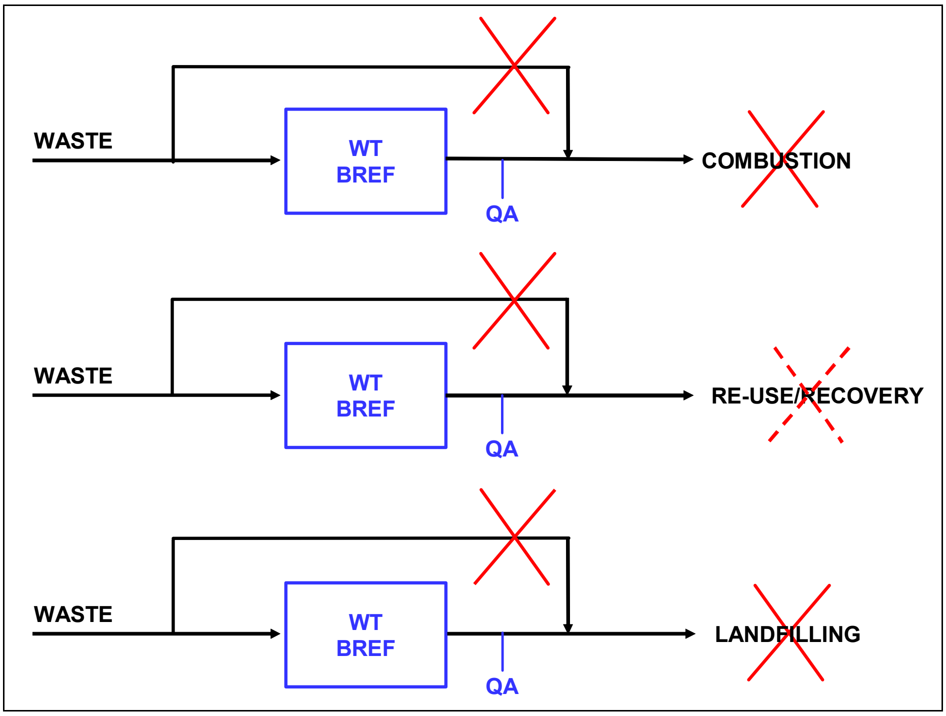
As shown in the previous figure, the actual combustion of waste is not included in the scope of this document. It is addressed in each individual BREF, where the different combustion processes are analysed depending on the industrial sector in which they are applied (e.g. waste incineration, large combustion plants, cement kilns). By including the processing of waste to be used as fuel, this document covers the treatments that can be applied to make different types of waste suitable for the fuel quality required by different combustion processes.

Some materials are categorised according to legislation for example as recovered fuels (REF), refuse derived fuels (RDF) or solid recovered fuel (SRF). It is not the intention here to enter into a discussion of the definition of any waste term. For example in the latter issue, some information can be found in CEN proposals. Also some of those materials can be classified as hazardous according to legislation.

This document includes those treatments that can make a waste re-usable or recoverable. However this document does not include re-use or recovery options that go directly from one industrial sector to another without treatment (e.g. re-use of foundries sand or some compatible catalysts as a raw material in cement kilns, re-use of waste metals in non-ferrous metal processing). This issue is shown in the next figure.

As mentioned above, no techniques related to landfills are included in this document. The only issues covered are those related to the treatment of waste to make it more suitable for landfilling.

The following figure tries to clarify and summarise the issues covered in the above paragraphs.



Examples of waste treatments not covered in this document
Note: QA: quality assurance

Waste activities covered in this document

Considering all the issues/arguments stated above, Annex I of the IPPC Directive, the other BREFs produced or under production and, the legal advice of the European Commission, the following table lists the waste treatment activities that are covered in this document:

Treatment	Type of waste or examples of type of waste	Additional information
Installations dealing mainly with treatments that result in outputs for disposal		The TWG recognised that in many cases there are installations where it is very difficult to differentiate between outputs as materials for other uses or for disposal, e.g. variations due to market reasons, waste availability or waste composition, which may mean that depending on conditions at the time the output might be recycled, disposed of, or in certain economic conditions, even sold as a product/raw material for other processes
All types	Excavated soil	
All types	Materials containing CFCs	Some HCFC incinerators
All types	Materials contaminated by POPs (e.g. PCBs and dioxins)	Communication from the Commission to the Council, the European Parliament and the Economic and Social Commitee (COM(2001) 593). The communication refers to IPPC and BAT (pp. 7,15,17) but specifically to the waste treatment BREF (so-called Waste R&D). It says: 'In the context of the BAT Reference document on Waste R&D activities, to be prepared in 2002 to 2004, special attention will be given to determining BAT for the treatment of waste materials contaminated by PCBs and dioxins.' The incineration of such materials are not covered in this document

Treatment	Type of waste or examples of type of waste	Additional information
All types	Oil/water sludge	
All types	Plastics containing pollutants	
All types	Sludge from WWTPs	
All types	Spent catalysts	The catalyst treatment sector includes those treatments that can make a spent catalyst re-usable or regeneratables. However, this document cannot include the use options that go directly from one industrial sector to another without any treatment being necessary (e.g. re-use of catalysts as raw material in cement kilns, re-use of waste metals in non-ferrous metal processing). Those issues are covered in each industrial sector BREF. This document will consider and analyse the impact of the different types of waste to be handled and transformed so that the waste ends up in a suitable form to be used in certain processes. Catalyst regeneration can be carried out on-site or off-site. This document deals with off-site installations. Spent catalysts can sometimes be regenerated in industry in process-integrated plants. The regeneration of catalysts carried out in industry in integrated plants as an associated activity is not going to be covered in this document. For this reason, this document focuses on standalone regeneration installations
All types	Waste contaminated with mercury	
Common treatments		
Blending and mixing		
Repackaging		
Storage of waste and raw materials		Storage BREF Intermediate waste storage
Waste reception, sampling, checking and analysis		Associated activities to waste facilities
Waste transfer and handling installations		
Waste transfer stations (hazardous or non-hazardous)		
Biological treatments		
Aerobic/anaerobic treatments	Excavated contaminated soil	Ex-situ remediation
Aerobic/anaerobic treatment	Non source-separated waste (e.g. mixed municipal waste)	Pretreatment prior to disposal, generating a material not suitable to be used as a compostable product
Biological treatment	Biodegradable aqueous liquids e.g. food wastes, methanol and other water miscible solvents	Bulk liquid wastes tankered into waste water treatment works Aerobic and/or anaerobic treatment depending upon the configuration of the works
Mechanical and biological treatments		Pretreatment prior to disposal

Treatment	Type of waste or examples of type of waste	Additional information
Physico-chemical treatments		
Acid neutralisation	Hydrochloric, sulphuric, nitric, hydrofluoric, phosphoric acids and acidic salts, such as aluminium chloride, etc.	Mixing of acids with either waste alkalis or raw materials, such as lime. Nitric and hydrofluoric acids are usually dealt with separately
Alkali treatment/neutralisation	Sodium and potassium hydroxide, lime, ammonia solution, ammonium salts and amine compounds	Caustic, alkalis and lime neutralised with acids. Air stripping can treat aqueous ammonia solutions. Ammonium salts and amines should be maintained at pH <9 to prevent a gaseous release
Chromic acid treatment	Chromium oxide (CrO_3) is acidic, toxic, water soluble and an oxidising agent	Conversion of Cr^{6+} to less hazardous Cr^{3+}, by the addition of a reducing agent, such as sodium metabisulphite followed by precipitation
Cyanide treatment	Cyanide salts, e.g. sodium cyanide from metal surface treatments	Conversion of cyanide to less hazardous cyanate maintaining pH >10 using on oxidising agent
Dewatering	Sludge created by sedimentation	Production of a solid filter cake by filtration through fabric filter cloths/centrifuges or filter presses
Ex-situ treatments	Excavated contaminated soil	
Filtration	Effluent from dewatering, also used for aqueous materials contaminated with oil	Micro- and ultrafiltration to remove particulates. Nanofiltration and reverse osmosis can be used to remove dissolved molecules, but are not currently utilised for physico-chemical treatments
Harbour reception facilities	Contaminated water	
Oil water separation	Aqueous materials contaminated with oil	Tilting plates or coalescing separators utilising differences in specific gravity
Physico-chemical treatment	Asbestos	
Physico-chemical treatment	Contaminated wood	
Physico-chemical treatment	Contaminated refractory ceramics	
Physico-chemical treatments	Liquid, sludge and solid wastes (e.g. salts and solutions containing cyanides, pesticides, biocides and contaminated wood preserving agents)	Physico-chemical treatments are used in practice in a very broad sense including all measures to treat liquid, sludgy and solid wastes. Phase separation (particulates removal, de-emulsification, separation of unsoluble liquids, precipitation, sedimentation), mechanical treatments, evaporation, dewatering, drying, stabilisation and solidification of waste, neutralisation, detoxification, calcination, blending, mixing
Precipitation	Metals, for example, Zn, Ni, Cr, Pb, Cu	Precipitation using acids and alkalis to adjust the pH to achieve minimum solubilities
Separation of mercury from waste	Waste contaminated with mercury	
Separation, physico-chemical treatment	Oil/water mixtures and emulsions	
Settlement	Effluent containing neutralised acids/alkalis, precipitated metals and other solid particulates	The particles are allowed to settle out of the effluent. The particles and the efficiency of settlement can be assisted by the addition of a flocculant. Dissolved Air Flotation (DAF) to produce a floating flocculated solid is used at some installations (mainly for organic sludges)

Treatment	Type of waste or examples of type of waste	Additional information
Solidification and stabilisation	Fly and bottom ashes before landfilling. In some cases, for liquid and semi-solid hydrocarbons. Mineral industrial solid waste and sludges	Bottom ashes are mostly covered by other BREFs as part of their processes. Mixing of wastes with absorbents or binders, e.g. bentonite, ash, kiln dust, to reduce the environmental impact
UV and ozone treatments	Contaminated water	
Treatments to recover mainly the waste material		
Re-concentration	Acid and bases	Plants for the thermal regeneration of HCl and the reconcentration of spent H_2SO_4. The rest of the regeneration processes of sulphuric acid are covered in the Large Volume Inorganic chemical BREF
Recovery of materials	Waste from pollution abatement	
Recovery of metals	Liquid and solid photographic waste	
Regeneration	Organic solvents	
Regeneration	Spent ion exchange resins	
Regeneration and treatment	Spent activated carbon	Includes the regeneration of activated carbon. Regeneration of spent activated carbon in the mercury based chlor-alkali production is covered in the chlor-alkali BREF
Re-refining	Oils	
Treatments to produce mainly a fuel		
Preparation of waste to be used as fuel	Hazardous and non-hazardous materials	All types of treatments (e.g regrouping, blending, mixing, separation) for the preparation of waste to be used in all types of combustion processes (incineration, large combustion plants, cement kilns, chemical works, iron and steel, etc.)
Preparation of solid waste fuel	Non-hazardous waste	e.g. from municipal solid waste, commercial waste
Preparation of solid waste fuel	Hazardous waste	
Preparation of liquid fuel from liquid waste, e.g. oil processing or blending	Waste oils Oils (including vegetable oils) Oil contaminated with water Organic solvents	All type of treatments which are applied to waste oils or waste solvents will be covered within this document (e.g. cleaning of waste oils and further processing, refining). Coarse filtering, heating and/or centrifuging and blending to produce material to be burned

Waste and waste treatment installations covered in this document

1 GENERAL INFORMATION

[5, Concawe, 1996], [7, Monier and Labouze, 2001], [13, Marshall, et al., 1999], [14, Ministry for the Environment, 2000], [36, Viscolube, 2002], [39, Militon, et al., 2000], [40, Militon and Becaud, 1998], [41, UK, 1991], [42, UK, 1995], [53, LaGrega, et al., 1994], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [100, UNEP, 2000], [121, Schmidt and Institute for environmental and waste management, 2002], [122, Eucopro, 2003], [124, Iswa, 2003], [125, Ruiz, 2002], [126, Pretz, et al., 2003], [128, Ribi, 2003], [150, TWG, 2004], [152, TWG, 2004]

1.1 The purpose of waste treatment

Secondary products are inherent to any industrial process and normally cannot be avoided. In addition, the use of products by society leads to residues. In many cases, these types of materials (both secondary products and residues) cannot be re-used by other means and may become not marketable. These materials are typically given to third parties for further treatment.

The reason for treating waste is not always the same and often depends on the type of waste and the nature of its subsequent fate. Some waste treatments and installations are multipurpose. In this document, the basic reasons for treating waste are:

- to reduce the hazardous nature of the waste
- to separate the waste into its individual components, some or all of which can then be put to further use/treatment
- to reduce the amount of waste which has to be finally sent for disposal
- to transform the waste into a useful material.

The waste treatment processes may involve the displacement and transfer of substances between media. For example, some treatment processes results in a liquid effluent sent to sewer and a solid waste sent to landfill, and others result in emissions to air mainly due to incineration. Alternatively, the waste may be rendered suitable for another treatment route, such as in the combustion of recovered fuel oil. There are also a number of important ancillary activities associated with treatment, such as waste acceptance and storage, either pending treatment on site or removal off site.

1.2 Installations for the treatment of waste

This section summaries the waste treatment sector in the EU. A short explanation of the treatments performed is included here.

The waste sector is highly regulated in the EU. For this reason many legal definitions of common terms used in this sector are available (e.g. waste, hazardous waste). Some definitions are available in the European Waste Framework Directive and amendments to it.

Ultimately, waste is either recovered or disposed of. Waste treatment installations therefore carry out operations for the recovery or disposal of waste. Waste treatment installations are not typically considered to produce a product like other industrial sectors. Instead, it is considered that they provide services to society to handle their waste materials. A waste treatment facility typically covers the contiguous land, structures, and other areas used for storing, recovering, recycling, treating, or disposing of waste.

As in the case with the classification of waste types, waste treatment (WT) activities are legally classified by Annex II of the Waste Framework Directive. A copy of this classification is provided in Section 8.1.1 of the Annex of this document, together with examples of their application.

The concept of a facility dedicated to the management of waste is not new. Long before the enactment of waste legislation (hazardous or non-hazardous), companies which produced waste already recognised the need for the specialised treatment and disposal of their wastes. Many waste producers constructed and operated their own dedicated facilities, typically on-site facilities.

Other companies that generated waste, and do not have have suitable site or do not generate a sufficiently large volume of waste to justify the investment in an on-site facility, transported their waste off site to specialised facilities for treatment and disposal. Such facilities are typically referred to as commercial, off-site facilities. The commercial waste management industry thus began the development of these off-site facilities in the late 1960s. His role was to collect and transport waste to specialised off-site facilities where they carried out the treatment and disposal of that waste.

Just as there are many types of waste, there are many ways in which wastes can be managed. For example, there are at least 50 commercially applied technologies for the treatment of hazardous waste. A waste facility may function with just one technology, or it may combine multiple technologies, particularly if it is a commercial facility serving a number of waste producers.

There are some differences between a typical commercial off-site facility and an on-site facility typically specializing in the treatment of a particular type of waste. This derives in part from the fact that an off-site facility accepts waste from outside the local community, while an on-site facility handles only that waste generated by what could be a long-standing and important economic activity in the community. From a technical perspective, the off-site facility generally handles a wider range of waste types and is typically larger and more complex.

For example, off-site waste facilities may be categorised as follows:

- installations focused mainly on recovering material as a saleable product (typically solvents, oils, acids, or metals). Some use the energy value in the waste
- installations focused on changing the physical or chemical characteristics of a waste, or degrade or destroy the waste constituents, using any of a wide variety of physical, chemical, thermal, or biological methods
- installations focused on permanent emplacement of waste on or below the surface of the land. Such installations are not covered in this document.

The following sections within this section cover more specific information gathered, on the types of waste installations, classified by the main type of waste treatment carried out. Not all types of waste treatments covered in this document are covered in this section, possibly because such a treatment may be considered quite minor.

1.2.1 Waste transfer installations

Operations carried out in these installations include: reception, bulking, sorting, transferring pending, prior to submission to a disposal/recovery operation. In some cases, blending and mixing may also be carried out in these installations. Waste transfer stations may involve individual operations or may be an integrated part of a treatment process. All sites typically undertake some kind of bulking operation to agglomerate the solids, where liquids are decanted from one container to another. The liquid transfer can be from a tanker to a holding tank, or from fractions of litre up to a more than 200 litre drum. Operations typically carried out are inspection, sampling, physical sorting and packaging, decanting, blending, drum emptying, storage, drum/IBC reclamation and in some cases disposal of wiping cloths, solidification and the crushing of oil filters. Waste transfer stations tend to fall into two categories according to the objective of the installation:

- **focus on the output stream.** This corresponds to sites that act as a feeder for other processes: e.g. solvent regeneration, incineration, chemical treatment. These sites target specific waste streams that can be checked, analysed and bulked up to provide a steady feedstock for an associated process. They may also take in and process a variety of other materials in order to provide a full service to their clients. These sites tend to handle a much higher proportion of certain waste streams and acceptance, storage and control systems are therefore designed for these wastes
- **focus on the input waste.** These sites are independent transfer stations and generally accept a full range of materials from the neighbouring area. Typically they also bulk and blend materials to produce a range of waste streams suitable for disposal through different treatment, recovery and disposal processes, but they do not usually target any specific waste group. There may be a bias towards particular waste streams, but this will likely be due to local patterns of waste arisings and commercial opportunities, rather than the need to provide a feedstock for a particular downstream process.

The majority of operations linked to waste preparation may be distinguished under two groups:

- **regrouping/reconditioning.** Here the aim is to group together wastes in small or medium quantities, when they have the same nature and when they are compatible. The resulting waste though still has to be treated. The purpose of regrouping is to obtain larger and more homogeneous volumes for waste treatment, to improve safety (e.g. facilitation of handling) and to rationalise the logistics cost. The combination of processes used in waste preparation and in pretreatment operations depends on the specifications of final treatment
- **pretreatment.** Here the aim is to adapt the waste to the type of recovery and/or disposal of the final treatment available. Pretreatment covers several aspects. It can be defined as those operations that lead to homogenisation of the chemical composition and/or physical characteristics of the wastes. Pretreatment produces a waste, which may be very different from the initial waste, although not from a regulatory point of view. This pretreated waste still has to be treated in a recovery and/or disposal plant. At the end of the pretreatment process, the pretreated waste should comply with chemical and physical specifications that are fixed by the end users.

Grouping and pretreatment activities may be located at the same site as the final treatment, on the waste production site or on a particular dedicated site. Nevertheless, regardless of the location, the operating processes are the same.

Table 1.1 below shows the number of waste transfer installations and capacity in different European countries.

Country	Number of known installations		Known capacity (kt/yr)	
	Hazardous	**Non-hazardous**	**Hazardous**	**Non-hazardous**
Belgium	10			
Denmark	0		0	
Germany	125			
Greece	6			
Spain	68			
France			3000	
Ireland	12			
Italy	0		0	
Luxembourg	1			
Netherlands	2			
Austria	16			
Portugal	5	143	3975 m^3	Y
Finland	5	0[1]	58	0
United Kingdom	439	2073		
Iceland	0		0	
Norway	0		0	
TOTAL	**689**	**2216**		

[1] No non-hazardous installations, other than facilities where waste is unloaded in order to permit its preparation for futher treatment.

Note: Numbers within this table may not reflect the real number of installations or capacity. The main reasons are that the market is so dynamic that numbers change rapidly and/or because no data have been provided by the TWG at all on certain topics. Cells without numbers mean that no information has been provided.

Table 1.1: Waste transfer installations
[39, Militon, et al., 2000], [60, Azkona and Tsotsos, 2000], [61, Weibenbach, 2001], [86, TWG, 2003], [150, TWG, 2004]

1.2.2 Installations containing a biological treatment of waste

Refer to the Scope chapter of this document to see which biological treatments of waste are covered. However, note that the data contained in Table 1.2 refer to all biological treatments, including those not covered in the Scope. The reason for this is that available statistics typically refer to national data and it is difficult to separate information of only those installations covered in the Scope of this document.

Country	Number of known installations		Known capacity (kt/yr)	
	Hazardous	Non-hazardous	Hazardous	Non-hazardous
Belgium	5	Y		
Denmark	1	0		0
Germany	57	200		
Greece	0	Y	0	
Spain	3	Y	140	
France	0	Y	0	
Ireland	1	Y		
Italy	74	3		180
Luxembourg	0	Y	0	
Netherlands	7	Y		
Austria	8	16[1]	103	706[1]
Portugal	1	9	88	514
Finland	20	41	98	305
Sweden		Y		
United Kingdom	0	173		
Iceland	0	0	0	0
Norway	0	Y	0	
TOTAL	**177**	**442**	**429**	**1705**

Y: exists but no data are available

[1] Data corresponds to MBT only

Data in this table correspond to all types of biological treatments and not only to those related with the ones inside the scope of this document. Therefore, the number of installations covered by this document will be less than the figures appearing in this table

Note: Numbers within this table may not reflect the real number of installations or capacity. The main reasons are that the market is so dynamic that numbers change rapidly and/or because no data have been provided by the TWG at all on certain topics. Cells without numbers mean that no information has been provided.

Table 1.2: Installations for the biological treatment of waste
[39, Militon, et al., 2000], [60, Azkona and Tsotsos, 2000], [61, Weibenbach, 2001], [86, TWG, 2003], [150, TWG, 2004]

In Finland there are 561 waste water treatment installations in which the septic tank sludges are also treated. There are 41 installations (aerobic 27 and anaerobic 14) for treating non-hazardous wastes. Besides the non-hazardous waste installations mentioned in Table 1.2, there are also 129 composting facilities, with a total capacity of 542 kt/yr.

In some countries (e.g. UK and Italy), biological treatment is mainly carried out by water companies, utilising existing capacity on waste water treatment works. It is estimated that there are potentially around 30 possible installations. The volumes of waste treated are small, typically less than 1 % of the input of the waste water treatment works, but in some cases this represents a significant COD load (in one case, 50 % of total COD input to the waste water treatment works). However, this type of treatment poses questions because there is a possibility of diluting contaminants as well as contaminating the sewage sludges coming from this kind of treatment.

1.2.3 Installations for the physico-chemical treatment of waste waters

This sector is represented by a large range of processes which are classed as 'chemical treatments'. These range from blending systems with no actual chemical interactions to complex plants with a range of treatment options, some custom designed for specific waste streams.

The process is designed to treat waste waters (contaminated with, e.g acid/alkalis, metals, salts, sludges), but usually accepts a range of organic materials as well, e.g. process plant washings and rinsings, residues from the oil/water separation, cleaning wastes, interceptor wastes, etc. These could contain almost any industrial material. It is likely that the treatment process will have some effect on the organic materials, for example due to some chemical oxidation of COD, some organics could be adsorbed or entrained in the sludge or, in emulsion treatment, part of the organic content could become separated from the aqueous phase.

These treatment systems remove and/or detoxify hazardous constituents dissolved or suspended in water. The selection and sequence of unit processes will be determined by the characteristics of the incoming wastes and the required effluent quality. An example of a physico-chemical treatment facility of waste waters typically contains the following unit processes: cyanide destruction, chromium reduction, two-stage metal precipitation, pH adjustment (e.g. neutralisation), solid filtration, biological treatment, carbon adsorption, sludge dewatering, coagulation/flocculation and some others.

Country	Number of known installations		Known capacity (kt/yr)	
	Hazardous	**Non-hazardous**	**Hazardous**	**Non-hazardous**
Belgium	8	Y		
Denmark	4	Y		
Germany	249	9000		
Greece	0	0	0	0
Spain	49		901	
France	19	Y	301	
Ireland	4	Y		
Italy	147	Y		
Luxembourg	1	0		0
Netherlands	30	0		0
Austria	33	Y	515	
Portugal	2	Y	22000 m^3	
Finland	36	0 [1]	144	0
United Kingdom	32	289		
Iceland	0	0	0	0
Norway	4	Y		
TOTAL	**618**	**9289**	**1883**	

Y: exists but no data are available

[1] No non-hazardous installations with this operation only

Note: Numbers within this table may not reflect the real number of installations or capacity. The main reasons are that the market is so dynamic that numbers change rapidly and/or because no data have been provided by the TWG at all on certain topics. Cells without numbers mean that no information has been provided.

Table 1.3: Installations for the physico-chemical treatment of waste
[60, Azkona and Tsotsos, 2000], [61, Weibenbach, 2001], [86, TWG, 2003], [150, TWG, 2004]

The physico-chemical (Ph-c) treatment of waste water typically divides the waste into another type of waste (typically solid) and an aqueous effluent which is not usually considered waste as it is part of another legislation.

Ph-c plants are essential to medium and small companies including commercial enterprises. Waste which must be treated by Ph-c plants will, in future, continue to be produced (in the course of production); obligatory acceptance of waste by generally accessible Ph-c plants is an advantage for trade and industry, facilitating correct disposal of waste and easing the economic burden for industry and trade.

The following principal configurations can be identified:

- company in-house Ph-c plants. These are specialised for the treatment of the waste produced by a company
- generally accessible Ph-c plants (service plants). These are suitable for the treatment of waste produced in certain regions.

1.2.4 Installations for the treatment of combustion ashes and flue-gas cleaning residues

During combustion processes, solid waste may be generated. Such solid waste is typically called ‘ashes’. Two types are usually present; one called ‘bottom ash’, typically recovered at the bottom of the combustion chamber and another called ‘fly ash’ that is smaller and flows with the combustion fumes. This latter one is usually recovered with flue-gas cleaning equipment. Such flue-gas cleaning equipment is not only applicable to fly ash but also to extract from the other pollutants flue-gases. In doing so, different types of waste can be generated. This section contains those installations that treat such a variety of waste generated during combustion processes as well as other flue-gas cleaning processes.

Combustion ashes and flue-gas cleaning residues are one of the main waste stream treated by stabilisation and solidification processes, either in the combustion plant (e.g. in some incinerators), or on waste treatment facilities. Other methods are vitrification, purification and recycling of some components (e.g. salts). Another method of treating combustion ashes involves the fusion of ash by plasma at very high temperatures in order to vitrify the structure. One installation exists in France with a total treatment capacity of 3.5 kt per year.

1.2.5 Installations for the treatment of waste contaminated with PCBs

Incineration, when available, is the most widely available and used technology for PCB destruction. The complete destruction of PCB by incineration only takes place under well defined conditions (e.g. high temperature and a higher residence time). Because of the cost of incineration, however, and its non-availability in many countries, alternative technologies are sometimes used.

1.2.6 Installations for treatment of waste oil

Used lubricating oils can be recovered to a quality essentially equal to some groups of base oils used to produce lubricating oils (some base oil groups III and IV rarely, if ever, contain re-refined oils). This process is typically referred to as ‘oil re-refining’.

The recovery of oil from waste is typically a part of the waste industry. There are licensed sites that specialise in the recovery of oil from different waste streams. In addition, a number of chemical treatment plants and transfer stations have oil separation units that undertake a first separation of oil from water before sending the oil layer through to a specialist plant for further processing. Some factors that define this sector are:

- companies that serve particular industrial sectors tend to offer a general waste service to that sector, and this may include waste oils
- companies that collect used lubricating oils from garages are also likely to collect oil filters, steering, brake and transmission oils, antifreeze and batteries
- companies handling transformer oils are likely to collect oils with some small amounts of PCBs
- some chemical and biological treatment plants undertake small scale oil recovery operations as part of their pretreatment processes. These are generally simple gravity separation systems.

There are large numbers of dedicated oil treatment and processing plants in the EU. Some companies carry out simple purification, removing the sediment and water from waste oil. Two type of treatments are applied to waste oils. One refers to its use as fuel and the other one corresponds to the re-refining of it so that part of it (typically 50 – 60 %) can be re-used as a base oil for lubricants. Oil processors show a wide range of intrinsic knowledge about their operations.

There are a wide variety of processes and licensors currently offering ways to deal with waste oils. There are four main processes used for the treatment of waste oils: blending, separation-chemical treatment, distillation and cracking.

In all waste oil treatment processes, the economic and calorific values of the waste oils are recovered to varying degrees. The two main techniques used are re-refining and direct burning (mainly in cement factories), each accounting for about 30 % of the total quantity recovered. The two other methods which, together, account for the remaining third are reprocessing and reclaiming, the latter principally being used for hydraulic oils.

The level of knowledge about oils is markedly different between sites. Partly due to the fact that waste oil is an extremely complex and changing material with a huge potential range of individual components that are not all categorised at present.

Data currently available regarding waste oil (WO) management in Europe are of very poor quality, particularly concerning regeneration. Figure 1.1 shows a summary of the percentages of the types of treatments used for the WO in each EU country. According to data from the sector in 1993, the used oils collected where disposed of by direct burning (32 %), by re-refining to base oils (32 %), by reprocessing to industrial fuel (25 %) and by reclaiming specific industrial oils 11 %. These percentages however have since changed considerably, as shown in the following figure.

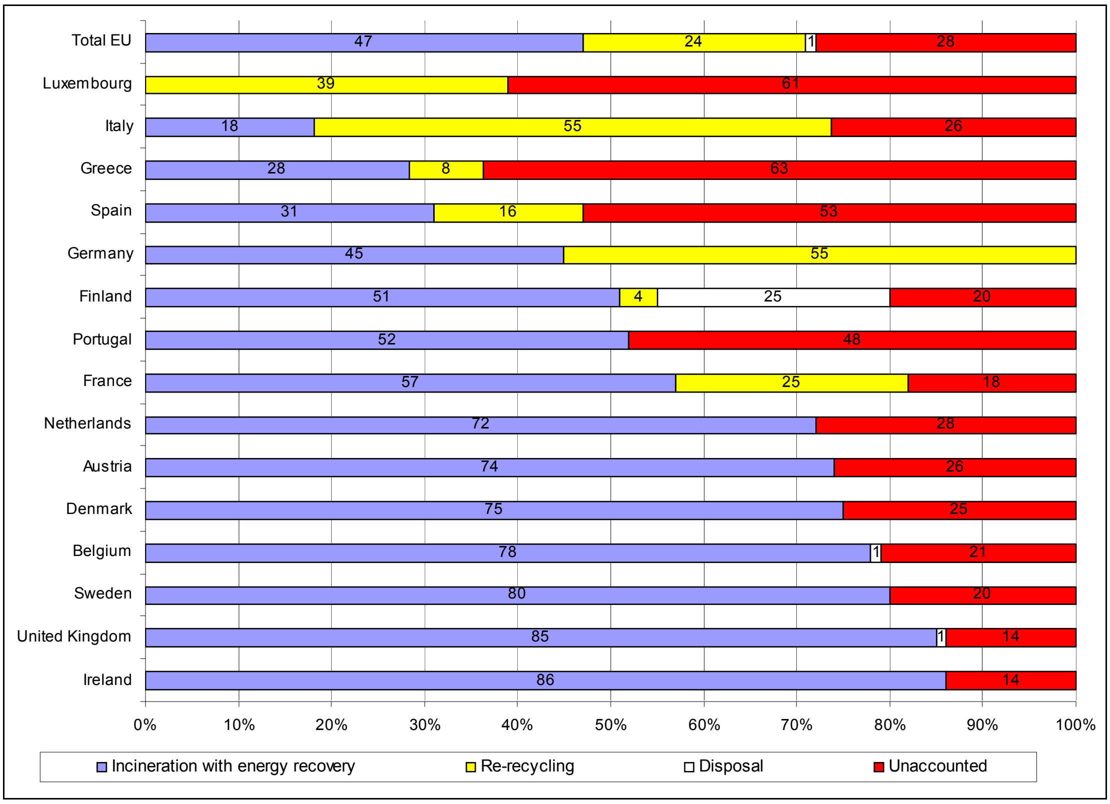


Figure 1.1: Management of waste oils in the EU in 1999
[7, Monier and Labouze, 2001], [86, TWG, 2003], [150, TWG, 2004]

Re-refining

About 220 kt of re-refined base oil was produced in 2000 according to [7, Monier and Labouze, 2001], which accounts for less than 5 % of the overall base oil demand in Europe.

In recent years, the level of regeneration carried out has noticeable decreased in some EU countries which were pioneers in its use such as France, Germany, Italy and others such as the UK. This is tempered by the fact that there are some new projects emerging in several countries: France, Germany, Italy, Spain.

The known installed feed capacity for re-refining base oil throughout Europe is just over 500 kt/yr, with installation capacities ranging from 35 to 160 kt/yr. Currently, there are around 400 re-refining facilities worldwide, with an overall capacity of 1800 kt/yr. Although most of these plants are located in East Asia (India, China and Pakistan), their individual capacity is mainly low, c.a. 2 kt/yr each, on average. Most of these plants use acid/clay and there are few which produce good quality re-refined base oils or which take into account environmental issues.

Country	Number of known installations	Known capacity (kt/yr)
Belgium	2	45
Denmark	1	40
Germany	8	770
Greece	1	40
Spain	2	69
France	2	200
Ireland	0	0
Italy	7[1]	273[1]
Luxembourg	0	0
Malta	2	2.4
Netherlands	0	0
Austria	0	0
Poland	1	80
Portugal	0	0
Finland	5	88
Sweden	0	0
United Kingdom	3 [2]	5 [2]
Yugoslavia	1	
TOTAL	**35**	**1612.4**

[1] two installations are currently not working. Capacity of the two installations not working is 25 kt/yr.
[2] A TWG member questionned such figures to not be correct
Note: Numbers within this table may not reflect the real number of installations or capacity. The main reasons are that the market is so dynamic that numbers change rapidly and/or because no data have been provided by the TWG at all on certain topics. Cells without numbers mean that no information has been provided.

Table 1.4: Installations for re-refining waste oil in European countries
[5, Concawe, 1996], [7, Monier and Labouze, 2001], [13, Marshall, et al., 1999], [36, Viscolube, 2002], [86, TWG, 2003], [128, Ribi, 2003], [150, TWG, 2004]

Re-refining plants can adjust the quantity of re-refined base oil and fuels produced according to the international and local situation (crude oil prices, market demand, subsidies, etc.).

Preparation of waste oil to be used mainly as fuel

About 50 % of WOs (i.e. waste oil from ship and tank cleaning, waste oil from oil/water separator, waste oil from emulsions, etc.) is not waste lubricant oil or cannot be regenerated into base oil. These WOs can be converted into other oil products (e.g. fuel).

About 50 % of WOs were used as fuel in the EU in 1999. About 400 kt of WO are burned in cement kilns at the European level, which represents about 17 % of the total WO and 35 % of the WO burned, with the rate varying greatly between different countries. It represents the major exploitation route in France, Greece and Sweden, but only one of several alternative routes in Austria, Belgium, Italy and the United Kingdom. Some other sectors in the EU using WO as fuel are:

- blast furnaces, as a substitute for coke (e.g. Belgium)
- brick kilns (e.g. Spain)
- ceramic kilns (e.g. Spain)
- large combustion plants (e.g. Spain)
- lime kilns (e.g. Spain, Belgium)
- cracking plants, to produce new fuels (e.g. in Belgium in accordance with legal standards)
- port receiving facilities which convert waste oil into ship's fuel (e.g. Malta)
- waste incinerators (e.g. 2 kt in 2002 in hazardous waste incinerators in Belgium)
- space heaters (e.g. service stations, greenhouses, etc.)
- asphalt plants.

The two latter applications are no longer used in Flanders (Belgium) because of more stringent environmental regulations brought into force in January 1999. Table 1.5 indicates the amount of used oil burned in some EU countries

Burning options	Amount of waste oil (kt)	%
Cement kilns	307	42
Mixed with fuel oil	213	29
Other	120	16
Waste incinerators	52	7
Garage heaters	40	6
Total burned	**732**	**100**

Data only correspond to Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Spain and the United Kingdom.
Note: Obtaining a complete set of data on volumes of used oil burned in all EU countries in this study is difficult as details of the burning options are not consistently recorded.

Table 1.5: Volumes of used oil burned in EU per year
[5, Concawe, 1996]

There is also a significant volume of oil contaminated waters collected for recovery. These wastes have a net negative value but are processed so as to maximise the recovery of the hydrocarbon for use as a fuel. Table 1.6 shows some installations carrying out this activity.

Country	Number of known installations			Known capacity (kt/yr)		
	Using waste oil in direct burning	Using reprocessed waste oil as fuel	Non-hazardous oil	Using waste oil in direct burning	Using reprocessed waste oil as fuel	Non-hazardous oil
Belgium	1	10				
Denmark	4	Y				
Germany	12	1		310	100	
Greece	0					
Spain	4	Y	1			
France	60			725		
Ireland		Y				
Italy	2					
Luxembourg	0	0		0	0	
Malta	0	1		0	4.7	
Netherlands		Y				
Austria	4	0	0		0	0
Portugal	Y	Y	1			
Finland	3	4	1	155	54.5	0.2
Sweden	2	3				
United Kingdom	160	Y				
TOTAL	**252**	**19**	**3**	**1190**	**159.2**	**0.2**

Y: exists but no data is available
Note: Columns related to non-hazardous oil correspond to the production of biodiesel from used vegetable oil.
Note: Numbers within this table may not reflect the real number of installations or capacity. The main reasons are that the market is so dynamic that numbers change rapidly and/or because no data have been provided by the TWG at all on certain topics. Cells without numbers mean that no information has been provided.

Table 1.6: Installations where waste oils are used as fuel or where waste oil is reprocessed to produce a fuel
[7, Monier and Labouze, 2001], [13, Marshall, et al., 1999], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [128, Ribi, 2003], [150, TWG, 2004]

Under EU legislation, it is illegal to dispose of WO in landfills, storm-water or waste water drains. In some cases, used oil is applied to unsealed roads as a dust suppressant in some rural areas. About 25 % of the WO in the EU was unaccounted eliminated for in 1999.

1.2.7 Installations for treatment of waste solvent

Solvents are extensively used in chemical and biological processes. During these processes, waste solvent is produced and it is recycled in-house. These treatments are an integral part of the chemical/biological processes and they are covered in the different BREF documents. However for economic or technical reasons, sometimes the waste solvents are delivered to a third party (e.g. waste manager) for treatment. In some cases, the product of the treatment is returned to the waste producer and in other cases this does not happen.

Waste solvents are also produced in the area of solvent-based surface treatment (such as cleaning or degreasing in many different industrial sectors and in dry cleaning installations). In most cases, the contaminated solvents or the bottoms of the distillation columns (solvent content 1 – 10 % in the case of closed cleaning installations/devices with internal distillation devices) are delivered to solvent distillation installations and regenerated. The quality of the distillation products is as good as that of new solvents.

In accordance with the Waste Framework Directive, the first option for waste solvents, as well as for the rest of waste, is that it should be recycled. This has helped to generate an active solvent recycling market. Similarly to waste oils, waste solvents which are not suitable for regeneration because of certain compositions or because of very low purity can also be recovered as a secondary liquid fuel (SLF), for example, in the cement industry and hazardous waste incinerators. A fundamental difference with waste oils is that waste solvent qualities fluctuate much more than the quality of waste oil.

Solvent regeneration facilities separate contaminants from waste solvents and thus restore the solvent to its original quality or may be to a lower grade product (e.g. in the case of lacquer thinner). Distillation (batch, continuous, or steam) is used by most commercial solvent processors, and typically recovers about 75 % of the waste solvent. The residue, known as ‘distillation bottoms’, can be a liquid or a sludge, depending upon a number of conditions, and typically requires management as a hazardous waste. Other separation technologies used by solvent processors include: filtration, simple evaporation, centrifugation, and stripping.

Country	Number of known installations	Known capacity (kt/yr)
Belgium	5	>8
Denmark	0	
Germany	21	
Greece	3	
Spain	14	64
France	27	90.7
Ireland	2	
Italy	2	
Luxembourg	0	
Netherlands	8	
Austria	2	
Portugal	1	10000 m^3
Finland	4	11
United Kingdom	8	>12
Iceland	0	
Norway	11	
TOTAL	**108**	**185.7**
Note: Numbers within this table may not reflect the real number of installations or capacity. The main reasons are that the market is so dynamic that numbers change rapidly and/or because no data have been provided by the TWG at all on certain topics. Cells without numbers mean that no information has been provided.		

Table 1.7: Waste solvent installations in European countries
[40, Militon and Becaud, 1998], [60, Azkona and Tsotsos, 2000], [61, Weibenbach, 2001], [86, TWG, 2003], [129, Cruz-Gomez, 2002]

1.2.8 Installations for the treatment of waste catalysts, waste from pollution abatement and other inorganic waste

The treatment of waste catalysts depends on the type of catalyst (catalytic active substance and supporting structure or carrier) as well as the included by-products from the catalytic process. These treatments include: regeneration of catalysts to be re-used as catalysts again, recycling of components from catalysts and disposal in landfills. An example installation is an Austrian facility for the recovery of Ni from food industry catalysts (Fe/Ni alloy).

Hydrometallurgical technology can be used to extract and concentrate metals from liquid waste. Non-liquid wastes first require dissolution.

In Malta, there are two underground asbestos storage sites and one overground pending treatment. The asbestos originated from ships being repaired in dock yards and from unused asbestos pipes.

	Treatment of waste catalysts		**Treatment of other inorganic waste (excluding metals and metal compounds)**		**Recovery of waste from pollution abatement**	
Country	**Number of known installations**	**Known capacity (kt/yr)**	**Number of known installations**	**Known capacity (kt/yr)**	**Number of known installations**	**Known capacity (kt/yr)**
Belgium	0	0	13		1	
Denmark	0	0	3		1	
Germany	1		63		2	
Greece	5		0	0	0	0
Spain	0	0	6	195	15	3
France	3	4.9	0	0	0	0
Ireland	4		0	0	0	0
Luxembourg	0	0	0	0	0	0
Malta			3			
Netherlands	2		17		1	
Austria	3		14		0	0
Portugal	0	0	0	0	0	0
Finland [1]	0	0	9	3	0	0
Iceland	0	0	0	0	0	0
Norway	2		1		0	0
TOTAL	**20**	**4.9**	**129**	**198**	**20**	**3**

[1] The treatment of 1 million lamps containing mercury is not included.

Note: Numbers within this table may not reflect the real number of installations or capacity. The main reasons are that the market is so dynamic that numbers change rapidly and/or because no data have been provided by the TWG at all on certain topics. Cells without numbers mean that no information has been provided.

Table 1.8: Installations for the treatment of waste catalysts, waste from pollution abatement and other inorganic waste in European countries
[40, Militon and Becaud, 1998], [60, Azkona and Tsotsos, 2000], [61, Weibenbach, 2001], [150, TWG, 2004]

1.2.9 Installations for treatment of activated carbon and resins

Most waste activated carbon and resin is a result of water purification processes. It is very difficult to estimate the regeneration throughput in Europe, mostly due to the fact that many operators regenerate their adsorbent on site (often sporadically) rather than sending it to large centralised reactivation plants.

Activated carbon is used in three principal applications: the treatment of drinking water; in the food and drink industry, for example for removing colour in the refining of sugar; and in general industrial applications, e.g. removal of VOCs from process vent streams. These applications affect the type of contamination on the carbon and the regeneration process that is then required.

For example, carbon which has been used in industrial applications ('industrial carbons'), such as in effluent treatment, requires a more stringent pollution abatement system than that used for the treatment of potable water or for that from the food industry.

At some point in the lifetime of the process, the carbon will become exhausted with the material that it is adsorbing. The carbon should then be regenerated or, if this is not possible, disposed of. The choice of route is naturally determined by economics and scale. In the treatment of potable water, the carbon is used in large quantities and is contained in large open topped concrete-lined carbon beds. These have a life expectancy before exhaustion of a few years. When they are regenerated, they result in large quantities to be treated. It is this application that represents the most common in the UK in terms of volume and it is regenerated either on site by a purpose built plant or transported off site for regeneration by a merchant operator. Because of the nature of the market there is a tendency that more regeneration facilities, once designed purely for 'in-house' materials, now offer a merchant regeneration service.

There are at least 19 sites in Europe regenerating activated carbons from off site. The estimated numbers are mentioned in the next Table 1.7.

Country	Number of known installations	Known capacity (kt/yr)
Belgium	2	
Germany	3	
France	1	
Italy	5	
Netherlands	1	
Austria	1	
Finland	1	
Sweden	1	
United Kingdom	4	
TOTAL	**19**	**>50**
Note: Numbers within this table may not reflect the real number of installations or capacity. The main reasons are that the market is so dynamic that numbers change rapidly and/or because no data have been provided by the TWG at all on certain topics. Cells without numbers mean that no information has been provided.		

Table 1.9: Activated carbon installations in European countries
[150, TWG, 2004]

The most common reactivation furnaces are direct fired rotary kilns and multiple hearth furnaces. Indirect fired rotary kilns, fluidised bed, vertical tube type and infrared are sometimes used. The type of granular activated carbon (GAC) reactivation furnaces in use worldwide in early 1990 are shown in Table 1.10.

Type of GAC reactivation furnace	Number of units
Multiple hearth	>100
Fluidised bed	<20
Indirect fired rotary kiln	>50
Direct fired rotary kiln	<30
Vertical tube-type	<30
Infrared furnaces (horizontal and vertical)	<9

Table 1.10: Type of GAC reactivation furnaces in use worldwide
[42, UK, 1995]

Quantitative figures for ion exchange resin regeneration facilities are not available.

1.2.10 Installations for the treatment of waste acids and bases

There are several installations in the EU which regenerate HCl. No installations have been identified to recover HBr. Waste sulphuric acid can be regenerated in the following ways:

- thermal decomposition of waste/spent/recovered sulphuric acid, the result then being used as a primary or supplementary source of SO_2 feed to a sulphuric acid contact process. This is covered in the LVIC(AAF) BREF [62, EIPPCB, 2003], as is any process that produces SO_2 as a feedstock by decomposition/calcinations
- a process based on the reconcentration of weak/spent/waste sulphuric acid, with or without separation of potential impurities (e.g. salts). This will be included in this document
- industrial processes that use sulphuric acid and include a recycling of the spent sulphuric acid as an integral part of the process. This will be covered in the BREF where the industrial process is covered (e.g. BREF LVIC-solids and others for titanium dioxide production).

Country	Number of known installations	Known capacity (kt/yr)
Belgium	1	
Denmark	1	
Germany	2	
Greece	0	
Spain	1	42
France	3	2
Ireland	1	
Luxembourg	0	
Netherlands	0	
Austria	4	
Portugal	0	
Finland	0	
Iceland	0	
Norway	0	
TOTAL	**13**	**44**

Values correspond to regeneration installations covered by this document and the LVIC-AAF BREF
Note: Numbers within this table may not reflect the real number of installations or capacity. The main reasons are that the market is so dynamic that numbers change rapidly and/or because no data have been provided by the TWG at all on certain topics. Cells without numbers mean that no information has been provided.

Table 1.11: Installations for the regeneration of waste acids or bases
[40, Militon and Becaud, 1998], [60, Azkona and Tsotsos, 2000], [61, Weibenbach, 2001], [86, TWG, 2003]

Acid recovery usually involves the separation of unreacted acid from an acid waste such as spent pickle liquor generated by the steel industry. One method used in the steel industry, involves cooling the sulphuric acid to precipitate ferrous compounds. In another method, acid can be regenerated by injecting it into a spray roaster.

1.2.11 Installations for the treatment of contaminated wood

In some cases, contaminated wood is directly incinerated. In other cases, contaminated wood is thermally treated by carbonisation/pyrolysis. All these treatments are covered by the WI BREF. However, in some cases treatments are used focused on the extraction of heavy metals from the solid residue generated by carbonisation of contaminated wood – these processes are covered in this document. One installation is in operation in France.

1.2.12 Installations for the treatment of contaminated refractory ceramics

Two installations are in operation in France with a total treatment capacity of 50 kt per year.

1.2.13 Installations for the preparation of waste to be used as fuel

Currently, there are several factors driving the concept of using waste as a fuel in combustion processes:

- Waste Framework Directive and its amendments sets a waste management hierarchy. This gives a preference to recycling and recovery (including the use of waste as a source of energy)
- waste sector regulations, such as the 'packaging waste' Directive, 'end-of-life vehicles' Directive, 'waste from electrical and electronics', 'waste incineration' Directive, 'waste catalogue', 'dangerous substances' Directive and 'dangerous preparation' Directive may also influence the option
- the Landfill Directive prohibits the landfilling of waste with a high content of biodegradable materials. Therefore, there is a need to establish alternative ways for treating the respective waste fractions. Co-incineration is one option among others (e.g. incineration, mechanical-biological treatment)
- under the requirement of the Kyoto protocol, greenhouse gas emissions have to be reduced worldwide. Co-incineration of waste fractions as a replacement for conventional fuels may be one option to reduce greenhouse gas emissions
- as liberalisation of the energy market intensifies economic pressure on the energy producers/consumers. The co-combustion of waste opens a new scope of business for them, which makes operation of combustion plants more attractive economically
- to reduce the cost of fuel used in the combustion processes.

The term 'waste fuel' is used in this document for all types of waste materials that are prepared to be used as fuel in any combustion process. Waste fuels can be gaseous, liquid or solids. For instance, liquid waste fuels can be prepared from waste oils, solvents, and distillation bottoms. The way the liquid waste fuel is going to be used in the combustion process influences the way the waste fuel is prepared. For example, some liquid waste fuels can be prepared by blending different wastes that have high calorific values and feed them independently into the combustion chamber or they can be mixed/blended with conventional fuels (e.g. waste oil and fuel oils). Some liquid wastes, for instance oils, normally need pretreatment to remove bottoms, sediments, and water. This may be achieved through separation and dehydration.

Some combustion processes that may use waste as (part) fuel are the combustion plants for the production of heat and/or power, marine engines, cement kilns, blast furnaces in iron and steel production, brick kilns in the production of ceramics, lime kilns and asphalt production. The type of furnace or boiler used, the combustion conditions (e.g. temperature) that the process should operate, the impact on the emissions or products and the type of fuel already in use has a strong influence in which the type of waste(s) may be acceptable and how the waste fuel is prepared.

The purpose of those installations is to guarantee the following aspects:

- optimise the valorisation of certain waste avoiding its landfilling
- the quality of thermal destruction
- provide the required physico-chemical properties of the waste fuel to end user.

The basic principles of waste fuel production are the following:

- the chemical and physical quality of the fuel shall meet any specifications or standards ensuring environmental protection, protection of the kiln/furnace process, and quality of the material produced, where the combustion process where the waste fuel is used produces a product (e.g. cement)
- energy and mineral contents must remain stable to allow optimal feed in the kiln/furnace
- the physical form must allow safe and proper handling, storage and feeding.

Country	**Number of known installations**		**Known capacity (kt/yr)**	
	Hazardous	**Non-hazardous**	**Hazardous**	**Non-hazardous**
Belgium	12	Y		
Denmark	4	13		
Germany	16	34		
Greece	0	0		
Spain	33	5	204	
France	54	Y	542	1400
Ireland	2	Y		
Italy		27		2080
Luxembourg	0	Y		
Netherlands	1	Y		
Austria	8	10		
Portugal	0	Y		165
Finland	7	37	106	800
Sweden	Y	Y		
United Kingdom	Y	Y		
Iceland	1	Y		
Norway	2	Y		
TOTAL	**140**	**126**	**852**	**4445**

Y: exists but no data are available

Note: Numbers within this table may not reflect the real number of installations or capacity. The main reasons are that the market is so dynamic that numbers change rapidly and/or because no data have been provided by the TWG at all on certain topics. Cells without numbers mean that no information has been provided.

Table 1.12: Installations for the preparation of waste to be used as fuel
[39, Militon, et al., 2000], [40, Militon and Becaud, 1998], [60, Azkona and Tsotsos, 2000], [61, Weibenbach, 2001], [86, TWG, 2003], [150, TWG, 2004]

Preparation of municipal solid waste to be used as fuel

The current best estimate of the quantity of solid recovered fuels produced and consumed in Europe is about 1.4 Mt/yr, as set out below.

Country	Producers	Production		Consumption		- Export/Import +		CK
		kt/yr	toe/yr	kt/yr	kt/yr	toe/yr	kt/yr	%
Belgium	7	<100	<50000	<100	<50000	n.a.	n.a.	(100)
Denmark	1	0	0	0	0			
Germany	19	500 (650)	250000 (325000)	500 (650)	250000 (325000)	n.a.	n.a.	85
Greece		0	0	0	0			
Spain		n.a.	n.a.	n.a.	n.a.			
France	3	0	0	0	0			
Ireland		<200 (250)	<100000 (125000)	<200 (250)	<100000 (125000)	n.a.	n.a.	
Italy	25	0	0	0	0			
Luxembourg	23	0	0	0	0			
Netherlands		250 (350)	100000	15	6000	-145	60000	20
Austria	26 [3]	160	50000	100	50000			7
Portugal	8	0	0	0	0			
Finland	10	170	58000	170	58000	n.a.	n.a.	0
Sweden	4	[1]		[1]		+500 [2]		
United Kingdom		60 (100)	30000 (50000)	60 (100)	30000 (50000)	n.a.	n.a.	
Iceland		0	0	0	0			
Norway	29	[1]		[1]				
TOTAL	**155**	**1380**						

toe/yr = tonnes oil equivalent per year (It is assumed that solid recovered fuel has a calorific value of 21 MJ/kg, although it is lower in Finland and the Netherlands, and oil has a calorific value of 42 MJ/kg)

CK = % of consumption that occurs in cement kilns

The figures in this table are only indicative as they do not correspond to the same harmonised definition used throughout the European Union

[1] There is no overall statistic for Sweden or Norway because this fuel is used in ordinary heat/power plants and in waste incinerators without a demand for detailed specifications. Data for Sweden (2001) are: waste incineration plants for district heating 856000 t/yr and power plants for district heating 455000 t/yr.

[2] No exact figures exist, but approximate figures give 500 kt of waste imported in 1999. 90 % consisted of wood, paper, plastic and rubber.

[3] A TWG member thinks that this value is too high but has not provided any alternative value.

Table 1.13: Summary of European solid recovered fuels market in 2000 in Europe [21, Langenkamp and Nieman, 2001], [126, Pretz, et al., 2003], [150, TWG, 2004]

Industry’s best estimate of solid recovered fuel production in 2005 is about 11 Mt/yr. (Table 1.14)

Country	Production		Consumption		- Export/Import +		Δ 2000
	kt/yr	toe/yr	kt/yr	toe/yr	kt/yr	toe/yr	%
Belgium	100	50000	100	50000	n.a.	n.a.	0
Denmark	0		0				
Germany	3000	1500000	4000	2000000	+1000	+500000	
Greece	500	250000	500	250000	n.a.	n.a.	
Spain	1000	500000	1000	500000	n.a.	n.a.	
France	1000	500000	0	0	-1000	-500000	
Ireland	500	250000	500	250000	n.a.	n.a.	
Italy	1000	500000	1000	500000	n.a.	n.a.	
Luxembourg	50	25000	50	25000	n.a.	n.a.	
Netherlands	1000	400000	600	240000	-400	-160000	
Austria	500	250000	500	250000	n.a.	n.a.	400
Portugal	500	250000	500	250000	n.a.	n.a.	
Finland	350	120000	350	120000	n.a.	n.a.	100
Sweden	500	250000	1000	4500000	+500	+200000	
United Kingdom	600	300000	600	300000	n.a.	n.a.	
Switzerland	0	0	0	0			
Iceland	0		0				
Norway	150	75000	150	75000	n.a.	n.a.	
Total	**10750**	**5220000**					

Notes: toe/yr = tonnes oil equivalent per year (It is assumed that solid recovered fuel has a calorific value of 21 MJ/kg, although it is lower in Finland and the Netherlands, and oil has a calorific value of 42 MJ/kg)
Δ 2000 = Difference from year 2000
It is assumed that no solid recovered fuel (SRF) is exported outside the European Union.
The figures in this table are only indicative as they do not correspond to the same harmonised definition used t by the European Commission.
Note: Numbers within this table may not reflect the real number of installations or capacity. The main reasons are that the market is so dynamic that numbers change rapidly and/or because no data have been provided by the TWG at all on certain topics. Cells without numbers mean that no information has been provided.

Table 1.14: Forecast/potential for the European solid recovered fuels market in 2005 [126, Pretz, et al., 2003]

The consumption of hard coal and lignite for power production in the EU was 145 Mtoe/yr in 1999 (European Commission 1999 Annual Energy Review). Using this figure, it can be calculated that the total production of solid recovered fuel as forecast in Table 1.14 for 2005 (i.e. more than 5 Mtoe/yr) represents a substitution rate of 3.5 %.

Preparation of waste fuel from hazardous waste

The use of hazardous waste as fuel started in the mid seventies when the petroleum crisis drastically increased the cost of the fuel oil and also when, in different countries, new regulations were issued concerning waste disposal. As a large amount of energy rich waste (mainly solvents) was available, the co-processing of waste in cement kilns was an obvious answer to the situation on both environmental and economical terms. Later, in order to increase the energy saving, more and more sophisticated pretreatment processes have been developed, first to produce liquid waste fuel and more recently, i.e. in the nineties to produce solid waste fuel.

Estimated data were provided by some EU companies and are shown below in Table 1.15. These data are based on the market situation in EU-15.

Preparation of waste fuel from hazardous wastes	**Number of installations**	**2001 Production (kt/yr)**
Liquid waste fuel from organic liquid	107	650
Liquid waste fuel from fluidification	7	108
Liquid waste fuel from emulsions	3	48
Liquid waste fuel	117	806
Solid waste fuel	26	465
Total	**143**	**1271**
Note: The data correspond to estimations established in December 2002 Liquid waste fuel (excluding oils). Data have been established for regrouping and pretreatment plants from France, Belgium, the Netherlands, Germany, Italy, Switzerland, Spain, Portugal, Ireland, United Kingdom, Sweden, Norway, Czech Republic and Slovakia. The size and capacity of a liquid waste fuel pretreatment plant varies widely, from 5000 to 100000 tonnes/year. For regrouping facilities, the typical size of a plant ranges from 1000 to 20000 tonnes/year. Solid waste fuel. Data have been established for pretreatment plant production in 2001 from France, Belgium, the Netherlands, Germany, Italy, Switzerland, Spain, Portugal, Poland, Norway and Slovakia. The average size capacity of a solid waste fuel pretreatment plant is 18000 tonnes/year, with capacities ranging from 2000 to 70000 tonnes/year.		

Table 1.15: Production and site numbers of preparation of waste fuel mainly from hazardous waste in EU-15
[122, Eucopro, 2003], [150, TWG, 2004]

1.3 Economic and institutional aspects of the waste treatment sector

Waste treatment is typically a high volume low return process. A fixed or lowered base price, either for the incoming waste or for the recycled product, has placed the commercial emphasis on maximising throughput and reducing cost overheads.

Cost and price of waste treatment is typically established on the basis of investments and running costs. However, in some cases, prices may be determined by operators at the 'low' end of the market. In some other cases, the prices are fixed by agreement between the waste producer and the waste manager, where these may be different for a particular waste depending on who has produced it. Although there are exceptions, and also particularly for older plants, investment levels have been low, due to the low returns and competition with the low prices of landfills. It is expected that high levels of investment will be required to meet the standards set by the actual regulatory regime.

The industry has generally maximised the constructive use of some waste types to treat other wastes, this is expected to continue, particularly using waste as a raw material.

Competition exists between regional, national and international companies. One example is in the collection of waste oil, where national collectors work on large volumes as an economy of scale while local/regional operators, compete with the advantage of having lower overhead costs.

Hazardous waste management facilities typically, under the duty to tender delivery, accept all types of hazardous waste for correct disposal without regard to competition. However, some dedicated facilities which may be in competition for certain types of waste, would only need to bid for any hazardous waste that they can handle. In this respect, different configurations have been developed for the designated hazardous waste management facilities and competing facilities.

Some WT plants, due to their regionalisation and/or the need for proximity, contribute to a substantial decrease in waste transportation. However, other WT plants are working on a supraregional, national or even international basis mainly depending on the specialisation of certain treatment operations.

Impact of new waste legislation on the waste treatment sector

Waste production is avoided in accordance with Council Directive 75/442/EEC of 15 July 1975 on waste; where waste is produced, it is recovered or, where it is technically and economically impossible, it is disposed of while avoiding or reducing any impact on the environment. It is worth mentioning that the IPPC Directive would have a direct impact on the waste treatment industry as well as on producers of waste.

Regulatory conditions are being put in place, some of them at EU level (e.g. incineration, landfilling, electrical and electronic waste, end-of-life vehicles), to break the cycle of high volume, low return and low investment. This is expected to lead to greater investment in the sector and a move towards developing techniques to treat those wastes which were previously directly landfilled, or to improving processes which before were not treating the wastes effectively. This will require the development of dedicated plants and, probably, equipment for the treatment of specific wastes.

Whilst restrictions on landfilling, which will be introduced by the Landfill Directive, will require more treatment of waste either prior to or instead of landfill, this may lead to the continuing development of sites utilising stabilisation and fixation techniques. However, these techniques are still quite basic and subject to a number of serious problems.

Waste oil treatment is also likely to increase and change, especially as the implementation of the Landfill Directive bans the landfilling of oil/water streams from 2002 to 2007.

Regulatory compliance could be thought of as a separate function reacting to external forces, yet in reality this is essentially the driving force for the entire facility. The market for waste facilities is heavily influenced by dynamic regulatory programmes that continue to undergo significant change. The operation of a facility is thus geared around managing waste in a manner that meets, if not exceeds, environmental regulations. This is no easy matter due to the large amount of regulation the industry is subject to.

Waste oils

Environmental consciousness in the 1980s has had a number of consequences on the waste oils treatment sector, in particular:

- the shutting down of many acid/clay re-refining plants, mainly in the US, for both economic and environmental reasons
- the use of improved equipment and devices to reduce the potential pollution from burning used oil
- the development of improved re-refining technologies for both environmental and product quality reasons.

Physico-chemical (Ph-c) treatment plants

There are continuous changes in the production process modifying the type of waste as well as the auxiliary substances used. In this respect, even the Ph-c plants are subject to constant adaptation processes, both in terms of the procedures used and the controls. Furthermore, changes in the regulatory frameworks also lead to plant reconfigurations; in general, these changed regulations aim at a significant reduction in Ph-c plant emissions. The reconfiguration can affect all the functional areas of a Ph-c plant, including plant technology, process materials, laboratory equipment, and even the general and specialist knowledge of the staff.

Preparation of municipal solid waste (MSW) to be used as fuel

The history of use MSW as fuel goes back to the oil crisis of 30 years ago. Then RDF (refuse derived fuel) was promoted as a substitute low cost fuel, although the fuel was never fully accepted by the market. However, in the past 10 years there has been a growing interest within the cement, lime, steel and energy industries in fuels derived from waste, mainly due to economic reasons. Existing European energy policy targets and waste management policy give an impetus to the usage of waste derived fuels based on non-hazardous wastes. These fuels, with an average content of 50 - 60 % on biogenics, may contribute considerably to the reduction of CO_2 emissions and the doubling of the share of renewable energy. Moreover, due to market liberalisation and the need for cost reductions, industry is increasingly becoming more interested in less expensive homogenous substitute fuels of a specified quality. At present the main end-users are the cement and lime industries. However, the market potential for the future is the power generating sector.

Waste management policy aiming at a reduction in landfill disposal of biodegradable waste directly influenced the development of facilities for the production of waste fuels. Also the (high) tax system applied to landfilling is a major driving force in some Member States. Contrary to enforced changes 30 years ago due to the oil crisis, the producers of the waste fuels took the initiative for a quality system that should guarantee the properties of the solid waste fuel produced out of MSW and therefore make it a more reliable product. Quality systems exist in several Member States now. CEN was given a mandate by the Commission to develop standards for so-called ‘solid recoverd fuel’ (SRF) based on non hazardous wastes these are currently underway.

The main outlets of SRF are currently in the cement and lime industries. The use in coal fired power stations is an emerging sector. Steel mills use SRF as a carbon substitute. In Nordic countries, SRF is mainly used for the production of heat in industries and district heating.

The breakdown of the fuel consumption used to produce cement is given in Table 1.16.

Fuel	%
Petroleum coke	39
Hard coal	36
Fuel oil	7
Lignite	6
Gas	2
Waste	10

Table 1.16: Fuel consumption by the European cement industry
[126, Pretz, et al., 2003]

The specific energy consumption for cement is 3 – 4 MJ/kg clinker. Assuming 0.75 kg clinker/kg cement, a substitution rate of fuel of 30 – 50 % and a LHV of SRF of 19 MJ/kg, this means there is a potential use of 6 – 11 Mt SRF/yr. Assuming an energy consumption of 4 MJ/kg lime, at the same substitution rate as for cement kilns, this means a potential of 1 – 2 Mt SRF/yr could be used for an annual production of 20 Mt of lime.

The estimated use of SRF in hard coal and lignite for power production in the EU is 14 – 29 Mt SRF/yr (supposing a substitutation rate at a minimum of 5 – 10 % on heat bases). The total potential market for SRF may be 21 – 42 Mt/yr, which is a substantial amount of the SRF that could be produced from MSW and other combustible wastes. There are large differences between countries. Germany still has a lot of lignite and coal fired power plants. France, has a policy geared towards using nuclear power plants, and therefore only has few coal fired power plants. In the 'CEN report on Solid Recovered Fuels' [21, Langenkamp and Nieman, 2001] a potential of SRF use is indicated as between 33 and 50 Mt/yr. The conclusion is that the SRF production is increasing and can become an essential link in the waste management system.

1.4 General environmental issues related to installations that treat waste

Waste composition is very variable and the potential range of components that might be present is enormous. Due to such variance in components and composition, there are very few common emissions from waste management operations since each site has a slightly different combination of unit operations, and accepts a different range of wastes based on local circumstances.

The intention of this section is to give a short overview of the main environmental issues in the sector. A more precise picture of the environmental issues of the sector is developed in Chapter 3.

Air emissions
Most waste installations have emissions to air of carbon dioxide, ammonia and particulate matter. Certain organic substances can be commonly identified at almost every site and it is worth noting that most sites create some kind of particulate emission simply through handling products. Issues such as odour and volatile organic compounds are also relevant. Other contaminants that might be found at some sites are hydrogen chloride, ammonia, amines, hydrogen sulphide. Other components that may occur are PAHs and dioxins mainly because they are imported with the waste to be treated. These are a problem from both a health and an environmental point of view. They are formed during the incomplete combustion of organic matter (e.g. incineration, co-incineration, combustion of some fuels) and via reformatting during cooling down of the off-gas. PAHs are relatively difficult to break down. Table 1.17 shows the main air emissions from waste treatment operations.

Main air emissions	Waste treatment operation
Acids (HCl)	Incineration Physico-chemical treatments
Ammonia	Biological treatments Physico-chemical treatments
Carbon oxides	Energy systems Thermal treatments Biological treatments
Microbiological pollution	Biological treatments Biofilters
Nitrogen oxides (N_2O, NO, NO_2)	Energy systems Thermal treatments Biological treatments
Sulphur oxides	Energy systems Thermal treatments
Particulates (including metals)	Energy systems Storage and handling of solids Thermal treatments
Volatile organic compounds (VOC)	Biological treatments Waste oil treatments Waste solvent treatments Hydrocarbons/water separation systems Storage and handling of organic substances
Note: Refer to Chapter 3 for specific emissions to different waste treatment operations.	

Table 1.17: Main air pollutants emitted by waste treatments and their main sources

Water emissions

Most waste installations declare an emission of total nitrogen, total organic carbon, total phosphorus and chloride to water. Table 1.18 gives a summary of the main water emissions from waste treatment operations.

Main water emissions	Waste treatment operations
Chlorinated compounds (e.g. AOX)	Waste solvents treatments
Metals (e.g. As, Cd, Cu, Hg, Ni, Sn, Zn)	Biological treatments Common storage and handling of waste Physico-chemical treatments of metal extraction, finishing waste, fine chemicals and organic manufacture. Waste oil treatments
Organic chemicals (e.g. BOD, COD, TOC, hydrocarbons, phenols, BTEX)	Waste oil treatments Waste solvent treatments Energy systems
Total nitrogen	Physico-chemical treatments Biological treatments
Total phosphorus	Physico-chemical treatments Biological treatments
Note: Refer to Chapter 3 for specific emissions to different waste treatment operations.	

Table 1.18: Main water pollutants (parameters) emitted by waste treatments and their main sources

Waste outputs

Generally, the output from WT installations is a treated waste. However, those outputs can be differentiated in two types. One type refers to the treated waste (typically representing the main part of the output) that in some cases can be re-used elsewhere. The other type is represented by the waste generated by the treatment process itself. The appearance of the latter one does not only just depend on the type of waste treated, but also on the type of treatment given to the waste. Indeed, this second type of waste is more dependent on the treatment than on the actual type of waste treated.

Soil and groundwater contamination

In the past, unprecautionary handling of wastes has been at the origin of land contamination, as has been the case in almost all industrial sectors. As is the case in many other industries, the waste treatment industry is not currently an activity which leads to land contamination. According to the process and the type of wastes used, prevention actions have been developed such as retention, impermeabilisation, and undergroundwater monitoring, in order to prevent and control soil and groundwater contamination.

2 APPLIED PROCESSES AND TECHNIQUES

This section describes those treatments and processes within the waste treatments sector which are included within the Scope of this document. This chapter is for those interested in gaining a general understanding of the processes and activities found in the industrial sector, and for those interested in the interrelationships between the industrial processes and the topics described in later chapters of this document, i.e. consumptions, emissions and best available techniques.

Therefore, the aim of this chapter is not to replicate published engineering information already available in general literature. This means that some techniques widely used in the WT sector will not be described in this chapter because they are simple unit operations widely explained elsewhere. For those techniques, summary tables will be presented which will highlight as far as possible the purpose, the principle and the users.

Structure of this chapter

The processes and activities found in the WT sector are divided into six sections in this document. Such structure/classification should not be interpreted as any attempt to interpret IPPC Directive or any EC waste legislation. These are:

- common techniques. This covers those stages found in the waste sector that are generally applied and that are not specific to any individual type of waste treatment (e.g. reception, blending, sorting, storage, energy system, management). The unit operations associated with these treatments are also covered. Figure 2.2 shows a flow diagram for a typical waste treatment installation. The brown boxes correspond to the parts that will be covered in this first section
- biological treatments and some mechanical-biological treatments (e.g. aerobic/anaerobic digestions). The unit operations associated to these treatments are also covered
- physico-chemical treatments. This covers treatments such as precipitation, decanting and centrifuging, solvent recovery and any thermal treatments not included in the WI BREF. The unit operations associated to these treatments are also covered
- treatments applied to waste in order to enable the recycling/regeneration of materials (e.g. catalysts, solvents, waste oils, etc.). The unit operations associated to those treatments are also covered
- treatments applied to turn a waste into a material that can be used as a fuel in different industrial sectors. The unit operations associated to these treatments are also covered
- end-of-pipe techniques used in waste treatment installations for the abatement of emissions.

Figure 2.1 and Figure 2.2 illustrate the classification mentioned above. This classification is also repeated in each of the following chapters to maintain coherence and to make it easier for the reader to cross-reference information.

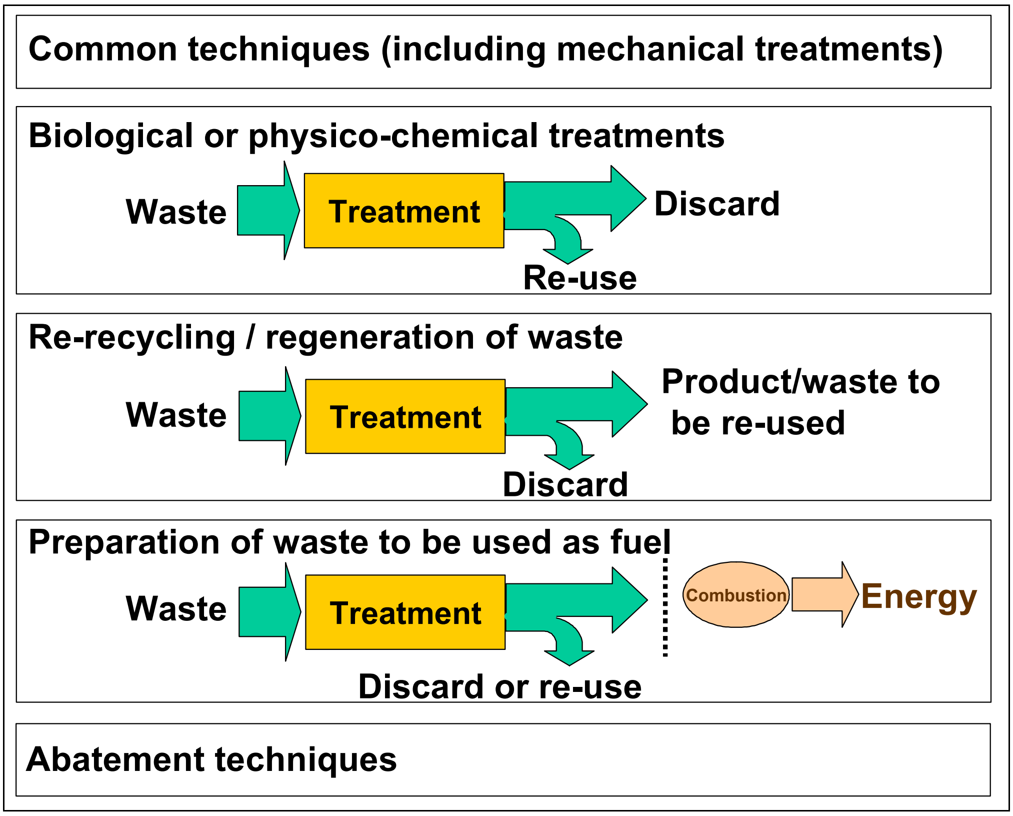


Figure 2.1: Structure of the chapters
Note: This figure only tries to give a snapshot of how information is structured in this document. Exceptions to any of these categories might be present and sometimes it is difficult to classify a treatment under certain block.
Within the block 'preparation of waste to be used as fuel', the combustion process is not included under the scope of this document. For further information, please refer to Scope section.
Such structure should not be interpreted as any attempt to give guidance if a waste treatment is Recovery or Disposal under the EC waste legislation.
[150, TWG, 2004]

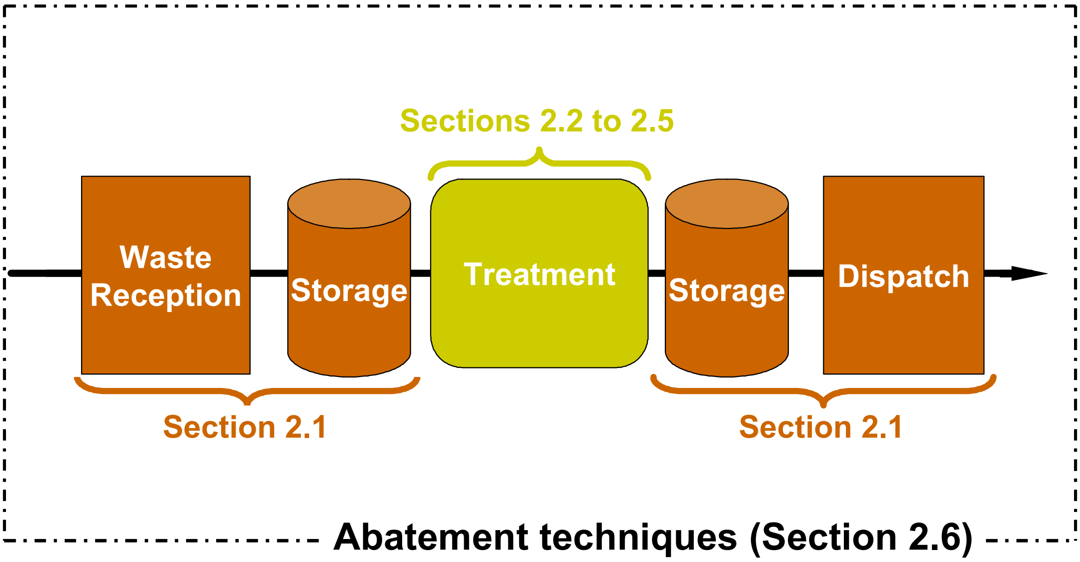


Figure 2.2: Typical operations in waste treatments and how these have been distributed in this and subsequent chapters

Many techniques listed in this chapter are briefly described, with information provided in the structure shown in Table 2.1. This same structure is used for each technique, to help the reader to easily assess the information within this document.

Name of the type of information	Type of information included
Purpose	A brief explanation of what this type of WT is used for
Principle of operation	The type of process carried out and a brief explanation of it
Feed and output streams	The type of waste that can be treated by the treatment, as well as details of any products of the operation
Process description	A brief description of the process. Where appropriate, figures and diagrams will be used
Users	Reference to the number of plants using the technique in Europe and worldwide. Also, details of which WT sector uses this type of technique

Table 2.1: Information contained in the description of each technique included in Chapter 2 [150, TWG, 2004]

Waste treatment installations

While the waste is in storage, a treatment schedule is developed that identifies the waste to be treated, its storage location, any necessary preparations, the treatment method, and the rate at which the waste is to be fed. At the start of the waste treatment, the waste is typically fed by bulk materials handling systems, such as pipelines or conveyors, to the equipment used to perform the prescribed treatment steps. Treatment operations may be carried out on a batch or continuous basis.

Different types of approaches are common for waste treatment installations. They can broadly be classified into three groups:

- waste installations included in the same place where the waste is produced. These typically serve a rather small number of wastes types and can provide only a restricted number of treatments
- specific dedicated waste installations, which may provide one or several operations but which typically treat only a small number of waste types or which produce a relatively small amount of output
- integrated waste treatment installations. Some waste treatment installations are not standalone installations only containing a single type of treatment. Some of them are designed to provide a wide variety of services, and they are designed to treat a great variety of waste types. As mentioned in Section 1.1, waste treatment installations are designed to produce required waste treatment services. For example, sometimes they are designed to provide a certain type of treatment to deal with a large amount and variety of different waste types (e.g. aqueous wastes, municipal solid wastes). Figure 2.3 is one example of such a complex installation.

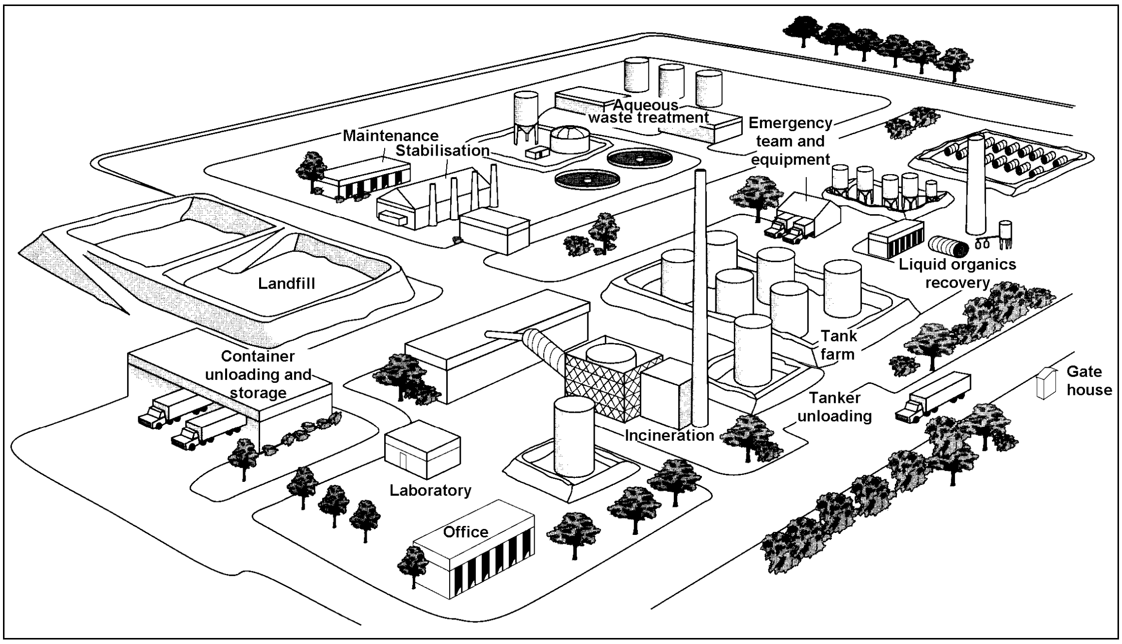


Figure 2.3: Example of an integrated waste treatment installation
[53, LaGrega, et al., 1994]

Table 2.2 matches the operations carried out at WT installations with the components of the fully integrated facility. It is important to note that all components operate under an umbrella of a number of special measures. These special precautionary measures include security, inspections, maintenance, training, incident prevention, emergency planning, safety, monitoring, and auditing.

	Operations subsystems				
Facility components	**Pre-shipment waste analysis**	**Waste receiving**	**Waste storage and preparation**	**Waste treatment**	**Solid outputs management**
Analytical laboratory	X	X			
Truck waiting area		X			
Gatehouse		X			
Weighbridge		X			
Drum unloading and storage		X	X		
Tank farm		X	X		
Bulk waste and waste preparation		X	X		
Biological treatment				X	X
Physico/chemical treatment				X	X
Stabilisation plant				X	X
Regeneration				X	
Preparation of waste to be used as fuel				X	X
Incinerator*				X	X
Landfill cells*					X
* Not covered in this document					

Table 2.2: Examples of operations subsystems and their components
[53, LaGrega, et al., 1994], [150, TWG, 2004], [152, TWG, 2004]

<u>What processes are applied to each type of waste?</u>
In order to select which type of treatment may be given to a certain waste, decision trees have been developed.

2.1 Common techniques applied in the sector

[40, Militon and Becaud, 1998], [50, Scori, 2002], [51, Inertec, et al., 2002], [53, LaGrega, et al., 1994], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [100, UNEP, 2000], [116, Irish EPA, 2003], [119, Watco, 2002], [121, Schmidt and Institute for environmental and waste management, 2002], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004], [156, VROM, 2004] [157, UBA, 2004].

This section discusses the pretreatments/activities or post-treatments/activities (see the introduction to Chapter 2 and Figure 2.2) commonly used in the WT sector and included under the scope of this document. It also includes some treatment activities that are commonly used in the whole sector. For example, it includes techniques used for repackaging, crushing, sieving, drying, blending, sorting, homogenisation, scrapping, fluidification, washing, baling, regrouping and storage, transportation, reception and traceability control, as well as management techniques used in waste treatment installations. Only those techniques important from an environmental point of view are described in detail. Other techniques considered to be generic techniques or very specialised techniques have not been described but have been listed in the two last sections of this Section 2.1. Those techniques applied for the abatement of emissions (e.g. air filters, biofilters, waste water treatments) are briefly mentioned in Section 2.6 and are widely analysed in the last three sections of Chapter 4.

2.1.1 Reception, acceptance, traceability and quality assurance

For most WT plants, the following order is relevant: a) acceptance b) storage c) treatment d) storage of residues and emissions. Each of the previous steps requires knowledge and control of the waste as well as specific acceptance and processing management. Knowledge of wastes, before they are accepted and treated, is a key factor for the management of a WT plant. The aim of this section is to present the different types of controls and analyses which can be carried out during the waste treatment process, from the pre-acceptance and arrival of the waste at the site, to the final dispatch of the waste.

Pre-acceptance and acceptance procedures

Many WT sites (e.g. hazardous waste treatment facilities) require information and/or samples to be provided prior to the transport of waste to the site, to enable them to ensure that the waste is within the requirements of the site licence and will not adversely affect their treatment process. Pre-acceptance includes taking a sample, filling out an identification form, carrying out the analysis and then assessing whether the waste can be accepted into the installation. If it can be pre-accepted, the waste is transported into the installation, where a second analysis is carried out to once again help make the decision of whether to accept or reject the waste. Then the acceptance procedure contains two stages: First, the pre-acceptance phase; and second the acceptance phase.

Pre-acceptance

Pre-acceptance procedures of wastes follow three main steps:

a. information is provided from the waste producer. For example, a specific formula about the waste identification (main characteristics, health and safety considerations, how they are produced, etc.)
b. preliminary and complete analyses are carried out in order to characterise the waste
c. on the basis of all the information, the operator makes the final decision on whether to accept the wastes into the installation or not (bearing in mind the specifications included in its permit and other process requirements). There are always rules to accept wastes as complying with the description. Some of these rules are developed at national level and others are developed at installation level. For example, this can be certain percentages of differentiation or parameters restricted by the permit. In certain cases, a risk assessment may be carried out. The waste processor can evaluate the risk of contravention of certain rules in this way (e.g. national rules). An example of classification of the risk in the pre-acceptance phase may be:
    - waste is classified as 'high' risk if the waste or the client are new
    - waste is classified as 'low' risk if:
        - it is a known waste from a known client and
        - the waste is predictable in properties and composition and
        - there are low risks of contamination or dilution of the waste with other wastes or material.

In certain cases, part of this procedure (e.g the analysis) may have to be adapted, e.g if dangerous conditions for sampling occur at the time or when there is a very small quantity of waste.

The purpose of the full characterisation before shipment is to satisfy the following requirements, to:

- determine if the waste is acceptable for receipt at the facility in terms of:
    - the facility's permit
    - the capability of the facility to treat or dispose of the waste
- identify the inherent hazards of the waste so that appropriate precautions can be taken during its handling and storage at the facility to prevent incidents
- determine the physical characteristics and chemical constituents of the waste to allow selection of effective waste processing and disposal methods
- select the verification parameters to be tested upon arrival at the facility. These parameters can ensure that each shipment of waste is the same type as the fully characterised waste
- select any treatability parameters to be tested that could vary, so as to influence how waste processing would be programmed
- develop an estimate of the cost of treatment or disposal of the waste.

Acceptance

Upon receipt, a unique code is assigned to the waste containers, or batch, to ensure that the waste is traceable at all times. Individual containers or specific storage locations are marked accordingly. Some waste oil recovery companies tend to check the incoming feedstock by interviewing the truck driver and subjecting top and bottom samples from the truck to visual and olfactory inspection. A classification of the risk in the acceptance phase may be:

- wastes with high risk classification are typically always analysed at delivery
- wastes with a low risk classification are occasionally tested on conformity with the data from the pre-acceptance phase. The process of acceptance is typically guided by receivers with a role independent from process operators or waste acquirers. The whole procedure classifying the risks of non conformity with data from the pre-acceptance phase and the description of roles and responsibilities of the various persons involved in waste acceptance is typically part of the waste analysis plan.

Upon accepting the waste, the facility signs a declaration and sends a copy to the waste producer (originator). At that point, the facility may share liability, in some cases, with the producer and the transporter. In other cases, the waste producer maintains the responsibility of the waste treatment until the last treatment is performed. Thus, it is critical that the pre-shipment waste analysis has already been completed and the shipment scheduled. Without prior scheduling of the incoming shipment or if the shipment is improperly documented, the gatehouse will refuse entry to the truck.

Sampling and analysis

A proportion of the waste is screened at the site. The level of screening is a function of the amount of processing to be carried out, and the size of the container. For example, materials to be treated in an adjacent plant will be tested to check compatibility, as will drums of material for bulking and onward transfer. Screening systems vary from site to site according to the type of waste and its subsequent treatment. For example, screening may involve an initial check of the pH level, odour and flashpoint as the materials are unloaded, followed by a more detailed screening against the stated contents on the packing lists for materials that will be decanted at the site.

The way sampling and any analysis is carried out may vary depending on the purpose of the checks, for example pre-acceptance, acceptance, reception, process analysis, traceability, dispatch analysis, reception at the final user site or external analysis. CEN TC 292 work provides information on sampling and sample preparation. Some more information is also available in Section 3.7.

Laboratory

Upon collection of the sample, the laboratory typically analyses a portion for the verification parameters and retain the remainder for subsequent testing of treatability parameters. Upon verification of the waste shipment, the truck is directed to an unloading area where it is emptied and then reweighed before it leaves the facility. The essential tasks of the laboratory are:

- acceptance and identification
- establishing the treatment programme
- process control
- final inspection.

A waste analysis plan is a critical part of a facility. The plan specifies the parameters for which each waste will be analysed, the sampling and analytical methods to be used, and the frequency of analysis. Before a facility treats, stores, or disposes of a waste, it must profile the waste, including a detailed chemical and physical analysis of a representative sample of the waste. Commercial facilities require this full characterisation prior to shipment by the waste producer. Representative sampling of a waste shipment is conducted upon arrival at the facility to verify that the composition of the shipped waste matches the information given on the fully characterised waste sheets.

Plant laboratories assume central importance, for example in physico-chemical treatments of waste waters. Both process simulations to establish treatment programmes and analytical work is undertaken to determine the sequence of processes in the sense of process controls as well as emissions (waste water, exhaust air); the treatment programme contains exact instructions regarding how the waste is to be treated, which chemicals are to be used – according to type and quantity/dosage – and which controls and documents are drawn up. One example of these interrelationships is diagrammatically represented in Figure 2.4.

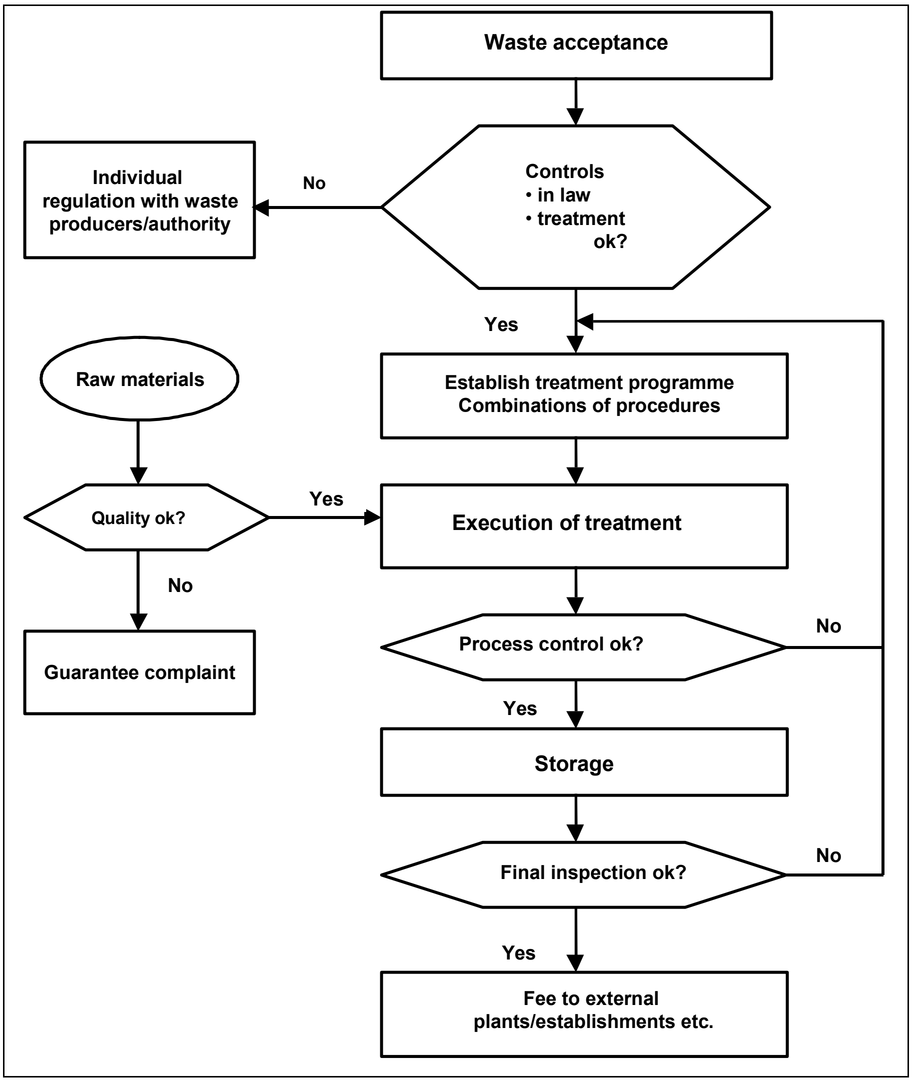


Figure 2.4: Simplified flow chart of an example of checking/inspection in a physico-chemical treatment plant of waste waters
[121, Schmidt and Institute for environmental and waste management, 2002]

Reception
Typically, wastes are physically inspected when they arrive at the site, to check the integrity of the containers and to visually verify the waste type. Most sites have a regular daily inspection of containers' integrity at the site.

Waste shipments typically arrive by truck at a facility's gatehouse. Scheduled and properly documented shipments are directed to the receiving station where any packaging is checked, the loaded truck is weighed, and representative samples are collected to test the verification parameters. The waste may arrive as bulk liquids in a tank truck, containerised liquids or sludges in drums, bulk shipments of contaminated soil in dump trucks, or by a number of other methods. Collecting a representative sample can pose a difficult task considering that a waste may be in multiple phases and states or have pockets of high contamination. The receiving station must use previously established procedures for each situation to ensure the collection of a representative sample.

The mere 'emptying' of a truck can pose a difficult challenge if the waste has stratified, a container has leaked, or if a solidification reaction has occurred. For such abnormal situations, facilities typically plan procedures and are prepared with special equipment to resolve such problems. Finally, the truck may need to be cleaned to remove any trace residues.

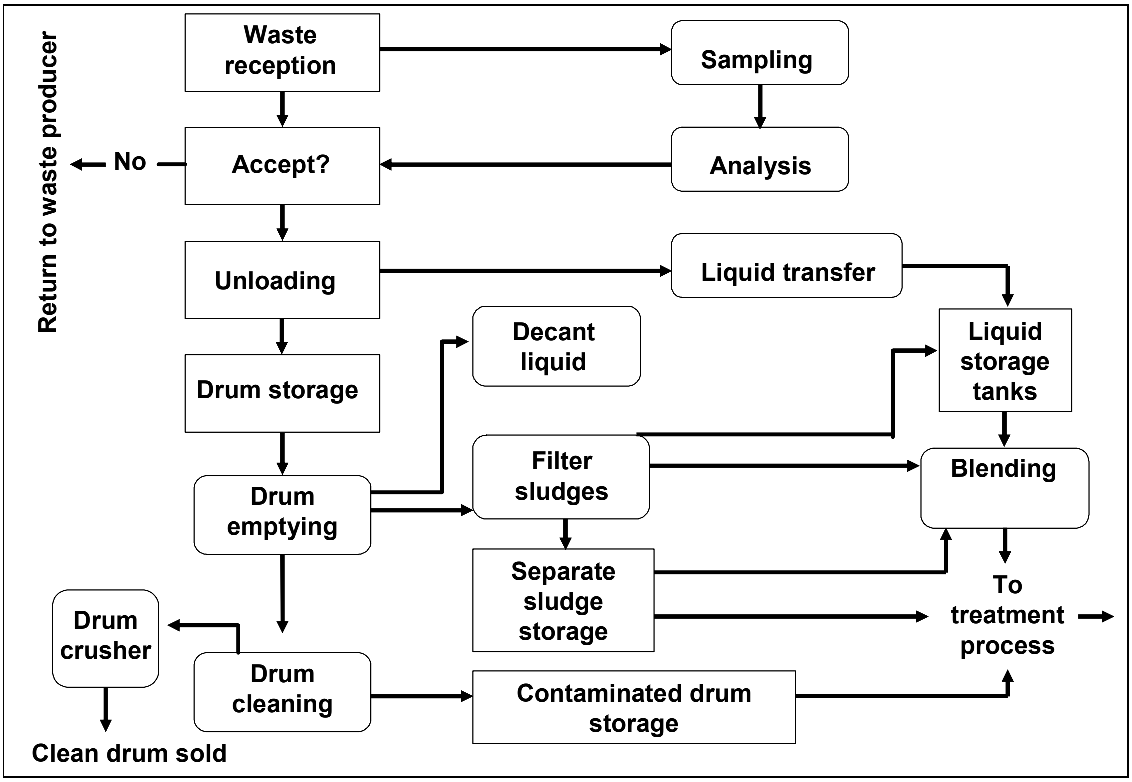


Figure 2.5: Example of waste reception and acceptance at a facility handling bulk liquids and drums
[80, Petts and Eduljee, 1994]

Quality assurance systems
One part of the waste management in the installation is the logistical organisation, for example, of solid waste fuel processing. By choosing and using specific waste materials, solid waste fuel producers set a kind of quality assurance themselves. Quality assurance systems already exist and further regulations are in the development phase.

In the past, solid waste fuel was mainly produced from process related wastes as mono-batches which were easier to handle because of their constant qualities. Nowadays, high calorific fractions of municipal solid wastes and of other mixed wastes are in the picture as a source for the production of solid waste fuel. The aim of a quality assurance system is to attain and ensure constant qualities to increase acceptance by end users and permitting authorities. The requirements mainly concern product quality.

2.1.2 Management techniques

This section covers operational management and emission management in the installation. Some special precautionary measures need to be applied regarding:

- security
- inspection and maintenance
- incident prevention
- emergency planning
- employee training
- safety
- monitoring
- audits.

Accidents

Accident risk is inherent when dealing with waste and in particular hazardous waste. Wastes are heterogeneous in nature and are often intrinsically aggressive to plant and equipment. Any failure in the management of the waste, from the process of characterisation and checking of wastes to the operational control reactions and the mixing of wastes, will significantly increase the risk from unwanted or runaway reactions.

2.1.3 Energy systems

Energy management issues are discussed in this section. Installations for the generation of steam and/or power are not covered here because they are covered by other BREF documents (e.g. large combustion plants, waste incineration).

Heat and power are needed to run an installation. Some common site equipment using fossil fuels include fork-lift trucks, small boilers, shredders and grinders. These take a mixture of standard vehicle diesel fuels, and a range of fuel oils. Some of this equipment can be electrically or even pneumatically powered. Some sites have on site boilers for steam production.

The main uses of energy on a waste treatment facility are:

- heating, lighting and power in facility buildings
- power for treatment processes and facility equipment, such as pumps, air compressors, centrifugues, etc.
- fuel to power vehicles.

Good design and management of energy systems are important aspects of minimising the environmental impact of a waste treatment facility.

2.1.4 Storage and handling

The objectives of storage are to:

- store the waste safely before its introduction as feed into the treatment
- provide adequate accumulation time. For example, during periods when treatment and disposal process systems are out of service, or when there is to be a time separation between treatment and dispatch of waste or for the purpose of controls and inspections or to accumulate enough waste to use the full capacity of the treatment, etc.
- uncouple the treatment and dispatch of waste
- allow effective use of classifying procedures to be made during storage/accumulation periods
- facilitate continuous treatment processes. Continuous treatment processes are not capable of reacting to sudden and significant changes in composition and reactions of waste while guaranteeing a specific treatment result. For this reason, homogenisation of the various properties and level of treatability of the waste must be achieved and ensured by intermediate storage/accumulation of the waste to be treated. Storage/reservoirs must therefore be set up before the actual treatment in Ph-c plants under continuous operation
- facilitate mixing, blending, and repackaging of the waste as deemed necessary
- allow the staged input of various wastes with reagents to the subsequent unit treatment processes
- collect a reasonable amount of waste prior to sending for certain treatments (e.g. transfer stations).

From small packages to large scale storage (regrouping)
Wastes can be sorted into different categories depending on the bulk shipment of compatible materials to specific disposal or treatment sites. For example, small containers may be packed into 205 litre drums with vermiculite as a packer filler for easier handling and transfer. Larger containers may simply be sorted into different waste categories and stored on pallets prior to onward shipment.

Certain wastes are decanted and bulked into larger containers, for example:

- laboratory containers or small commercial containers into 205 litre drums or IBCs
- drummed waste may be transferred into IBCs
- the liquid fraction of drummed waste is decanted into IBCs
- the aqueous fraction of two-phase wastes is decanted
- part of tanker loads can be stored to await further material to make up a full load.

Decanting the waste reduces the tonnage of packaging materials associated with the onward transfer; and produces a consistent set of larger units that can be stored more easily at the site and that are packaged and labelled ready for onward transit. This will be important for the onward receiving site, that may need a controlled and checked stream of material for their process.

One role of waste solvent facilities is to regroup and recondition of small volumes (drums, etc.) to prepare then as fuels or to regenerate a solvent that can be re-used. The goal of a solvent regroupment/liquid fuel preparation facility is to prepare a tailor-made, stable and homogeneous waste, which fits the requirements of its final uses (recycling, incineration or co-incineration).

Transfer of materials
The next stage destination for waste may be for reclamation, treatment or disposal, and may be processed at an adjacent site within the same complex, or it may need to be transferred to other vehicles for onward transfer.

The choice of transportation for the material depends on the physical form of the material to be transported. In other words, the transport of gases, liquids and solids all involve different techniques. Solids are transported by: conveyor belts, fork lift trucks, trucks, pneumatic conveyors, load shovels, cranes, walking floor, etc. Liquids and semi-liquids are transported by: pumps, pipes, conveyor belts, screws, elevators, etc., and gases by: compressors and pipes.

Due to consistent efforts to avoid waste arising and the separate collection of any waste arising, the handling of small quantities up to approx. 1 m^3, is particularly significant. Systems have been developed in some countries to separate the collection and transport of waste (e.g. the AS container system in Germany).

Package acceptance
Physico-chemical treatment plants accept waste, by tanker, truck, pipeline or ship, and generally store the waste prior to treatment, either in small containers or tanks.

Washing and cleaning of vehicles and receptacles/containers
After delivery and emptying, the vehicles/constructions and receptacles/containers could be cleaned on site (e.g. under agreement with the transport company) or off site except where the receptacles/containers are disposed of, the adherent residue is not harmful, or the constructions, receptacles or containers are used again to transport similar waste.

Because of the many different kinds of drums/containers/constructions, the cleaning – apart from the exceptions – is performed manually using spraying devices, high pressure rinsing devices, or brushing and brooming techniques. Cleaning can be performed inside or outside, in order to guarantee the re-use of the drums/containers/constructions. Cleaning inside is important to prevent substances being carried over. This may be crucial, for example, when the limit of chlorine-organic adsorbable materials in the waste water of a Ph-c plant (AOX value) is 1 mg/l, and this concentration can be affected by left over concentration in the refilling (e.g. by residues with corresponding AOX ingredients). Typically, a separate treatment of cleaning waters is carried out in order to assure that the sewer is not contaminated by such waters.

A facility for cleaning the containers can be an automatic installation which cleans their exterior and interior. The cleaning process is computer controlled by means of contact free sensors. The maximum capacity of the facility is 10 containers per hour. The working movements of the handling devices are carried out hydraulically. The cleaning devices are supplied with water by two high pressure pumps with a capacity of 132 kW each. The wash-water is run in a closed loop over the existing water treatment system.

Reclamation of containments

The majority of incoming containers (glass, metal or plastic) are shredded or crushed prior to recycling or disposal. Some drums and IBCs are sorted for re-use within the transfer operations and others are washed (or vented) prior to re-use or sale.

Drum emptying may be a simple bulking operation, and a sensible screening operation to check the contents of drums prior to landfill, as happens in some countries. The latter mentioned practice is actually forbidden by the Landfill Directive.

Ways of storage and facilities

Tank farms can be an integral part of a transfer and bulking operation, or can operate as stand alone activities. Bulk storage is likely to becoming more common as more wastes require treatment under the Landfill Directive. As this occurs there is likely to be difficulties in matching the wastes arising to the finite capacity of treatment plants, and consequently more interim storage units will be needed. Attention is drawn to the Storage BREF, the Seveso II Directive and to national regulations.

Liquids may be stored in tanks and/or containers (e.g. glass containers, drums, big containers), storage cells, storage buildings and outside storage (e.g. waste waters). Solids can be stored in heaps, sacks and bulk bags, silos and bunkers, and packed. Solid waste can be stored in closed areas, as for example closed building (e.g. with an appropriate filtering system and exhaust gas treatment to lower odour and air emissions) and handled with a crane, travelling crane or conveyor belt or silos (e.g. cylindrical or parallelepiped silos with a screw or a walking floor to extract the solid waste).

Upon unloading, the wastes are moved into storage, which may consist of tanks or impoundments for bulk liquids, hoppers for solids and sledges, or pads and warehouses for containers.

Some sites can store blended or raw waste material pending transfer for use in another process.

Storage areas are often the most visible aspects of the installation. The key issues for operators to address in relation to waste storage on the installation includes the following:

- location of storage areas
- storage area infrastructure
- condition of tanks, drums, vessels and other containers
- stock control
- segregated storage
- containment used to protect the environment and workers health.

Containers used to store shredded drums or intermediate bulk containers (IBC) are also covered in this document.

An important safety consideration in storage and handling is fire prevention and protection.

Laboratory smalls essentially consist of substances in containers of less than five litres capacity. They generally contain pure chemical elements and compounds from laboratories or arise when laboratory stores are cleared. The majority of operators offer a packing and collection service for laboratory smalls.

Laboratory smalls are usually sorted and bulked into drums (e.g. 205 litre or other sizes depending on the further treatment) in either designated enclosed buildings with positive ventilation and flameproof lighting, or within open-sided roofed areas.

Tanks are also used to store wastes. This may be part of a medium scale bulking operation to ensure that part tanker loads are bulked to give a full load for onward transfer to the next process; or a large scale tank farm operation. The former tends to have limited controls, similar to the storage of fuels on the site. Tanks are typically in the open, on hard-standing and bunded. The type of storage applied will depend on the need for homogenisation in the storage unit.

Often storage in containers also involves classification processes, the containers used also being fitted with skimming apparatus to remove floating material and suction apparatus to remove sediment. If classification procedures are disabled, the waste may instead undergo continuous agitation to maintain a state of homogeneity.

The storage, treatment and after-treatment functions are not separated but rather take place in the same container. A batch treatment process is used.

Storage capacity
Storage capacities need to be designed to typically ensure a continuous service. Other issues to be considered are the re-treatment of the output if its quality does not meet the required specifications and the dispatch frequency.

Emptying of containers
Fluid wastes are accepted and sedimentation is carried out. The fluid wastes are delivered either in containers, tank vehicles or suction pressure vehicles. When they are delivered in containers, they are picked up from the conveying band by a handling device, transported to the pre-selected receiving basin and there semi-automatically emptied. The contained coarse solids are removed and collected in containers. The fluid phase follows the downward slope and flows into the sedimentation basin. The sedimentation basins (8 in total) are selected by a control system.

When they are delivered in tank or suction pressure vehicles, they drive into the emptying area and their tanks are connected to the sieve filter via a tube. The fluid wastes flow from the tanks through the tube to the sieve filter, where coarse impurities (e.g. gloves and cloths) are removed. Metal elements are removed via a magnet separator. Afterwards, they are transferred via a pipe system into a basin pre-selected by a control system.

Computer-controlled high rack storage area for hazardous wastes
The high rack storage area serves as a secure storage and control area of wastes which have been delivered in closed containers. Non-packaged wastes cannot be put in storage. The storage area has 1680 storage positions in 2 store vessels and is geared to 250 to-bin and from-bin transfers. For these transfers the high rack area disposes of chain conveyors and bucket elevators. For fire prevention the reception area has fixed fire extinguishers that are coupled with acoustic alarm signal systems. Additionally, portable fire extinguishers are installed. From the high rack storage area, the wastes are transferred to the individual facilities where they are disposed of, recovered or pretreated for disposal or recovery.

Handling of materials from a Ph-c plant

The handling of material requires its correct packaging and load safety. Small quantities are packed in packaging units that are easy to handle, e.g. bottles or boxes. Large quantities in containers of, e.g. 100 to 12000 litres content volume. Prior to treatment, the units/containers have to be emptied. For this purpose appropriate devices are necessary, e.g.:

- tools for opening
- holding and clamping devices
- lifting and rotating devices.

In order to limit the variety of technical devices and, in order to ensure handling, the packaging units/containers are safe and efficient. The units/containers are combined with the systems. The emptying process requires:

- experienced staff
- knowledge about material/wastes
- safety equipment/devices
- measures/facilities for emission control
- suitable and easily manageable intercepting tanks
- regulation of the destination of the emptied units/containers.

Likewise, the upper bodies of the transport vehicles have to be emptied; this is usually done by means of pumps or in a free flow along a gradient. Experience shows that residues always remain inside the units/containers or in the upper bodies of the vehicles. Without regard to the kind of their subsequent utilisation these enclosures have to be completely emptied and cleaned. As experience shows, emptying is often hampered by sedimentation of solid, adhesive and hardening components in the waste. This may make it necessary, e.g. when emptying the upper bodies of the tank and suction vehicles, to remove the hardened components with tools or manually. It is advantageous for the process flow if the solid material can be transported in a lower container (folding plates, slides etc.).

After emptying, the units/containers/upper bodies have to be cleaned independent of their further utilisation. Exceptions to this rule can be made if:

- the units/containers are disposed of as waste and the adhesive residues of the transported waste do not make a difference
- if the subsequent utilisation is identical to the previous one.

The residues resulting from emptying, as well as the washing residues, are treated in the same way as the waste unless this is not possible due to its consistency. For example, sludge from the disposal of petrol or oil separators can be processed and recovered partly by simple washing procedures while the water phase has to be subjected to physico-chemical treatment. Washing is usually done with water. The effect can be enhanced by pressure (up to 100 bar), temperature (up to 80 ºC and vapour) and/or adding of solvents and/or tensides.

2.1.5 Blending and mixing

Wastes, once produced, should in principle be kept separate from other wastes. The reasons for this are that the re-use/recovery of homogenous streams are generally easier than that for composite streams. Under certain conditions, however, different waste streams can be processed just as well, or sometimes even better if they are composite. In this section, it is explored the different rules that may be applied on whether or not mixing/blending may be allowed and under what conditions this should be carried out.

Purpose

Due to the heterogeneous nature of waste, blending and mixing are required in most waste treatment operations in order to guarantee a homogeneous and stable feedstock of the wastes that will be finally processed. The term ‘blending’ is used more for mixing liquids than for solids, unless mixing a solid into a liquid. The term ‘mixing’ is used more for solids and semi solid materials (e.g. pasty material).

Certain types of wastes will require prior mixing or blending before treatment. For example, the concentration of waste constituents can vary considerably because of differences in incoming waste strengths. This is particularly true at most commercial treatment facilities. Mixing can control such variations to a range that will not upset the performance of the subsequent unit treatment processes. However, this issue should not be confused with dilution and this is the reason why these treatments are many times prohibited (e.g. hazardous waste and landfill Directives) over a wide range of concentrations. Blending and mixing are processes carried out because it is a technical requirement from the WT facility to guarantee a homogeneous and stable feedstock and not techniques to facilitate acceptance of waste.

As is prescribed in the Hazardous Waste Directive 91/689/EEC, mixing and blending operations are not permitted unless this is explicitly established in the licence of a collector or processor. An exemption from the permit requirement may be applied by the competent authority if establishments or undertakings carry out waste recovery and if competent authorities have established general rules for each type of mixing and blending laying down the types and quantities of waste and the conditions under which the mixing and blending may be applied and if Art 4 of the Waste Framework Directive is taken into account by establishing these general rules for the concerning establishments and undertakings. In this exemption case, registration of the establishments and undertakings is mandatory in order to ensure that the establishments and undertaking comply with the stated general rules. The following basic principles apply for granting such a licence:

- the mixing of wastes must be prevented from leading to a risk to human health and adverse effects on the environment
- mixing must be prevented from leading to any of the wastes to be mixed being treated or processed to a lower quality level than is desirable
- the mixing of wastes must be prevented from leading to environmental damage by the diffuse dispersal of environmentally hazardous substances.

The following elaboration of the basic principles for the mixing of waste applies to both hazardous and non-hazardous waste. Hazardous wastes must be kept separate from one another. Mixing can only be permitted if it will not result in risks to humans and the environment, and if there will be no problems with safety due to the mixing for all types of operations (for example safety risks for workers, neighbours of the plant etc.). Article 2, paragraph 3 of the Hazardous Waste Directive states that such an operation can only take place if a licence has been granted. Conditions may be attached to a licence, making it possible for the hazardous wastes referred to in the licence to be mixed with other (hazardous) wastes, preparations and other products referred to in the licence. Where the primary function of mixing wastes is to achieve dilution of a specific species in order to comply with less stringent regulations, this is prohibited. Within the boundaries of the licence for mixing and blending, the waste treatment manager is responsible for writing and applying operational guidelines on mixing and blending. Firstly, the basic principles for granting a licence are elaborated. Secondly, principles and considerations are given for writing operational guidelines for mixing and blending given these boundaries of a permit.

Principle of operation

Mix two or several wastes in order to typically generate a single output.

Feed and output streams

Applicable to solid and liquid waste. Outputs can also be in solid or liquid phase.

Process description

The basic principles referred to above in the purpose section (risk prevention, substandard processing and prevention of diffuse dispersal), have, as their main objective, protection of human health and of the environment against harmful influences and promotion of the recovery of wastes within these boundary conditions. For the sake of a high level of protection and effective supervision, these general basic principles need to be translated, in licensing procedures, into operational criteria on the basis of which it can be clearly determined if the mixing/blending of wastes can be allowed. The following elaboration of the basic principles is prescriptive:

- the mixing of substances that react strongly with each other (heat, fire, gas formation) or explosive substances (explosion) must be prevented. Mixing must be prevented from giving rise to risks to human health and the environment, both during the mixing operation itself, and during the subsequent treatment process. For licensing purposes, this means that the acceptance and processing policy of licence-holders is drawn up in such a way that, before wastes are combined, it is assessed whether this combination can take place safely. This can be achieved by carrying out compatibility tests before mixing/blending for any purpose for any type of waste
- the mixing of wastes must be prevented from leading to a lower level of processing waste than the best possible level of waste management or from leading to the application of non-environmentally sound waste management. This means, for example, that if a recovery operation is the minimum standard of processing a waste stream mixing of such wastes with other wastes in order to bring the mixture to any disposal route shall not be accepted. For instance, the mixing of liquid wastes or clinical wastes with other wastes for the purpose of landfilling is not permitted. Mixing of wastes with POP content above the low POP content (as defined under the Basel and Stockholm Treaties) with another material solely for the purpose of generating a mixture with POP content below the defined low POP content is not allowed because this is not environmentally sound
- the mixing of wastes must be prevented from leading to the undesired diffuse dispersal of environmentally hazardous substances. The effects of diffuse dispersal are determined by the type and concentrations of environmentally hazardous substances in combination with the processing route to be chosen, the emissions occurring and the quality and purpose of the residual substances released. In combination, it must be assessed what the negative consequences are of processing the environmentally hazardous substances concerned with regard to emissions into the soil, water, air or in residual substances and how these negative consequences compare with the environmental effects of another processing route. This assessment must also take into consideration the cyclical character of future re-use.

For solid wastes, the waste may be mixed with a crane, a closed mixer or a closed mixer with a turn-cup and an axis with knives. Blending operations generally involves large volumes, i.e. the discharge of tankers into tanks.

Users

Blending and mixing is typically applied only when quality and analytical values of the waste inputs are under or equal to the values of acceptance in the planned output treatment plant. These operations take place in all waste treatment activities (biological treatment, fuel preparation, contaminated soils, waste oils, etc.), and sometimes are quite specific to each WT activity. Some of these issues are also covered in the individual sections for each WT activity.

2.1.6 Decommissioning

Purpose
The purpose of decommissioning is to return the facility, on surrender of the waste licence, to a condition suitable for the selected afteuse. The importance of a proper closure is such that development of a closure plan is a necessity, since it will provide and document a plan for the final closure of a site prior to the startup of operation. This also fits in with a life cycle assessment of a planned site.

Principle of operation
For the decommissioning, the operator typically needs to demonstrate that, following decommissioning, the condition of the site will not cause, or be likely to cause, environmental pollution.

A closure plan needs to provide a clear and orderly set of actions and methods to be followed upon cessation of all operations at a facility. The steps need to be designed to ensure that the closed facility (a) poses a minimal risk to human health and the environment, and (b) requires minimal post-closure maintenance.

Feed and output streams
Not applicable.

Process description
The extent of the decommissioning/restoration will be dependent on the types of materials accepted, the design of the facility and the selected afteruse.

The cessation of waste acceptance at a facility typically initiates a review of the waste licence. This review allows the licence to be surrendered or amended to reflect the change in activities on site.

A closure plan requires assurance that funds are available to close the facility even if the facility owner starts bankruptcy proceedings. This assurance can be in the form of a bond, corporate guarantee, or some other financial instrument. The monetary amount is determined based on a cost estimate prepared as part of the closure plan. For example, the cost estimate may be equal to the maximum costs of closing all the waste management units ever activated at the facility.

Closure of a storage or treatment facility requires removal of all the remaining waste to another facility. All equipment and structures that had been in contact with waste must also be decontaminated. This may entail removal of concrete pads used to hold waste containers, as well as contaminated soil where leaks have occurred.

Users
Applicable to the whole WT sector.

2.1.7 Treatment of smalls

Purpose
The aim is to identify different types of wastes for their correct treatment.

Principle of operation
The substances that are to be treated are manually sorted and repackaged, crushed if necessary, conditioned and transferred to internal and/or external disposal plants.

Process description
The system is divided into three spatially separated parts:

- sorting of chemicals. This is carried out with a sorting cabin and an aspiration device for the separation of laboratory chemicals for different processing paths (e.g. recycling, disposal (incineration) and deposit in underground disposal)
- packing treatment for emptying fluid containers with a volume of 0.1 to 200 l. The small volumes are combined for the purpose of creating large batches (solvents or acids). These are disposed in the downstream high temperature incineration or recovered in the in-house physico-chemical treatment plant. A downstream facility crushes the emptied containers
- treatment of plant protection products, reactive and odour intensive substances in an special cabin.

Users
Treatment of hazardous wastes from private households, universities, laboratories and business enterprises.

2.1.8 Size reduction

Purpose
Adapt the waste solid granulometry for further treatments or to extract wastes which are difficult to pump or decant. Reduces the particle size.

Principle of operation
Techniques used in the installations are shredding, sieving, fractionating, conditioning and confectioning. Slow motion shredders, hammers and dedicated shredders are used.

Feed and output streams
Bins and aerosol cans are fed into the system. The gases are treated in a cleaning facility and the liquid and solid components are disposed of or sent for recovery.

Process description
Some examples are described below:

Bin shredder
The treatment facility consists of a shredder for the comminution of empty, half empty and full bins with sizes ranging from 1l to 1000 litres. The feed system works with an electronic wheel loader. The shredder itself is placed in a pressure surge-proof channel of 12 m high with an offloading area on top. The bins are transported by the electric wheel loader through the open door to the shredder. Afterwards, the door closes and the shredding process starts automatically. In the next step the shredded material falls into a tank, which, after complete filling, is transported from the channel to further processing steps. The released exhaust gases are treated in a regenerative post-combustion facility. Other protection devices are a double-layered vacuum controlled polyethylene high density foil on the bottom and an automatic nitrogen and water flooding in the closed channel.

Aerosol can shredder

The treatment facility consists of a shredder for aerosol can crushing, two condensation units and one collecting tank. The collecting tank has a filling device for condensed and warmed (outside temperature) gases. This tank has also a nitrogen supply device for cooling the condenser and for the inertisation facility. Other parts of the facility are a collection tank for liquid waste solvents and a bin for scrap metal. The shredder crushes the aerosol cans batch-wise. The shredder works in a nitrogen environment (inert) and is gas-proof. The gases and other active agents that may still be contained in the aerosol cans are released within the shredder. These released gases (mostly propellants) are run over the condensation unit and condensed. The condensate is stored in a gas collection tank. In the next step the gases are filled into compressed gas cylinders and transported to an incineration facility for hazardous waste. The uncondensed gases are transported to a regenerative exhaust air cleaning facility, where they are combusted. The solid residues from crushing (scrap metal) are separated from the liquid substances. The liquid and the solid components are separately discharged over different locks. The solid components, e.g. metal fraction, are forwarded to recovery or disposal. The liquid compounds, e.g. paint and hairspray, are temporarily stored in a tank and then decanted into 800 litre bins. The 800 litre bins are transported to a combustion plant for hazardous wastes where the liquid waste is used for auxiliary firing (thermal recycling).

Users

Bin and aerosol can treatment facilities. Preparation of waste to be used as fuel. Applied to different types of waste as plastic or metal drums, oil filters, municipal solid waste, solid bulk waste, waste wood, aerosol and glass.

2.1.9 Other common techniques

This section contains generic techniques used in the waste treatment sector. They are mainly mechanical treatments. They are typically used as pretreatments but some are also used as post-treatments (e.g. sieves). They are shown in Table 2.3, which also states the purpose of the treatments and where they are used.

Technique	Purpose	Users
Cleaning	Remove contamination that would otherwise prohibit waste materials being recovered	PCB capacitors and transformers
Re-packaging (e.g. baling)	Due to the disaggregated nature of some types of waste, it is sometimes necessary to compact them to make them easier to use in the following process. Pressure machinery is used to pack the waste into a certain physical form	Used for municipal solid waste to be used as a fuel and for plastic, paper and metal bales The size and form of the bale is typically optimised for its transport and re-use
Screening		
Sedimentation	Solid components within the fluid wastes are separated and the wastes are pretreated for further processing	Preparation of liquid waste fuel
Sieving	Used to separate big particles. Vibrating sieves, static sieves and rotary sieves are used	Preparation of waste to be used as fuel
Sorting and scrapping		
Washing	One purpose for washing may be to enable the re-use of drums into the installation or for selling to other installations for re-use. Drum washing operations often include no real treatment other than washing and settlement. A number of reprocessors wash the oil filters and provide a semi-cleaned metal fraction for recycling	Most treatment plants incorporate a road tanker washing-out facility to enable the removal of residues from vehicle tanker barrels. May also be applied to storage tanks and drums. Ph-c treatment plants

Table 2.3: Common techniques applied in waste treatment
[86, TWG, 2003], [122, Eucopro, 2003], [150, TWG, 2004], [156, VROM, 2004], [157, UBA, 2004]

2.1.10 Examples of waste treatment installations where only the common techniques are applied

Some waste treatment activities are very specific and particularly related to the type of waste that is processed. Some examples are listed below.

Cleaning transformers containing PCBs
Technologies, for cleaning transformers can be divided into three main categories:

- draining of the PCB oil from the transformer, followed by decontamination of this oil, and reinjection of the cleaned product into the transformer for re-use
- extraction of the PCB oil, by solvent washing of the transformer, followed by dismantling and further decontamination of the components to allow recycling of the metal components
- after suitable pretreatment, PCB oils may be treated with hydrogen at elevated temperatures. Here, the transformers are not recovered as such.

One example of the second case is the following: Carcases of used transformers are cleaned by means of trichloroethylene (TCE) wash. Here, the carcase is filled with the solvent and allowed to stand for an extended period before the solvent is replaced with fresh TCE. This operation is repeated (typically three times) until the carcase passes the requisite ‘swab test’. During the cleaning operation, the transformer carcase is left open to the atmosphere or loosely covered with a steel plate. As a consequence, the activity results in evaporative losses of TCE to the air.

Typically this activity is carried out at specialist sites, which clean the PCB contaminated transformers and bulk the PCB contaminated oils. Their wastes: oils, drums, cleaning waters and cleaning solvent sludge are all sent for off-site incineration.

Cleaned transformer carcases and windings are sent for reclamation after thorough cleaning with TCE.

Cleaning of capacitors containing PCBs
Capacitors are similar to transformers in that they are made up of an active core, held in a metallic casing. However, the active core is not copper windings, but instead consists of interwoven rolls of fine aluminium foil, separated by thin films of paper and/or plastic. The techniques used for cleaning these capacitors are:

- the casing of the capacitor is removed and decontaminated by solvent washing; this is a straightforward decontamination process since the casing is non-porous. The core is incinerated
- the possibility of going one step further and treating of the core after its removal from the casing. This decontamination step usually involves a shredding of the core, and treatment with a solvent. This allows the level of residual PCBs to be reduced
- the technology which allows the largest amount of recycling is similar to the above, but this also treats the mixed aluminium/plastic/paper residue to separate out these components, by solvent washing. The aluminium metal can then be re-used; the only component to be disposed of is the mixed paper/plastic shreds.

Aerosol crushers
The aerosol destructor may take manufacturing rejects or materials from collection banks. The potential contents are usually known. These can include propellant gases (this could be LPG, butane, propane, dimethyl ether or HCFC) and the active ingredients. A proportion of the aerosols are empty whilst others may still retain certain propellant gases, although this number is not quantified. Other rejects may have failed their pressure tests and will probably loose propellant on the way to the destructor unit. Any propellant still in the aerosol cylinders constitutes a risk of accident during the treatment.

At least one installation in France deals with aerosol treatment.

Glass crushing

Windscreen glass is laminated with polyvinyl butyrate, and this is removed in a preliminary crushing process and sent to landfill. The glass crushing operation handles municipal and industry glass. Sites typically do not take coated glass from electronic equipment.

Fluorescent tubes/lamp processing

Separate mercury from lamp tubes. Currently, this is a tiny activity in some countries, but existing operations are now experiencing an increasing demand for their services. At this time, most use a crushing process. However, another process recently developed is a process without crushing with a 99 % recovery of the mercury.

Treatment of wastes containing CFCs

In the EU, it is mandatory to collect CFCs for disposal. It is usual that the lubricating oil collected from the draining of refrigerants is also treated to remove residual CFC prior to being recovered. CFCs can later be incinerated. Few incineration plants in the EU have HF recovery.

2.2 Biological treatments of waste

[31, Greenpeace, 2001], [32, DETR and DTI, 2001], [33, ETSU, 1998], [51, Inertec, et al., 2002] [53, LaGrega, et al., 1994], [54, Vrancken, et al., 2001], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [80, Petts and Eduljee, 1994], [81, VDI and Dechema, 2002], [86, TWG, 2003], [114, Hogg, 2001], [117, DG Env, 2001], [132, UBA, 2003], [138, Lanfranchi, 2003], [150, TWG, 2004].

Biological treatment uses living micro-organisms to decompose organic wastes into either water, CO_2 and simple inorganics or into simpler organics such as aldehydes and acids. There are several biological treatments used for the treatment of wastes, however, not all are included in the Scope of this document. Table 2.4, together with information included in the Scope section, tries to clarify which treatments are included in this document.

Biological treatment	Brief description	Included in this document?
Activated sludge	Decomposes organic wastes in water by exposing waste to biological growth. Water is recycled and aerated to facilitate biological action and a sludge is generated. Two commonly applied systems: suspended growth systems and attached growth systems	Included as a waste water treatment (see Section 2.6)
Aerated lagoons	Large lagoons containing high concentrations of micro-organisms. The lagoon is aerated to encourage bacterial growth and decomposition of waste	Included as a waste water treatment (see Section 2.6
Composting	'Engineered' mounds of waste are built to encourage the biological breakdown of organic solids, producing a humic substance valuable as a soil conditioner	Not included in this document
Aerobic digestion	Reduction of the organic content of waste. Applied to solid waste, non-continuous waste waters, bioremediation and to sludge and soil contaminated with oil	Mechanical biological treatment (see Section 2.2.2 and Section 2.2.3) Only ex-situ bioremediation covered in this document
Anaerobic digestion	Decomposes organic matter in closed vessels in the absence of air. Uses two forms of bacteria: acid-forming and methane- forming. Applied to solid-liquid wastes, highly contaminated waste waters (e.g. chlorinated compounds), bioremediation and in the production of biogas to be used as a fuel	See Section 2.2.1 and Section 2.2.3 Only covered the ex-situ bioremediation

Table 2.4: Biological waste treatments

2.2.1 Anaerobic digestion

Purpose

Anaerobic digestion is used in industry to handle very high COD wastes and as a treatment process for sewage sludge after an aerobic treatment of the waste waters. The production of biogas from controlled anaerobic digestion is one of the principal advantages of the process.

Principle of operation

Anaerobic digestion involves the bacterial decomposition of organic material in the (relative) absence of oxygen. One of the main limits on the anaerobic digestion process is its inability to degrade lignin (a major component of wood). This is in contrast with the process of aerobic biodegradation.

Feed and output streams

Anaerobic processes may be used to directly treat liquid wastes, the biological sludge generated by an earlier aerobic stage, organic solids and sludges. The inclusion of other feedstocks, such as sewage sludge, alters the resulting digestate. However, it is important to note that the mixing of household waste with these feedstocks can improve both the environmental and economic aspects of the process and has already been adopted in a number of plants (particularly, co-digestion with slurries and manure at small scale farm-based plants).

In the process, carbon from incoming organics is mostly converted to methane and carbon dioxide, and then released as biogas, which is capable of being combusted to generate energy or be used as a fuel to abate VOC emissions for example. The proportion of methane to carbon dioxide will vary with the waste stream and the temperature of the system. The system needs to have a balanced feed to maximise methane production. Installations usually target carbon rich wastes, that will make use of the available nitrogen (and probably the extra required through bioaugmentation).

The anaerobic digestion process leads to a production of methane, with a theoretical methane production of 348 Nm^3/tonne of COD. In general, anaerobic digestion produces 100 – 200 Nm^3 of COD per tonne of biological municipal waste processed. Biogas generation is very sensitive to the feedstock, one plant found volumes ranging from 80 to 120 Nm^3 per tonne depending on the waste input. Biogas can be used to produce electricity (for internal consumption and/or for export) it can be burned in boilers to produce hot water and steam for industrial purposes, and it can also be used as an alternative fuel in light and heavy duty vehicles. Biogas has a typical composition of 55 – 70 % methane, 30 – 45 % carbon dioxide and 200 – 4000 ppm hydrogen sulphide.

The semi-solid residue, referred to as a digestate, is further treated normally through aerobic digestion. Some countries allow direct application of the digestate onto farmlands in certain circumstances (e.g. Sweden, Denmark). The risk of digestate application onto soil, mainly due to the heavy metals is typically controlled by national legislation in the different EU countries. As well as the main product from the process, i.e. a solid digestate, small quantities of surplus liquor are also available which can be dewatered to provide liquid fertiliser or sent to a waste water treatment plant (often following some separation of the solids).

Process description

The primary process variables are the methods of contacting the waste with the biomass (microbes), the moisture content of the waste (e.g. liquid, slurry or solid), and the method and degree of aeration. Anaerobic digestion generally involves the following stages:

Mechanical pretreatment

In order to improve the digestion process, materials, such as plastics, metals and oversized components are removed from the waste to be treated. Separation can be carried out under wet or dry conditions. Following this, a further process of size reduction is used to create a more homogenous material, which aids fermentation and facilitates processing. The size reduction could be brought about by screw-cutting, milling, drumming, pulping or shredding machines.

Digestion

There are a number of different techniques used to effect digestion. They are usually distinguished on the basis of the operating temperature (thermophilic plants operate at around 55 °C (50 – 65 °C), and mesophilic ones at around 35 °C (20 – 45 °C)) and the percentage of dry matter in the feedstock (e.g. dry systems with 30 – 40 % dry matter, wet systems with 10 - 25 % dry matter). Generally speaking, the higher the temperature, the faster the process, but the thermophilic process may be harder to control and will need more biogas for heating to keep them at the required temperature. Some common technologies currently available are listed in Table 2.5.

Technique	Description	Input
Wet single-step	Solid waste is slurried with the process water to provide a diluted feedstock for feeding into a mixing tank digester	The process can be used for MSW on its own, but the wet process lends itself to co-digestion with diluted feedstocks, such as animal manure and organic industrial wastes
Wet multi-step	Solid waste is slurried and fermented by hydrolytic and fermentative bacteria to release volatile fatty acids which are then converted to biogas in a high rate industrial waste water anaerobic digester	The system lends itself to the digestion of MSW and to the wet organic waste from food processors
Dry continuous	The digestion vessel is continuously fed with a material with 20 – 40 % dry matter through batch loading. In both mixed and plug flow variants, the heat balance is favourable for thermophilic digestion	
Dry batch	A batch is inoculated with digestate from another reactor and left to digest naturally. Leachate is recirculated to maintain moisture content and to redistribute methane bacteria throughout the vessel	
Sequencing batch	Essentially a variant of the dry batch process, in which leachate is exchanged between established and new batches to facilitate start up, inoculation and removal of the volatile materials from the active reactor. After digestion becomes established, the digester is uncoupled from the established batch and coupled to a new batch in another vessel	
Heap bioreactor		

Table 2.5: Anaerobic digestion technologies
[53, LaGrega, et al., 1994], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002]

Users
Anaerobic digesters are currently used for municipal waste (specifically biowaste separated at source) but have been tested for hazardous waste disposal as well. In some anaerobic digesters at sewage treatment works, spare capacity is being used for a range of industrial non-hazardous organic wastes. The anaerobic digestion of MSW has been commercially available for approximately 10 years and is utilised in Germany, the Netherlands and Denmark. There are developments in Spain, Portugal and Belgium, and it is used to a limited extent in other countries such as Sweden, the UK and France.

2.2.2 Mechanical biological treatments

Purpose
Mechanical biological treatment (MBT) is usually designed to recover materials for one or more purposes and to stabilise the organic fraction of the residual waste. The practical advantages of MBT plants are, above all, the reduction of:

- the volumes of waste
- the organic matter content of the waste, which are sent to final disposal (landfill or incineration).

Another purpose of MBT is material splitting for further processing (e.g. preparation of solid waste fuels). Biological digestion is intended to reduce the weight, and to render inert any biologically active organic materials (typically called ‘stabilised residue’).Typical values for the combined loss of water and biodegradable materials may be in the range of between 20 and 35 %, mainly depending on time the treatment occurs. Further reductions of the waste volume going to landfill may be achieved due to mechanical separation of the output and can then be finally even higher at 60 %.

Principle of operation

MBT plants significantly reduce humidity by extracting, reducing and stabilising the organic content in the waste. These treatments involve a mechanical separation of the waste, biological treatment (anaerobic and/or aerobic digestion) of the organic fraction, and a further mechanical separation if required.

MBT has to lead to a reduction of the contents of biodegradable organic substances, volume, water content, gas formation potential and respiration activity of the waste, as well as having a significant improvement in leaching and settlement behaviour.

Feed and output streams

In principle, many types of waste materials can be accepted at a MBT plant. The materials broken down and digested in the biological stage include paper and board, green/kitchen organics, and the organic content contained within nappies, packaging, textiles, some types of sewage sludge, etc. Generally, only mixed, unsorted waste enters the plant. However, some EC legislation and alterations in the treatment processes exclude or restrict some types of waste. Some examples are hazardous waste, waste for which a special treatment is obligatory because of EC legislation (e.g. Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption), waste for which a biological treatment is not appropriate and waste causing inhibition of the biological activity.

The output from MBT plants is greatly reduced in weight and stabilised (emission releases from the product compared with the non treated material could be reduced approximately 90 – 98 % under landfill conditions). Such figures are very variable and strongly depend on how reduction of emissions are calculated (e.g. gas generation and respiration activity) and typically can have significant variations in quality. In some countries, the waste OUT may be used as landfill cover if contamination is low enough (low grade compost, grey compost or stabilised biodegradable waste), or it may be landfilled. The quality of the waste OUT produced is generally not acceptable for widespread use because of the contaminants within related to both the inert content (glass, plastic, etc.) and also to the heavy metals content arising from other wastes entering the stream (batteries, etc). Other outputs are combustible fractions and recyclable materials (e.g. metals, plastic)

Process description

MBT plants are very flexible and they can be built on a modular basis. The mechanical treatment phase involves segregating and conditioning the wastes. The processes that may be involved are:

- open waste bags (where necessary) (e.g. shredders)
- extraction of undesirable components that might obstruct the subsequent processing (e.g. metal separators)
- optimising the particle size for subsequent processing (e.g. by sieves, or shredders)
- segregation of biodegradable materials in the underflows of primary screening, so that they can be sent to the biological treatment process (e.g. by sieves)
- segregation of materials with a high calorific value, such as textiles, paper and plastics, in the overflows of primary screening, so that they can be sent for use in the production of fuel. Also, segregation of those materials suitable for further material recovery (e.g. by air separation)
- homogenise materials destined for biological treatment.

Apart from these elements, the plant may include equipment for recovery of metals and for extraction of mineral fractions. The permutations regarding the design of an MBT plant are many and varied. Some plants are designed to separate and biologically treat the residual waste from MSW prior to landfill. A scheme of a MBT process is shown in Figure 2.6.

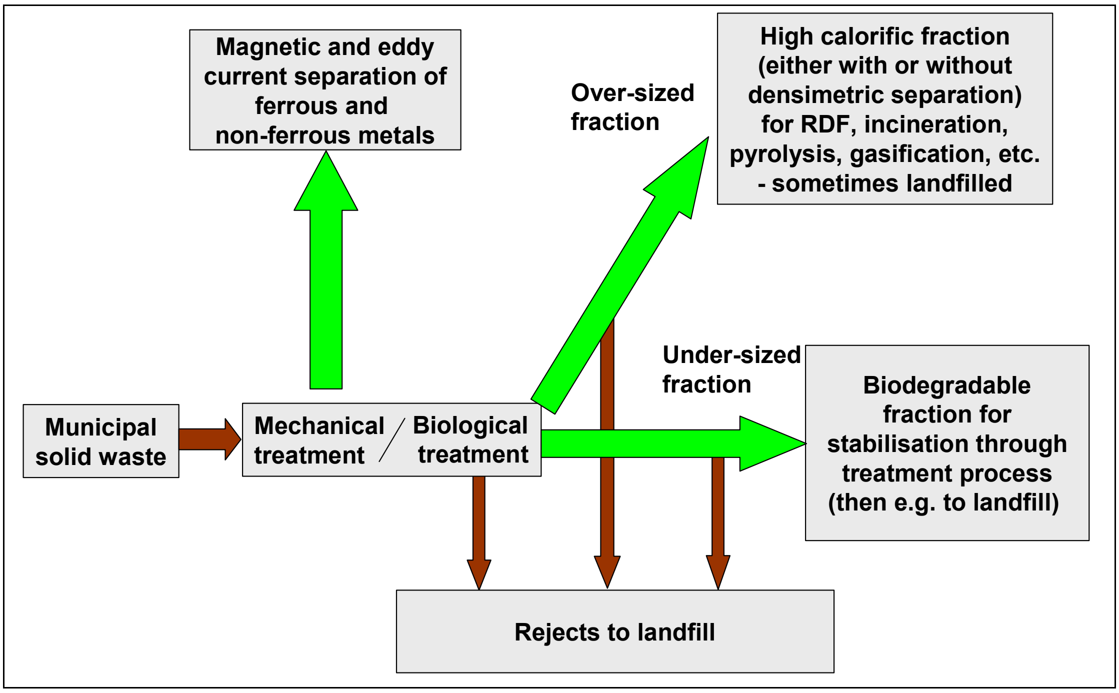


Figure 2.6: Schematic representation of mechanical/biological treatment inputs and outputs
Note: Brown arrows represent residual materials
Green arrows represent processed outputs
Mechanical treatment may be carried out before or after the biological treatment
[17, Eunomia Research & Consulting, 2002], [150, TWG, 2004]

Two types of systems exist: encapsulated and housed. *Encapsulated systems* (container, tunnel) are usually operated only under pressure with circulating air. Control is exercised through the parameters of temperature and oxygen content in the circulating air. The heat has to be led off from the system by cooling the circulating air. The condensate that is created may be used for watering the heaps or has to be disposed of as waste water.

Housed systems (wandering heap process) are operated both with pressure and with suction, in some plants both aeration methods are used alternatively. Circulating air systems are only possible to a limited extent in housed systems. In the suction operation, at least repeated re-use of the heap exhaust air is feasible. The heat generated can only be led off through water evaporation and exhaust air. In addition to specific aeration control, the periodic turnover of the biologically degraded material is of decisive importance for the progress of biological treatment. It serves the purpose of:

- mixing the material and making new surfaces accessible for the micro-organisms
- activating the biological degradation
- minimising the biological degradation times
- watering the heap evenly and compensating evaporation losses
- compensating for the volume loss of the biological degradation
- leading off heat from the heap.

So the biological process is optimised and the existing biological treatment capacities are cost-effectively utilised. In MBT plants with quasi-dynamical biological treatments according to the moving heaps process or the tunnel process, turnover usually occurs in weekly intervals. Some biological processes require two turnover cycles per week during the first three weeks. After this period, the material is turned over every five to seven days.

Users
Mechanical biological treatment is a tool for pretreating wastes prior to landfilling or for preparing solid waste (typically municipal solid waste) to be used as fuels. Although the popularity of mixed waste composting is declining, it is currently still carried out in Greece, Spain, and Portugal, whilst in Italy, Germany and Austria, it is being progressively or totally 'converted' to MBT of residual waste. These types of treatments are also emerging in the Netherlands and Belgium. There is currently a lot of interest in this technology in the UK with some plants currently being constructed and the UK Government sponsoring trials of such new technologies.

These plants tend to have large capacities because they treat large volumes of mixed waste. An average capacity of 50 – 100 kt/yr is quite normal, but they can be as large as 700 kt/yr, as is one in Milan in Italy and can be as small as 7 kt/yr. At least four examples exist in Europe with the purpose of achieving complete recovery of MSW in the form of recycling materials and energy recovery.

2.2.3 Biological treatments applied to contaminated soil

Purpose
To reduce the contamination of soil.

Principle of operation
Aerobic and anaerobic degradation of pollutants in the excavated soil.

Feed and output streams
The types of contamination to be treated are biodegradable pollutants, fuels (gasoline, kerosene, gasoil, heating oils, heavy fuels), mineral oil, waste oils and heavy organic oils. The main products of this type of treatment are decontaminated excavated soils.

Process description
The lack of oxygen is the most limiting factor of pollutant biodegradation in soil and lots of different processes have been developed to optimise soil oxygenation. The various biological treatments differ with the aeration techniques used. Two types of processes exist. *In-situ* and *ex-situ*.

In-situ biodegradation
In situ biodegradation is the term for biological treatment processes that are performed in the original place where the contaminated soil is. Such processes are not covered in this document.

Ex-situ biodegradation
Ex-situ biodegradation is the general term for treatment processes in which the contaminated soil or sludge is excavated and remediated through biological processes. Ex-situ bioremediation technology most often involves slurry-phase bioremediation where an aqueous slurry is created by combining contaminated soil or sludge with water and then the contaminants are biodegraded in a self-contained reactor or in a lined lagoon. Ex-situ biodegradation also encompasses solid-phase bioremediation, such as landfarming, composting, and biopiles. In these processes, the contaminated soil is excavated, and oxygen, nutrients, water, or micro-organisms are added to enhance the natural biodegradation of the contaminants.

Slurry-phase bioremediation
There are two main objectives behind using slurry-phase bioremediation: (1) to destroy the organic contaminants in the soil or sludge, and, equally important, (2) to reduce the volume of contaminated material. Slurry biodegradation has been shown to be effective in treating highly contaminated soils that have fuel or other organic contaminant concentrations ranging from 2500 to 250000 mg/kg. The slurry process has also shown some potential for treating a wide range of contaminants, including pesticides, creosote, pentachlorophenol, PCBs, and other halogenated organics.

Waste preparation is required before applying slurry biodegradation. The preparation may include excavation and handling of the waste material, as well as screening to remove debris and large objects. Particle size reduction, water addition, and pH and temperature adjustment may also be required to meet feed specifications.

Once biodegradation of the contaminants is completed, the treated slurry is sent to a separation/dewatering system. A clarifier for gravity separation can be used to remove the water from the soil.

Solid phase bioremediation
Solid-phase bioremediation involves the excavation and preparation of contaminated soil to enhance the bioremediation of contaminants in the soil. The techniques typically used for preparation of the soil to be bioremediated are sifting/riddling, homogeneisation, nutrient improvement and compost addition. The bioremediation is carried out in biopiles (soil turning or air injection).

Aerobic digestion involves the storage of biodegradable waste with a bulking agent to increase the porosity of the soil material. Bioremediation is similar to composting in that the contaminated soil is piled in large mounds. However, for these processes air is usually provided by pulling a vacuum through the pile.

Users
Contaminated soils.

2.3 Physico-chemical treatments of waste

[30, Eklund, et al., 1997], [51, Inertec, et al., 2002], [53, LaGrega, et al., 1994], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [89, Germany, 2003], [100, UNEP, 2000], [101, Greenpeace, 1998], [121, Schmidt and Institute for environmental and waste management, 2002], [123, Perseo, 2003], [124, Iswa, 2003], [136, Straetmans, 2003], [146, Galambos and McCann, 2003], [150, TWG, 2004], [152, TWG, 2004], [156, VROM, 2004], [157, UBA, 2004].

This section details the physico-chemical (Ph-c) treatments of waste. Treatments such as precipitation, decanting and centrifuging, and thermal treatments not included in WI BREF are included here. Due to the fact that many of these treatments are common unit operations, the description of some operations will only be mentioned briefly in this section. For those techniques considered less common and that need extra explanations, an independent section within this section has been created. Techniques for the abatement of emissions are covered in Section 2.6. Common activities carried out in these plants (e.g. storage, handling) are covered in Section 2.1.

The structure of this section relates to the physical conditions of the type of waste. Treatments carried out on liquids and solids differ a lot and it has been suggested that considering these separately may give a good structure to such a long section. At the end of the section, some special physico-chemical treatments carried out on special wastes (e.g. destruction of POPs) have also been included.

Some of the techniques for the treatment of waste may make use, for example, of the acidic solution from the first scrubber in a wet air pollution control system when air pollution control waste treatment is being considered. Some techniques involve a return of the treated residues to the combustion chamber for sintering with bottom ash. These techniques are not included in this document because they are integrated measures of the combustion technologies. These issues can be found in other BREF documents.

2.3.1 Physico-chemical treatments of waste waters

Purpose
Ph-c plants are planned in such a manner that the maximum amount of recyclable materials can be separated so that a minimum amount of auxiliary materials is used. The purposes of physico-chemical treatment plants are to:

- enable delivery of environmental protection goals, in particular, water quality management. In Ph-c plants, materials which may be hazardous to water are either treated, withheld and/or converted to a non-hazardous form
- enable the correct disposal of large quantities of, in general, aqueous liquid waste and waste requiring special controls
- separate the oil or the organic fraction to be used as fuel.

The procedures serve the specific application of physico-chemical reactions for material conversion (e.g. neutralisation, oxidation, reduction) and for material separation (e.g. filtration, sedimentation, distillation, ion exchange).

Principle of operation
During the physico-chemical treatment of contaminated waste water, water is separated and processed for discharge to sewerage systems or water bodies. This processed water becomes subject to various water legislation as soon as it is discharged.

Feed and output streams

The waste treated in Ph-c plants is aqueous liquid. Ph-c plants generally treat waste liquids or sludges with a relatively high water content (>80 w/w-%). Regardless of their origin and their relationship to their material characteristics, the wastes commonly treated by these plants are:

- emulsions/cooling lubricants
- acids (e.g. picking acids from surface treatments. Some information on STM BREF)
- alkaline solutions
- concentrates/saline solutions containing metals
- wash-water
- waste water containing a gasoline/oil separator
- solvent mixtures
- sludges
- aqueous liquid wastes with high concentrations of biodegradable materials
- aqueous marine waste.

An indication of the type of wastes accepted at sites in the UK is given in Table 2.6.

Waste stream	Percentage of sites accepting each type of waste (%)
Neutral aqueous inorganics	69
Acids	62
Oils	62
Alkalis	54
Neutral aqueous organics	54
Contaminated containers	23
Cyanides	23
Organic sludges	8
Water reactive chemicals	8

Table 2.6: Waste types accepted at physico-chemical treatment plants in the UK
[56, Babtie Group Ltd, 2002]

Process description

Ph-c plants are configured on a case-by-case basis depending on requirements and/or application. Each Ph-c plant has a specific individual technological and operational concept; this is geared to the waste to be treated. For this reason, there is no ‘standard’ physico-chemical treatment plant. Although all plants have inspection and process laboratories and tend to have a neutralisation function, the range of pretreatment processes, sludge handling methods and the combination of input waste streams makes each a unique operation. The modes of operation of Ph-c plants are:

- continuous operation: particularly suitable for large throughputs, waste of relatively constant composition and for automated operation
- batch operation: particularly well suited to the very variable characteristics/reaction of the waste to be treated.

Table 2.7 shows some differences between different Ph-c plants.

	Treatment of				
	emulsions	**emulsions and oil/water mixtures**	**emulsions and waste with contents to be detoxicated**	**liquid and aqueous waste with some organic solvents**	**liquid and aqueous waste containing organic solvents and tensides**
Sieving	■	■	■	■	■
Sedimentation					■
Ultrafiltration					▒
Evaporation					▒
Heating up				■	▒
Stripping				■	
Acid splitting	■	■	■		
Organic splitting			▒		▒
Oxidation/reduction			▒		
Membrane filtration				▒	
Flocculation/precipitation	■	▒	▒	▒	▒
Sedimentation	■	▒	▒	▒	▒
Draining	■	▒	▒	▒	▒
Sulphuric precipitation	■				
Filtration	■	▒	▒		
Ion exchanger	■				
Neutralisation				▒	▒

Note: Dark grey: required process, light grey: Optional process

Table 2.7: Analysis of some representative types of physico-chemical treatment plants
Based on [121, Schmidt and Institute for environmental and waste management, 2002]

The unit operations typically used are sieving, storage/accumulation, neutralisation, sedimentation, precipitation/flocculation, ion exchange, oxidation/reduction, sorption (adsorption/absorption), evaporation/distillation, membrane filtration, stripping, extraction, filtration/draining, acid splitting of emulsions and the organic splitting of emulsions.

Frequently several unit operations will have to be used to correctly treat a specific waste. The unit operations procedure combination (type of procedure, sequence of their application, controls) is specified by the Ph-c plant laboratory, on the basis of the composition of the waste and its reaction behaviour.

The following equipment is typically available for reactors in order to control reactions:

- storage vessels for separate storage, depending on the type of treatment
- reaction containers with adjustable agitators and temperature indicators
- sedimentation containers
- metering equipment
- receiver and storage tanks for chemicals
- storage tanks and reservoirs for the waste to be treated
- dosing equipment
- material resistant to acids and alkalis
- control of pH value for the chemicals
- containers for settling and mixing ancillary agents
- measurement and automatic controls
- ventilation and filtering of the reaction tanks with facilities for cleaning the exhaust air.

Users

From 25 to 30 % of all hazardous waste in Germany is disposed of by Ph-c plants. Some examples of the operations carried out via a Ph-c plant are:

- treatment of emulsions
- treatment of emulsions and waste with contents to be detoxified
- treatment of liquids, aqueous wastes with some organic solvents
- treatment of emulsions and oil/water mixtures
- treatment of liquids, aqueous wastes containing organic solvents and tensides
- detoxification (oxidation/reduction) of waste containing nitrites, Cr(VI), cyanide (as pretreatment).

The wastes processed are usually from various industrial and commercial production processes, and from maintenance, repair and cleaning activities. Some specific industrial sectors served are the printing and photographic industries. These are an example of those sites, which provide a service to a particular industrial sector, taking away a wide range of wastes and transferring those that cannot be treated or recycled in-house.

Figure 2.7 shows the treatment of aqueous marine waste.

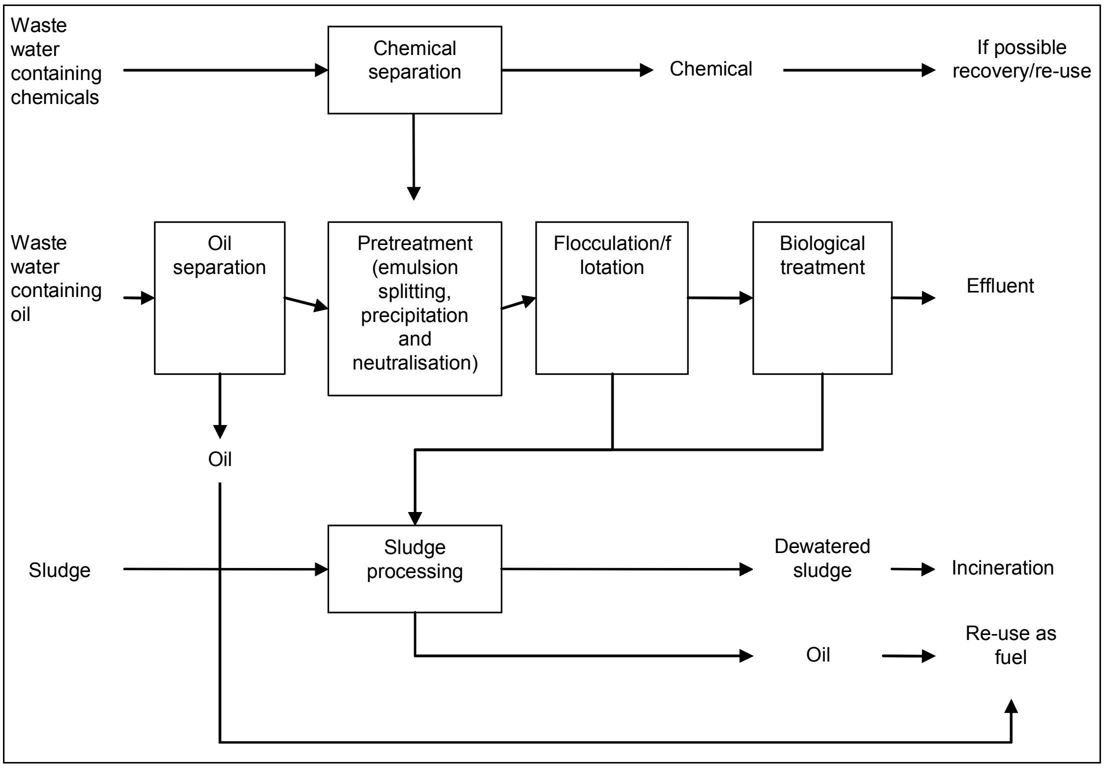


Figure 2.7: Treatment of aqueous marine waste
[156, VROM, 2004]

2.3.2 Unit operations used in Ph-c treatments of waste waters

Waste can be treated using any of a large number of commercially proven unit operations. The treatment methods fall into four categories:

- phase separation (e.g. sedimentation, steam stripping)
- component separation (e.g. ion exchange, electrodialysis)
- chemical transformation (e.g. chemical oxidation, incineration)
- biological transformation (e.g. fixed film aerobic treatment).

Table 2.8 summarises units operations used in physico-chemical treatments. Some more information on this issue can be found in the Common waste water and waste gas treatment BREF (CWW).

Unit operation	Purpose	Principle of operation
Separation operations		
Acid break-up of emulsions	The term 'acid break-up' is understood to be the treatment of emulsions. The aim of the treatment is the separation of the emulsion into waste water, oil/grease and undissolved metals as hydroxide sludge	
Centrifugation	Dewatering metal salt sludges from precipitation techniques	Separates solids and liquids by rapidly rotating the mixture in a vessel. Solids either settle at the bottom (sedimentation - type) or adhere to the inside wall of the vessel (filtration - type) through which the liquid passes
Evaporation and distillation	Evaporation and distillation are similar processes with different objectives. During evaporation the useful material in a mixture is evaporated through thermal effects and captured as vapour and generally condensed. Distillation is a separation process, which is used for the separation of mixtures, which obtains better separation ratios than evaporation	The aim of evaporation/distillation is to separate the oil into a good usable form. In the Ph-c plants, evaporation is used as a partition stage in order to separate vaporisable materials from the waste water. Depending on the ingredients of the waste water, evaporation can also be used as conditioning for a further preparation stage, such as membrane filtration. Evaporator technology is of great importance whenever organic solvents are to be separated from the waste to be treated
Extraction		Extraction is used for the specific separation of components from a mixture of substances. The mixture of substances is thoroughly mixed with a selective solvent. During mixing, the component from the mixture of substances migrate into the extracting agent. With the subsequent separation of the extracting agent from the substance mixture, finally the components of the mixture are also separated
Filtration/ dewatering	This is the most common operation applied, e.g. in drinking water treatment, industrial waste water treatment	Involves passing a mixture of liquid and solids (or gas and solids) through a filter medium to trap the solids. Different kinds of filters exist, such as gravel filters, sand filters and mechanical filters (e.g. waste water screen presses, chamber filter presses, membrane filter presses)
Filtration/ sieving	The sieving of the waste to be treated is essential for the protection and safety of functional units, such as pumps, sluice gates, valves	Sieving is a classifying/separating procedure with which the filtered material – liquid/solid mixture (slurry) – is separated into two mixtures, one with an average particle size smaller than the input, and another larger than the input

Unit operation	Purpose	Principle of operation
Filtration (by membranes)	Separation of substances/solids from liquid mixtures. Ultrafiltration can be used for break-up of emulsions	In membrane procedures the liquids to be treated are fed under controlled pressure and current conditions past a semi-permeable membrane. The separative power of the membrane is essentially based on the filtering effect and thus outputs are neither altered biologically nor chemically.
Flotation	Used by refining, meat packing, paint, paper milling and baking industries	Introduction of tiny air bubbles into a solution containing suspended particles. Particles attach to air bubbles and float
Ion exchange processes	Ion exchange is a process for the cleaning of liquid waste of dissolved electrically charged particles (ions) by means of ion exchanger materials. Can also be used in water-softening, as Ca and Mg ions are removed from the liquid stream. Some of substances suitable for ion exchangers are liquid waste from the electroplating industry, chromium electrolytes/chromating baths, phosphoric acid pickling, hydrochloric acid pickling and sulphuric acid anodising baths. Groups of material unsuitable for ion exchangers are: organic compounds as these can irreversibly block the resins in the exchanger or whose removal may be incomplete; strong oxidising agents, as these may damage the anion exchanger resins; metal cyanide complexes, as strong base anion exchangers damage the resins; aromatic and halogenised hydrocarbons, as they cause the exchanger resins to swell at times and thus can lead to interruptions in the exchanger availability.	Ion exchange resins have the ability to exchange their settled groups of ions (cations or anion) with ions contained in the water
Oil separation processes	Gravity settlement without heat to produce an oil rich layer, that is skimmed off and sent to oil recyclers for further processing, and an aqueous phase plus sludge that is processed through the main plant. At some plants, this is a major part of the day-to-day activities. At others it is an occasional batch process and only operated when needed to provide a full service to major customers but where the company does not actively seek oil/water streams for treatment. Some sites add acid to the oil to assist in the separation process (emulsion breaking)	Gravity separation of soluble oils and oil/water mixtures
Organic splitting of emulsions		For the destabilisation of the emulsifying agent, polyelectrolytes and/or similar products are used. These allow good splitting of the emulsion comparable to acid splitting

Unit operation	Purpose	Principle of operation
Reverse osmosis	Used to produce drinking water from brackish groundwater and seawater. Also for recovery of electroplating chemicals from plating rinse-water and sulphate from paper industry waste water. Used in leachate treatment	Uses a mechanical force, e.g. high pressure (17 – 100 atm) to drive solvent (usually water) through a membrane. This generate two fractions one that concentrate the dissolved components and another where the solvent is purified
Screening	Waste water containing solids, etc.	Removes large particles from waste water. There are three types of screens, rotating drums, vibrating and stationary
Sedimentation	Sedimentation is used in Ph-c plants specifically for the thickening of sludges, and the separation of heavy particles and suspended matter from the waste water and concentrate sludge	The forces of gravity cause the thicker phase of a suspension to separate. To this extent, the nature of the force determines the type of sedimentation: gravity sedimentation or centrifugal sedimentation
Sorption (absorption and adsorption)	If the waste water shows increased and/or inadmissibly high values of TOC, AOX or PCB, the organic materials generally separated using adsorption	Sorption is the uptake of a substance (gas, vapour, liquid) by another material, as a result of the contact of both materials. Absorption is designated as the penetration of a gas into a solid or liquid phase (absorbents) by diffusion. Adsorption is described as the accumulation of gases or solute materials at the surface of a solid or liquid material (adsorbents) by molecular forces. Adsorption is a physical process, and to this extent the chemical characteristics of the adsorbed material are unaltered
Stripping (by air or steam)	Stripping is used in order to be able to use the following procedures better and more effectively; or as a final stage to reduce the concentration of certain hydrocarbons (AOX). By stripping, volatile materials, for example hydrogen sulphide (H_2S), ammonia (NH_3), low boiling hydrocarbons and chlorine hydrocarbons (AOX) can be separated from aqueous solutions	Stripping is the driving out of easily vaporisable materials from liquid mixtures. Air or water vapour is used for stripping, with a simultaneous increase of the phase-boundary surfaces. Stripping is thus a separation process in which the separated material is in the exhaust air (stripping with air) or in the distillate (stripping with water vapour)
Chemical processes *		
Electrolysis	The recovery of metals from solutions (e.g. silver from photographic waste)	Use of electrical power to reduce metals from solution
Neutralisation	To neutralise the waste water or to recuperate some components from it by precipitation at a specific pH(s). Depending on equipment configuration, neutralisation and sedimentation can be carried out in the same container	Neutralisation is the adjustment of the pH values to a neutral level, for instance, pH ~ 7. Neutralisation is achieved by adding acids or alkalis to the material to be neutralised and/or by the mixing of acids and alkalis

Unit operation	Purpose	Principle of operation
Oxidation/ reduction	Redox reactions in connection with the Ph-c treatment of waste activity involve the detoxicating of nitrite and cyanide (oxidation) and chromium (VI) compounds (reduction). Other possible treatments are the destruction of sulphides or peroxides. Wastes are made less toxic, simpler and less volatile by subtracting or adding electrons between reactants	Oxidation and reduction are processes which are generally coupled. Oxidation is the release of electrons, and reduction is the uptake of electrons.
Precipitation/ flocculation	The separation of dissolved or suspended materials (e.g. metals) by the addition of chemicals	Precipitation is the conversion of a solute substance to an undissolved substance, in general by the addition of chemicals. Flocculation is the agglomeration of more or less fine particles (as well as solute substances) into larger flocs; these are separated by sedimentation or filtration
Wet air oxidation	Sewage sludge	Solids solubilised and oxidised under high pressure
* Some of these treatments induce separations (e.g precipitation)		

Table 2.8: Unit operations used in physico-chemical treatments
[80, Petts and Eduljee, 1994], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

2.3.3 Physico-chemical treatments of waste solids and waste sludges

The main goal in the physico-chemical treatments of waste solids and waste sludges is to minimise the long-term release by leaching out the primarily heavy metals and low biodegradable compounds. The available treatment options act to prolong the leaching time period by releasing, for example, heavy metals at lower and more environmentally acceptable concentrations for an extended period of time.

In principle, all treatment options can be applied to waste solids and waste sludges. However, the characteristics of the treated material and the effectiveness of a treatment technology can vary greatly depending on the specific properties of the original waste IN and on the type of cleaning system applied. The treatment options has been sub-grouped according to the following types:

- extraction and separation
- thermal treatment
- mechanical separation
- conditioning
- immobilisation (this treatment covers solidification and stabilisation)
- dewatering
- drying
- thermal desorption
- vapour extraction from excavated soil
- solvent extraction from solid waste (e.g. excavated soil)
- excavation and removal of excavated soil
- soil washing.

2.3.3.1 Extraction and separation

Purpose
To extract heavy metals and salts from solid wastes, using acid.

Principle of operation
Solubilises compounds and removes them with water.

Feed and output streams
Treatment options using extraction and separation processes can, in principle, cover all types of processes extracting specific components from the wastes.

Users
Several techniques have been proposed both in Europe and in Japan for air pollution control residues.

2.3.3.2 Thermal treatments

Purpose
Thermal treatment of FGT waste from combustion processes is used extensively in a few countries, mainly to reduce the volume and to improve their leaching properties.

Principle of operation
High temperature treatments use heat in order to melt waste and initiate vitrification and ceramisation processes. Thermal treatments can be grouped into three categories: vitrification, smelting and sintering. The differences between these processes chiefly relate to the characteristics and properties of the final material:

- vitrification is a process where wastes are mixed with glass precursor materials and then combined at high temperatures into a single-phase amorphous, glassy output. Typical vitrification temperatures are 1300 to 1500 °C. The retention mechanisms are chemical bonding of inorganic species in the waste with glass-forming materials, such as silica, and encapsulation of the constituents by a layer of glassy material
- melting is similar to vitrifying, but this process does not include the addition of glass materials and results in a multiple-phased product. Often several molten metal phases are generated. It is possible to separate specific metal phases from the melted output and recycle these metals, possibly after refinement. Temperatures are similar to those used in vitrifying
- sintering involves heating the waste to a level where a bonding of the particles occurs and chemical phases in the wastes reconfigure. This leads to a denser output with less porosity and a higher strength than the original waste. Typical temperatures are around 900 °C. Temperatures for sintering bottom ash from MSW incinerators can be up to 1200 °C.

Feed and output streams
Most commonly, FGT wastes are treated thermally in combination with bottom ashes.

Process description
Regardless of the process, the thermal treatment of FGT waste in most cases results in a more homogeneous, denser product with improved leaching properties. Vitrifying also adds the benefits of the physical encapsulation of contaminants in the glass matrix.

The thermal treatment of FGT waste requires substantial off gas treatment, thus creating a new solid residue to be treated. Also the high salts concentrations in FGT waste can cause corrosion problems in off-gas treatment systems.

Users

Sintering is not used as a dedicated treatment option for FGT waste, however some combined treatment methods may involve sintering.

2.3.3.3 Mechanical separation

Purpose

The aim of the treatment is to generate a material which is inert, does not negatively affect water bodies, and has the potential for safe recovery, e.g. as a soil substitute or in road construction. Such treatment reduces the mass of waste for disposal. Furthermore, the clean separated and collected ferrous and non-ferrous metal fractions can be re-used. In addition, the reduction in the amount of heavy metals, e.g. arsenic (salt) being emitted in the environment, is also a major benefit.

Principle of operation

In the case of bottom ash treatment, the bottom ash is separated into at least three fractions: mineral compounds, unburned material and scrap metal. A reduction of heavy metals and soluble compounds is required and is important for re-use of the material after treatment. The water soluble components are the most water-relevant ingredients of bottom ash.

Feed and output streams

One of the main products of waste incineration is the bottom ash generated through the burning process. An input of one tonne of household waste generates approximately 250 - 350 kg of bottom ash. The bottom ash is generally composed of components such as chloride, arsenic, lead, cadmium, copper, mineral materials and scrap metals.

Process description

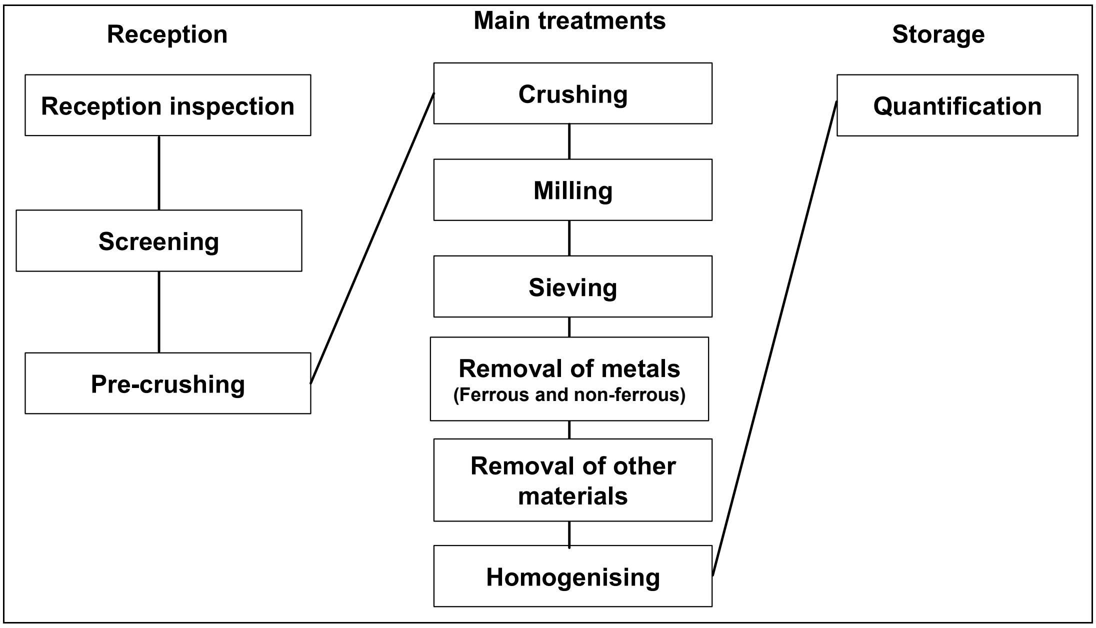


Figure 2.8: Example of some mechanical separations used for the treatment of bottom ashes [89, Germany, 2003], [150, TWG, 2004]

Users

Bottom ash and FGT waste.

2.3.3.4 Conditioning

Purpose
The aim is the treatment of the solid and paste like wastes for recovery/disposal in incineration plants or for landfilling.

Principle of operation
The substances that can only be incinerated or landfilled are conditioned by means of aggregates. Depending on the final disposal plant (e.g. incineration or landfill); diatomite, sawdust or other appropriate aggregates are added to the waste.

Process description
Wastes with certain resource contents may be passed on to the downstream plant for the recovery of recyclable substances. If necessary, the wastes may be run over a one step crushing, e.g. in order to crush the metal packaging such as paint cans, and transfer them via a conveyor system to the facility for recovery of recyclable material.

Wastes that are delivered in large capacity containers are pretreated in a second crushing facility. For dusty wastes, a third fully encapsulated two-shaft shredder is available. In the free-falling mixer, the pretreated wastes may be mixed with aggregates to produce a batch of maximum 10 m^3. The free-falling mixer consists mainly of an open cylindrical-conical container with a volume of 20 m^3. This container is filled via the last conveyor of the charging system. Rotation of the container produces a homogeneous mixture and the abrasive forces in the mixing drum cause a quasi-dry cleaning of metal and plastic components in the waste. The free-falling mixer is emptied into the loading facility which conveys the conditioned waste either to truck loading or to further treatment towards the facility for the recovery of recyclable substances.

Users
Preparation of waste to be used as fuel.

2.3.3.5 Immobilisation

Purpose
The aim of immobilisation is to minimise the rate of contaminant migration to the environment and/or to reduce the level of toxicity of contaminants, in order to alter or improve the characteristics of the waste so that it can be disposed of. The objective encompasses both a reduction in the waste toxicity and mobility as well as an improvement in the engineering properties of the stabilised material.

Principle of operation
Immobilisation relies on the properties of the reagent to produce an immobilised waste product, even where the waste product does not have a solid form. These processes retain substance(s) adsorbed to, or trapped within, a solid matrix. Some of these processes are reversible (i.e. the immobilised substances can be released), due to both poor process control and to subsequent mixing with other waste types. Two types of processes have been developed. These are commonly referred to as: stabilisation and solidification.

Stabilisation

This is a process by which contaminants (e.g. heavy metals) are fully or partially bound by the addition of supporting media, binders, or other modifiers. Stabilisation is accomplished by mixing the waste with a reagent (depending on the type of waste and reaction planned, this can be, for example, clay particles; humic organic substances, such as peat; activated carbon; oxidisers; reductors; precipitating reagents) to minimise the rate of contamination migration from the waste, thereby reducing the toxicity of the waste and improving the handling properties of the waste at the landfill. To achieve this, a process should include a physico-chemical interaction between the reagent and waste, rather than just a dilution.

These stabilisation methods make use of both the precipitation of metals in new minerals as well as the binding of metals to minerals by sorption. The process includes some sort of solubilisation of the heavy metals in the material and a subsequent precipitation in or sorption to new minerals.

The physical mechanisms used in stabilisation are: macro-encapsulation, micro-encapsulation, absorption, adsorption, precipitation and detoxification. There is an extensive range of sorbents and binders available for such purposes. Some of the most commonly used are: cement, pozzolans (alumino-silicious material that reacts with lime and water), lime, soluble silicates, organically modified clays or lime, thermosetting organic polymers, thermoplastic materials and vitrification (in-situ or in-plant).

In many cases, both types of reagents (chemical reagents as mentioned three paragraphs above) and sorbents and binders (as mentioned in the above paragraph) are used simultaneously.

Solidification

Uses additives to change the physical properties of the waste (as measured by its engineering properties such as strength, compressibility, and/or permeability). The term ‘solidification’ (and encapsulation or fixation) relate to the mixing of wastes with a reagent (pulverised fuel ash; cement, lime; blast furnace slag; cement kiln dust; organic binders such as bitumen/asphalt or paraffin; and polyethylene) to produce a solid waste form (with low porosity and low permeability matrix) for landfill disposal. Substances are either adsorbed to the reagent or trapped within the waste form. The output should possess a high resistance to chemical and biological degradation processes that could lead to the release of contaminants.

The addition of cement, for example, generally decreases the hydraulic conductivity and porosity of the material, and in addition increases tortuosity, durability, strength and volume. However, it usually increases the pH and alkaline capacity of the mixture, therefore improving the leaching behaviour of the product (e.g amphotheric metals, some organic compounds). In some cases, depending on the binder, solidification may result in chemical changes of the material matrix.

In summary, the fixation and insolubilisation of the pollutants is realised by means of four mechanisms: precipitation, complexation, encapsulation and adsorption.

Feed and output streams

This technology is applied for many inorganic wastes (typically hazardous waste) present in industry such as:

- pasty waste and slurries containing inorganic components (heavy metals, etc.) and small amounts of non-soluble organics (policyclic aromatics, fuel waste, etc.) For example, complex liquid and solid waste contaminated with heavy metals (Cu, Pb, Cd, Hg, Cr, etc.)
- solid and dry waste with inorganic components (in this case hydration water must be added). For example, contaminated soil and filter cakes; refuse with very few non-soluble hydrocarbons; bottom ashes and slag; FGT waste
- solidification is sometimes used for mixing various viscous liquids, such as glues and pastes, with sawdust to produce a solid crumb suitable for landfill. Such practice is not allowed, on landfill sites, in some countries, such as France, Germany and the Benelux Union. In some cases, such components are mixed with cement and lime or other suitable binder material.

Wastes that are legally not accepted by the Landfill Directive to be treated by immobilisation on installations located on landfill sites, are liquid wastes, waste containing toxic components, volatile compounds, foul smelling components or explosives. Key issues for immobilisation include: the suitability of the waste, the process control, the emissions generated and the output specification. Under the Landfill Directive (EC/33/2003) and its annexes, the output specification needs to be aligned with the acceptance criteria for the receiving landfill, which are developed by the European Technical Adaptation Committee and which will cover leachability, physical stability and reaction with other wastes. Their transcription into national legislation is due by the end of 2005.

The resulting output of solidification can either be landfilled or allowed to solidify in a holding area prior to landfill. The final stabilised/solidified waste is usually landfilled directly or sometimes cast into blocks (e.g. at a size of 1 m^3) before landfilling.

Process description

The process typically comprises storage of the reagents, a reaction vessel and in some cases the addition of water. Figure 2.9 shows a representation of a typical immobilisation process.

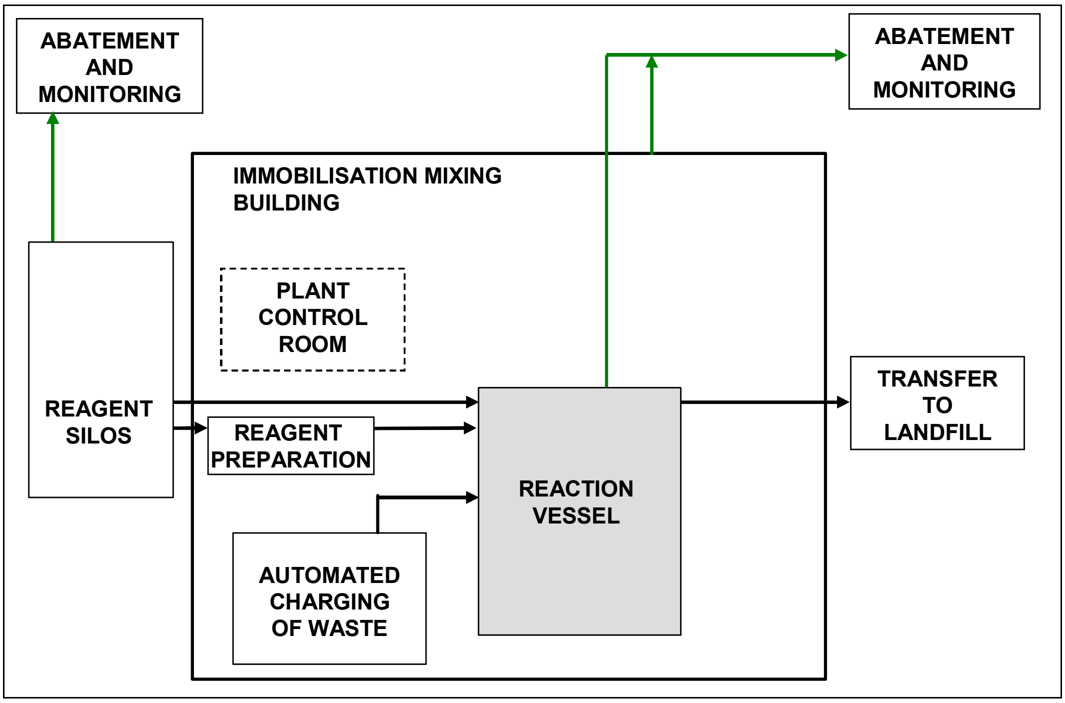


Figure 2.9: Representation of an immobilisation process
[55, UK EA, 2001]

Several of the stabilisation methods have an initial washing step, where a major part of soluble salts and to some extent metals are extracted before chemical binding of the remaining metals. These methods are finalised by dewatering the stabilised product, which will then be ready for landfilling.

Two solidification processes are widely used: a) cement solidification (the most prevalent solidification technique), based on mixing waste with cement, and b) special hydraulic binder processes, which are chemical processes, aimed at developing bonds between the binder and the waste. Another technique, also in large-scale use, includes, e.g. the curing of fly ash waste with aqueous neutral or acidic liquors to give a granular output prior to landfill.

Users
Immobilisation treatments (both stabilisation and solidification) are applied to:

- remediation of hazardous waste sites
- treatments of waste from other treatment processes (e.g. ash from thermal treatments, residues from end-of-pipe techniques)
- treatment of contaminated land where large quantities of soil containing contaminants are encountered.

In several EU countries stabilisation/solidification is not an issue at all due to their national legislation. In these cases, a lot of wastes do not need any such treatments to respect the parameters of the annexes of the EU Landfill Directive or national legislation.

Radioactive wastes have been encapsulated using cement/pulverised fuel ash and bottom ash (slag) for more than 30 years. However, radioactive materials are explicitely excluded from the IPPC Directive.

2.3.3.6 Dewatering

Purpose
Sludge dewatering increases the dry solids content of sludge producing a ‘solid’ waste. It is a grey area as to when a liquid sludge becomes a solid waste; however, any sludge typically over 10 % dry solids becomes difficult and expensive to pump.

Principle of operation
Dewatering at ratios typically higher than 10 % will first require some form of chemical conditioning to assist in the separation of the bound and entrained water from within the sludge. There is a wide range of high molecular weight polymeric flocculants that are particularly effective at improving dewatering performance.

Feed and output streams
Dewatering produces a sludge ‘cake’, which may be between 20 – 50 % dry solids, and an aqueous waste stream. Overall disposal costs would be expected to be reduced in cases where the aqueous waste stream requires no, or minimal, additional processing to remove contaminants.

Process description
A number of sludge dewatering processes exist and selection depends upon the nature and frequency of the solids produced, and the sludge cake required, e.g.

- filter (or plate) presses, which are batch processes and can be manually intensive. A filter press can produce up to 40 % dry solids cake
- the belt press, which is a continuous process with the filter cloth continually running through rollers that forcefully dewater the sludge. A belt press can produce up to 35 % dry solids cake
- centrifuges, also continuous processes that can produce a cake of up to 40 % dry solids for certain sludges. Because of the shear forces, it can break up the solid particulates
- filter drums.

Users
The majority of sites use filter presses on the sludge from the treatment plant and then send the aqueous fraction through clarification or DAF units prior to sewer discharge. Excess solids are returned to the treatment tanks.

2.3.3.7 High temperature drying

Purpose
The aims of the process are the following:

- removal of the water content from the wastes; making recycling economically viable
- concentration of the waste components (e.g. metal compounds); the heating value is considerably raised
- elimination of the problems with handling paste-like substances, as drying the waste transforms it into granulate material
- use of the waste heat in other processes, e.g. distillation
- the dissipated plume gives the necessary moisture to the biofilter.

Principle of operation
The input substances that are to be dried are provided by the gathering chain conveyor and put into the revolving tube drum in single portions. The residence time of the input substances in the drier and thus the dryness of the granulated product can be regulated by hydraulic adjustment of the tube angle. The energy required for the drying process is drawn from the waste heat of the incinerator. The air needed for cooling the flue-gases is cooled down to 150 ºC in air-air heat exchangers.

Up to 30000 m^3/h drying air (maximum 100 ºC) flow through the revolving tube countercurrently to the moist input. The heat is used for the evaporation of the water. The plume is extracted by suction via a dust filter and directly transferred to the biofilter. Hereby, a slight negative pressure is created in the dryer who prevents effectively the leakage of dust into the environment. The granulated dry product is discharged automatically by the rotation of the drum and filled into big bags or other containers.

Feed and output streams
Sludges are dried and transformed into granulated material.

Process description
Drying consists of the following processes:

- warm air supply controlled by temperature and differential pressure
- hydraulically adjustable revolving tube drum
- gathering chain conveyor for charging
- dust filter with 300 m^2 filter area
- plume dissipation towards biofilter by means of induced draft fan
- measurement technique (e.g. dust, temperature, pressure, volume flow and moisture)
- process control system.

2.3.3.8 Thermal distillative drying plants

Purpose
To process materials which cannot be accepted by hazardous waste incineration plants or hazardous waste landfill sites without complex prior conditioning.

Principle of operation
The input material is first crushed in the plant under inert conditions and bunkered. The released propellants are transferred to the high temperature incineration plant or to the biofilter. Afterwards, treatment is carried out in order to distillate the fluids from the input material.

Feed and output streams
Solid/paste like hazardous wastes which contain considerable amounts of free or bound fluids are treated. Both the solid and the fluid products that leave this facility may be recycled, thermally used, incinerated or landfilled.

Process description
The process consists of two parts: materials handling and crushing; and thermal distillation.

- Material handling and crushing:
  - lift-tilt installation for containers
  - inertable crusher
  - gathering conveyor
  - CO_2 fire extinguisher and inerting facility
  - discharge of solids with load container and carrying chain conveyor.

- Thermal distillation:
  - reactor and vacuum slider
  - plume filter and circulation fan
  - plume superheater
  - condensers, product coolers, product containers and phase separation
  - vacuum pump station
  - vapour, inert gas and cooling water distribution
  - exhaustive security measures
  - control system with two work places and one computer for data collection.

The containers are transported from the high rack storage area to the facility and individually emptied into the feeding hopper of the crusher. After crushing, the input material is stored under a CO_2 atmosphere on an inerted gathering conveyor. This is carried out until the quantity necessary for processing is reached in the mixing reactor (maximum 3 m^3) and the reactor is prepared for take-up of the next load. The waste solvent vapours released at the crusher are specifically drawn off in order to prevent the production of explosive mixtures in the hall. The drawn off air is fed to the biofilter as well as the exhaust air from the vacuum pumps.

If the mixing reactor has been re-inerted after emptying of the previous load, it can be charged by the gathering conveyor. After charging, the mixing reactor and the pipe system are pressurised by the vacuum pumps to 400 mbar. Then, the circulation fan is powered up. The nitrogen from inerting and the created plumes can then be run over the superheater where they are heated up to 450 ºC. Afterwards, they flow into the reactor where they heat up and dry the input material. The heating period may, if necessary, be supported by fresh vapour from a boiler. Vacuum control keeps the maximum pressure in the facility approximately at 100 mbar, below that of the ambient air.

At the end of the drying process; i.e. when the maximum temperature of 180 to 200 ºC is reached in the reactor, in the plume filter or in the circulation fan; the facility is evacuated to a pressure of <100 mbar. This is carried out in order to evaporate the remaining solvent residues and to cool the dried material. To keep the emissions of the dried material low at discharge, cooling water is added directly to the dried material. Here, it immediately evaporates under vacuum and thus cools the dry product down to the discharge temperature of 50 to 60 ºC. The condensate is recovered by the in-house distillation facility directly after phase separation or after treatment. Solvent fractions that cannot be recycled may be thermally utilised or incinerated in the in-house high temperature incineration facility.

2.3.3.9 Thermal desorption

Purpose
To separate relatively volatile compounds from solid waste.

Principle of operation
In the thermal desorption process, volatile and semi-volatile contaminants are removed from soils, sediments, slurries, and filter cakes. Typical operating temperatures are between 175 - 370 °C, but temperatures from 90 to 650 °C may be employed. Thermal desorption promotes physical separation of the components rather than combustion.

Feed and output streams
Soils contaminated with non-biodegradable organic compounds, soil contaminated with petroleum fuels, soil contaminated with hazardous wastes and tar containing asphalt or similar waste are the types of waste processed by this treatment. The contamination is transferred to a further treatment.

Thermal desorbers effectively treat soils, sludges, and filter cakes and remove volatile and semi-volatile organic compounds. Some higher boiling point substances such as PCBs and dioxins may also be removed (if present). Inorganic compounds are not easily removed with this type of process, although some relatively volatile metals such as mercury may be volatilised. The temperatures reached in thermal desorbers generally do not oxidise metals.

Process description
After contaminated soil is excavated, the waste material is screened to remove objects greater than 4 to 8 cm in diameter. Direct or indirect heat exchange vaporises the organic compounds, producing an off-gas that is typically treated before being vented to the air. In general, any one of four desorber designs are used: rotary dryer, asphalt plant aggregate dryer, thermal screw, and the conveyor furnace. The treatment systems include both mobile and stationary process units designed specifically for treating soil, and asphalt aggregate dryers that can be adapted to treat soils. Mobile systems are most often used, due to reduced soil transportation costs and to allow for backfilling of the treated soil. However, stationary systems are also available and it may be feasible to provide regional services. The desorbed gases may be incinerated.

Users
Treatment of contaminated soils and tar containing asphalt and similar waste.

2.3.3.10 Vapour extraction

Purpose

Vapour extraction can be used as a method for treating solid waste, e.g. excavated contaminated soil, with volatile hydrocarbons.

Principle of operation

In general terms, vapour extraction removes volatile organic constituents from contaminated waste by creating a sufficient subsurface airflow to strip contaminants from the vadose (unsaturated) zone by volatilisation. As the contaminant vapours are removed, they may be vented directly to the air or controlled in a number of ways.

Feed and output streams

Vapour extraction has been widely used to treat excavated soil contaminated with gasoline or chlorinated solvents (e.g. TCE). It is also sometimes used to minimise the migration of vapours into structures or residential areas during some other in-situ remediation not covered in this document.

Spills or leaks of fuels typically involve liquids containing dozens of different constituents. For removal by this treatment to be effective, the contaminants must generally have vapour pressures greater than 1.0 mm Hg at - 7 °C. Complete removal of contaminants may not be possible with this technique alone.

Process description

The success of the treatment for a given application depends on numerous factors with the twoe key criteria being: the nature of the contamination and the nature of the waste (e.g. soil). The tendency of the organic contaminants to partition into water or to be adsorbed onto soil particles also affects its effectiveness, and hence the compound's water solubility, Henry’s Law constant, and the sorption coefficient to the solid waste are of interest. The temperature affects each of these variables and hence, the rate of vapour diffusion and transport. Increasing the temperature is one option commonly considered for enhancing the treatment performance. Solid waste can be heated in one of three ways: 1) introduction of heated air or steam, 2) input of electromagnetic energy through the waste, or 3) heat release through a chemical reaction. The use of heated air or steam appears to be the most widely used approach.

Typical systems include extraction, monitoring, air inlet, vacuum pumps, vapour treatment devices, vapour/liquid separators, and liquid-phase treatment devices.

Users

Vapour extraction has been used successfully for several years as a combined two-phase treatment of both groundwater and contaminated soil, and is increasingly being employed. Although this treatment may be used for a variety of soil types, its effectiveness depends on the ability of air to flow through the soil.

2.3.3.11 Solvent extraction

Purpose

‘Solvent extraction’ is much more effective for treating organic compounds than inorganic compounds and metals. It can be used in conjunction with other processes to reduce remediation costs.

Principle of operation
Solvent extraction differs from soil washing in that it employs organic solvents (e.g. propane, butane, carbon dioxide, aliphatic amines (e.g. triethylamine)) rather than aqueous solutions to extract contaminants from the soil. Like soil washing, it is a separation process that does not destroy the contaminants. It works as the contaminants will have a greater solubility in the solvent than in the soil.

Feed and output streams
Sediments, sludge, and soils contaminated with volatile organic compounds (VOCs), petroleum wastes, PCBs, and halogenated solvents can be effectively treated with solvent extraction. The removal of inorganic compounds such as acids, bases, salts, and heavy metals is limited, but these types of compounds usually do not hinder the remediation process. Metals may undergo a chemical change to a less toxic or leachable form, however their presence in the waste streams may still restrict disposal and recycle options.

Whilst these separation processes may be more effective in treating soils contaminated with petroleum fuels, they are generally employed to treat soils containing metals or heavy organic compounds.

The concentrated contaminants can be analysed and subsequently designated for further treatment, recycling, or re-use before disposal. While solvent extraction may improve the condition of the solids, often they may still need dewatering, treatment for residual organic compounds, additional separation, stabilisation, or some other treatment. The water from the dewatering process, the solids, and the water from the extractor will need to be analysed to aid in the choice of the most appropriate treatment and disposal.

Process description
The remediation process begins with excavating the contaminated soil and feeding it through a screen to remove large objects. In some cases, solvent or water is added to the waste in order to aid pumping it to the extraction unit. In the extractor, solvent is added and mixed with the waste to promote the dissolving of the contaminants into the solvent. Laboratory testing can determine which solvent adequately separates the contaminants from the soil. Generally, the solvent will have a higher vapour pressure than the contaminants (i.e. a lower boiling point) so that with an appropriate pressure or temperature change, the solvent may be separated from the contaminants, compressed, and recycled to the extractor.

Users
Treatment of contaminated soil.

2.3.3.12 Excavation and removal of contaminated soil

Purpose
Excavation activities may be carried out in isolation but are also typically carried out as part are of the on-site treatment processes such as incineration, thermal desorption, ex-situ biotreatment, and certain physico-chemical treatments.

Principle of operation
If removal of the contaminated soil is the selected remedy, the excavated soil is typically transported off site for subsequent disposal in a landfill.

Feed and output streams
Contaminated soils and decontaminated soil.

Process description
Typical civil engineering machinery is used.

Users
The excavation and removal of soils contaminated with fuels is a common practice.

2.3.3.13 Soil washing

Purpose
Soil washing is carried out to separate the decontaminated fractions and pollutants.

Principle of operation
Soil washing is an ex-situ process in which contaminated soil is excavated and fed through a water-based washing process. It operates on the principle that contaminants are associated with certain size fractions of soil particles and that these contaminants can be dissolved or suspended in an aqueous solution or removed by separating out clay and silt particles from the bulk soil. Additives such as surfactants or chelating agents are sometimes used to improve the separation efficiency (the treatment using additives may be referred to as chemical extraction). The aqueous solution containing the contaminants is treated by conventional waste water treatment methods.

The process is a water-based process and removes contaminants from soils in one of two ways:

a. by dissolving or suspending them in the wash solution (which is treated later by conventional waste water treatment methods)
b. by concentrating them into a smaller volume of soil through particle size separation, gravity separation, and attrition-scrubbing (similar to the techniques used in the mineral processing industry).

The concept of reducing soil contamination through the use of particle size separation is based on the finding that most organic and inorganic contaminants tend to bind, either chemically or physically, to clay, silt, and organic soil particles. The silt and clay are attached to sand and gravel particles by physical processes, primarily compaction and adhesion. Washing processes that separate the fine (i.e. clay and silt) particles from the coarser (i.e. sand and gravel) soil particles effectively separate and concentrate the contaminants into a smaller volume of soil that can be easier further treated or disposed of.

Feed and output streams
Soil washing is effective for a wide range of organic and inorganic contaminants, including petroleum and fuel residues. Removal efficiencies range from 90 – 99 % for volatile organic compounds (VOCs) and from 40 – 90 % for semi-volatile compounds. Compounds with low water solubilities such as metals, pesticides or PCBs sometimes require acids or chelating agents to assist in the removal. Some pilot scale projects on radionuclides pollution treatment have been reported. The washing process is also applicable for contaminated sand and gravel from construction and demolition waste.

While these separation processes may be more effective in treating soils contaminated with petroleum fuels, generally they are employed to treat soils containing metals or heavy organic compounds.

Soil washing may can be effective for the remediation of soils with a small amount of clay and silt particles, but large amounts of clay and silt particles mitigate the effectiveness of soil washing.

Process description
The excavation and removal of debris and large objects precedes the soil washing process. Sometimes water is added to the soil to form a slurry that can be pumped. After the soil is prepared for soil washing, it is mixed with wash-water, and extraction agents are sometimes added.

After separation from the wash-water, the soil is rinsed with clean water and may be returned to the site. The suspended soil particles are removed by gravity from the wash-water as sludge. Sometimes flocculation is used to aid in sludge removal. This sludge is more highly contaminated than the original soil and undergoes further treatment or secure disposal. The spent wash-water from which the sludge is removed is treated and recycled. Residual solids from the recycling process may require further treatment.

Figure 2.10 presents a general flow scheme of a soil washing plant.

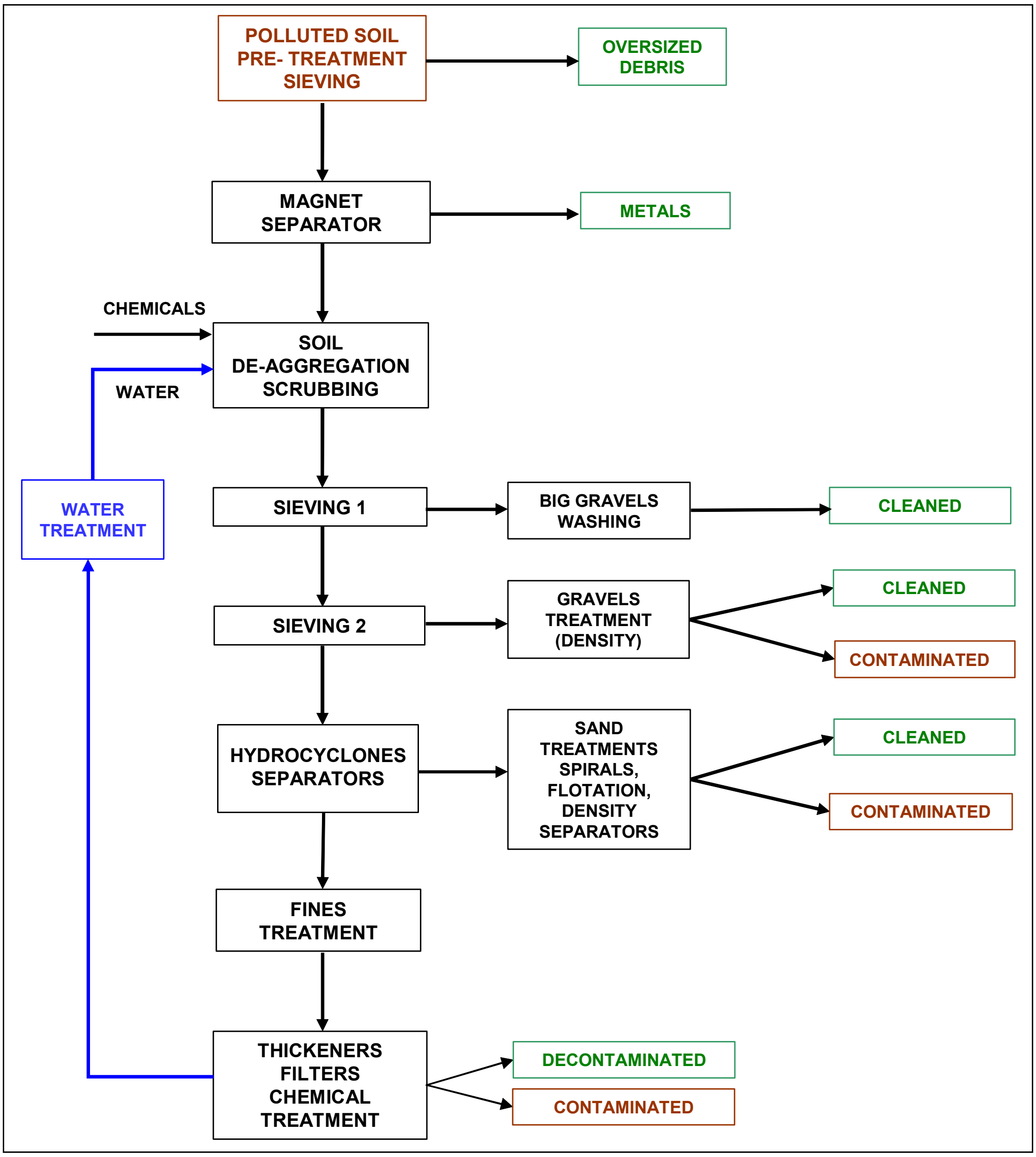


Figure 2.10: General flow scheme of a soil washing plant
[123, Perseo, 2003]

Typically, soil washing segregates a soil into a small volume of highly contaminated silt and clay and a larger volume of cleaned coarser soil.

Physical separation methods are mechanical methods for separating mixtures of solids to obtain a concentrated form of some constituents. Physical separations include screening, attrition scrubbing, or using hydrogravimetric separators as such hydrocyclones, jigs, spiral classifiers. In addition, in the majority of cases, the processes use water based chemical agents, which provide both dispersion and extraction. Chemicals (dispersants, collectors, frothers, etc.) may be added in some cases to enhance the quality of the separation.

Users
The soil washing technique is very well established in the Netherlands, Germany and Belgium, due to the sandy structure of the local soils. In 2003, eight plants in the Netherlands, six in Germany and six in Belgium were in operation. The technology is starting to become more developed in Switzerland and in northern Italy. Most plants have a capacity of 30 - 60 tonnes an hour. Furthermore, numerous on-site remediation projects have been performed with mobile plants, presenting usually smaller capacities (from 10 to 30 tonnes per hour).

2.3.3.14 Treatment of asbestos

Waste contaminated with asbestos are actually landfilled in the EU, however new techniques are appearing in order to treat them prior to landfill disposal.

2.3.3.15 Bottom ash treatment

Purpose
Improves the slag/bottom ash quality and therefore can help to improve its opportunities to be used as construction material.

Good bottom ash treatment facilities can produce a good quality material mainly scrap metal and mineral fractions. The residues from the treatment constitute 1 – 5 %. The residues are going back to the incineration. In addition, it is reduced the amount of heavy metals and e.g. arsenic (salt) that is emitted to the environment. Thus, the bottom ash treatment reduces the mass of waste to be landfilled.

Principle of operation
Bottom ash treatment plants exist in two types: wet and dry process.

Feed and output streams
Bottom ash from incinerators and other combustion processes.

Process description

The following points describe some general measures which can be taken to help to improve the quality of slag for re-use after it has been generated (i.e. after the incineration and after the drying process). These include (no order is suggested with this list):

- separating the bottom ash from all other burning products, such as filter and boiler dust, with the intention to reduce the leaching possibilities of the waste (e.g reducing leaching of heavy metals)
- avoiding mixing bottom ash from different sources
- removal of some of the organic material that it has not been entirely incinerated. Afterwards, incinerating this organic material removed. It is typically applicable when the waste OUT is used as a building material
- dewatering the bottom ash (it is commonly dried by storing it for a period of 2 - 4 weeks); this process requires a solid base (such as a concrete surface) and a collecting system for the effluent
- utilising a preliminary washing process to reduce the easily water soluble fraction of the bottom ash
- separating the scrap metal fraction from the bottom ash
- classifying and excluding the fine fraction from the bottom ash (the fine faction is the most problematic fraction for the environment as it leaches out easily). Excluding the small fraction from the bottom ash leads to more landfilling, since there are no real alternatives for such fraction
- ageing the bottom ash. This improves the consistency and reduces adverse leaching effects. A ventilation system and an installed water circulation system can allow a better bottom ash quality
- analysing the eluate and the solids to assess the recovery possibilities of the material.

The ageing processes require a solid base and a collecting system for effluents. The common aging time is up to 3 months. The end of the ageing process is noticeable by specific temperature changes. The sieving, separation and wet preparation of the bottom ash are important steps to achieve a good result.

Two different types of bottom ash analysis are possible. The first method analyses the available mobile compounds (eluate analysis (i.e. leachate)) of the bottom ash fraction. The second method analyses the complete compounds of the bottom ash (solid analyses). It is common to use both methods in parallel to define the environmental effects of the bottom ash. However, the eluate analysis is more important with assessing the possibility of material recovery.

Users

These techniques are seen by some Authorities as an important step to decrease the use of landfill. The amount of bottom ash from burning processes will rise, as probably the incineration of waste in Europe will become more common. Not only is the reduction of waste to disposal an environmental benefit, but it is also considered the re-use of the metal scrap fraction.

The wet process shows advantages concerning chloride-salts and final copper leaching, but is not compulsory in order to reach a bottom ash quality that allows re-use as a construction material in e.g. NL and DE.

2.3.4 Unit operations used in the physico-chemical processing of waste solids and sludges

This section contains common physico-chemical techniques used in the waste treatment sector. They are mainly common unit operations. They have been tabulated in Table 2.9, which gives the purpose and principle of the treatments and their main users.

Technique	Purpose and principle of operation	Users
Adsorption	See Table 2.8	
Centrifuging	See Table 2.8	Applied to liquid waste. Centrifuging is typically used together with recovery of the organic phase
Decanting	The principle of operation is the density difference of the different components to separate	Applied to liquid waste (e.g. separation of two inmiscible liquids, recovery of liquid layers after separation of suspended solids or biological/chemical flocs)
Drying	Thermal drying as evaporation	Applied to contaminated soils, sludges
Extraction	See Table 2.8	
Filtration	See Table 2.8	
Flotation	See Table 2.8	Flotation is used on liquid waste when gravity settlement is not appropriate. It occurs when: • the density difference between the suspended particles and water is too low • there is a space constraint at the site • the waste contains oil or grease that needs to be removed before treatment • recovery of the sludge is required
Metal recovery		
Oil separation processes	See Table 2.8	Gravity separation of soluble oils and oil/water mixtures
Oxidation	See Table 2.8	The chemical oxidation of wastes is a well-established technology that is capable of destroying a wide range of organic molecules, including chlorinated organic carbons, VOCs, mercaptans, phenols, and inorganics such as cyanide. The most common oxidising agents used for hazardous waste treatments are ozone, hydrogen peroxide, and chlorine. Ultraviolet (UV) light is usually added along with ozone and/or hydrogen peroxide to accelerate the oxidation of chlorinated VOCs. It is a very common pretreatment operation at many plants, but has a variety of technologies
Scrubbing	Air scrubbing	
Sedimentation (settlement)	See Table 2.8	Applied to liquid waste. Sludges liberated from a settlement stage are typically around 1 % dry solids content
Stripping	See Table 2.8	*Air stripping* is one of the most commonly used processes for separation of waste water contaminated with VOCs, such as solvents. It can be used to remove the halogenated or non-halogenated hydrocarbons from dilute aqueous solution. Solutions high in ammonia can also undergo such pretreatment to reduce the concentration of ammonia. *Steam stripping* is utilised for the removal of volatile and sometimes semi-volatile compounds from waste water.

Technique	Purpose and principle of operation	Users
Supercritical treatments	Extraction and/or oxidation of pollutants from contaminated water or sediments. Supercritical fluids (e.g. carbon dioxide, water, ammonia, cyclohexane) are materials at elevated temperature and pressure that have properties between those of a gas and a liquid. In extraction, the organics in soils, sediment or water are dissolved in the fluid at elevated temperatures and pressure conditions and are then released from the extraction at lower temperatures and pressures. In supercritical water oxidation, air and contaminated water are brought together above the critical point of water and the complete oxidation of organic compounds occurs rapidly	Treatment of POPs
Water reactive chemicals pretreatment	These are scrubbed in a caustic solution and both treated liquors and scrubber liquors are treated in the main plant	The pretreatment of materials such as thionyl chloride, acetyl chloride, silicon tetrachloride with water to liberate acid gases
* The thermal treatments covered are those not included in the WI BREF		

Table 2.9: Common unit operations used in physico-chemical treatments
[53, LaGrega, et al., 1994], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [150, TWG, 2004]

2.3.5 Physico-chemical treatments of other wastes

Physico-chemical treatment of wastes containing POPs

Three ways have been identified for the destruction and irreversible transformation of the POP content in wastes [154, UNEP, 2004]. One is the incineration on land (not covered in this document but in the waste incineration BREF that also covers plasma techniques), another is the use of waste as fuel (e.g. co-incineration in cement kilns not covered in this document) and last one is the physico-chemical treatment of waste. This section concentrates on those physico-chemical treatments related to these very specific types of waste (e.g. waste containing PCBs, dioxins, furans) and they are summarised below in Table 2.10.

Technique	Principle of operation	Feed and output streams	Process description
Dechlorination with metallic alkali	Reaction of metallic alkali with chlorine atoms contained in the chlorinated compounds	Waste IN: PCB oils Waste OUT: organic compounds (oil which may be re-used) and salt	The dispersion is carried out at a temperature above that of the melting point of the sodium, i.e. 98 °C. Being liquid, the metal surface can be renewed continuously. In this way a reasonable reaction rate can be achieved, thus decreasing the cost of the decontamination process. The process must avoid the formation of polymer (which occurs in one or two of the technologies identified) or must take the formation of this solid into account and introduce a separation step to yield the pure re-usable oil
Hydrogenation of POPs	Hydrogen reacts with chlorinated organic compounds or non-chlorinated organic contaminants, such as (PAHs), at high temperatures	Waste IN: transformer fluids; bulk PCB solids, including electrical capacitors; and high strength DDT waste pesticide mixtures Waste OUT: primarily methane and hydrogen chloride for PCBs and methane and minor amounts of light hydrocarbons for PAHs	Typical process used in mineral oil refineries and carried out at temperatures of 850 °C and higher. This technique converts approximately 40 % of the methane produced to hydrogen, via the water shift reaction, and the remaining part to hydrogen in the catalytic steam reformer. In this way, the process can operate without an external supply of hydrogen. For highly concentrated wastes, the process produces an excess of methane. It uses draw combustion air from off-site or ambient air on-site after first filtering it through active carbon, for the combustion process
Solvated electron process	Free electrons in a solvated electron solution convert contaminants to relatively harmless substances and salts	Waste IN: halogenated organic compounds, including PCBs, dioxins, pesticides, chlorofluorocarbons (CFCs) and chemical warfare agents. Waste OUT: decontaminated soils are said to be suitable for returning to the site, and as an additional benefit enriched in nitrogen from the trace amounts of residual ammonia	This technique uses an alkali or alkaline earth metal dissolved in a solvent such as ammonia, or certain amines or ethers to produce a solution containing free electrons and metal cations. Destruction efficiencies vary from 86 to 100 %. Chlorine and other halogens are selectively stripped from organic halides by free electrons and captured by the metal cations to form salts (e.g. $CaCl_2$). For example, a PCB molecule can be converted to biphenyl in a rapid reaction at ambient temperatures.
Supercritical water oxidation	A high temperature and pressure technique that uses the properties of supercritical water in the destruction of POPs	Waste IN: wastes containing organic compounds and toxic wastes Waste OUT: carbon dioxide; hydrogen to water; the chlorine atoms derived from chlorinated organic compounds to chloride ions; nitro-compounds to nitrates; sulphur to sulphates; and phosphorus to phosphate	Supercritical conditions
Note: Some other treatments outside the scope of this document are available for the treatment of wastes contaminated with POPs. These identified are co-incineration in cement kilns, hazardous waste incineration and plasma treatments			

Table 2.10: Some specific treatments for waste containing PCBs and/or POPs
[100, UNEP, 2000], [154, UNEP, 2004]

Physico-chemical treatments of CFCs

The aim is to treat the waste to transform the CFC in hydrochloric acid and hydrofluoric acid. An example of such plant is shown in Figure 2.11.

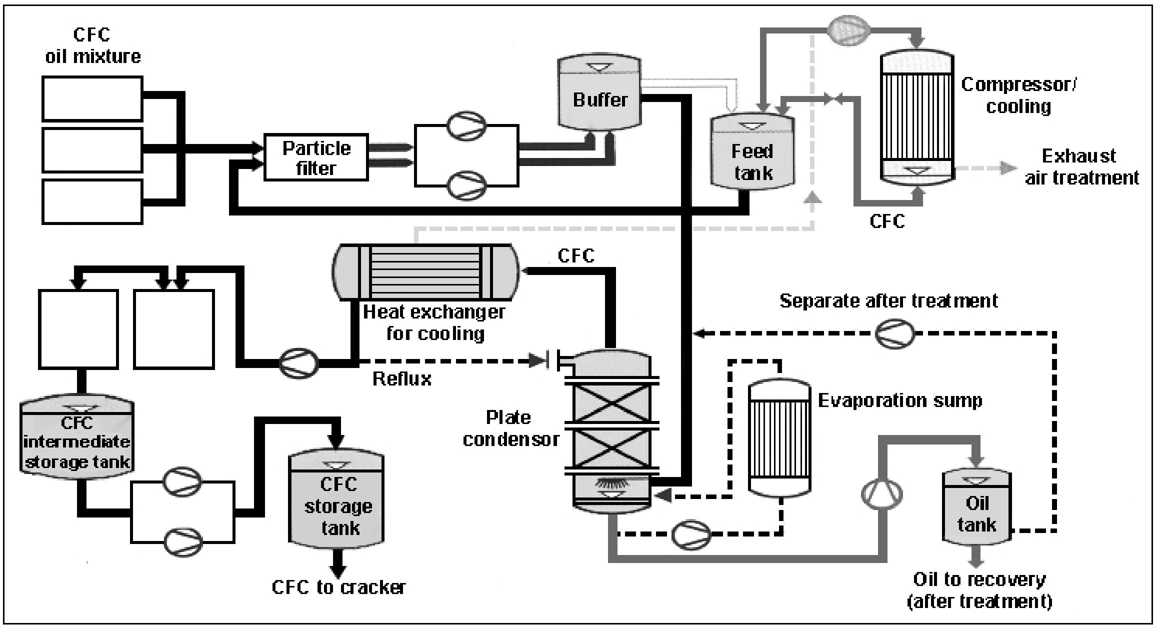


Figure 2.11: Treatment of CFCs to generate hydrochloric acid and hydrofluoric acid [150, TWG, 2004]

Physico-chemical treatment of waste containing mercury

Purpose
The aim is to treat the waste to separate the mercury.

Principle of operation
In the process of vacuum distillation, waste containing mercury is evaporated under vacuum conditions at approximately 300 to 650 ºC. The liquid components (e.g. mercury, water and oil) are distilled from the waste and condensed. In the condensation, a separation is established between the mercury and the distillate. The metallic mercury is drained and possibly refined. The mercury is recycled as a secondary raw material.

Feed and output streams
Sludge containing mercury from the oil and gas production industry, batteries, catalysts, activated carbon filters, thermometers, waste from the dental sector, fluorescent tubes, blasting grit and soil.

The destination of the residue from the vacuum vessel depends on the waste treated. It can be used as a secondary raw material (e.g. for batteries) or landfilled (e.g. in the case of sludge containing mercury).

Process description
The process is shown in Figure 2.12.

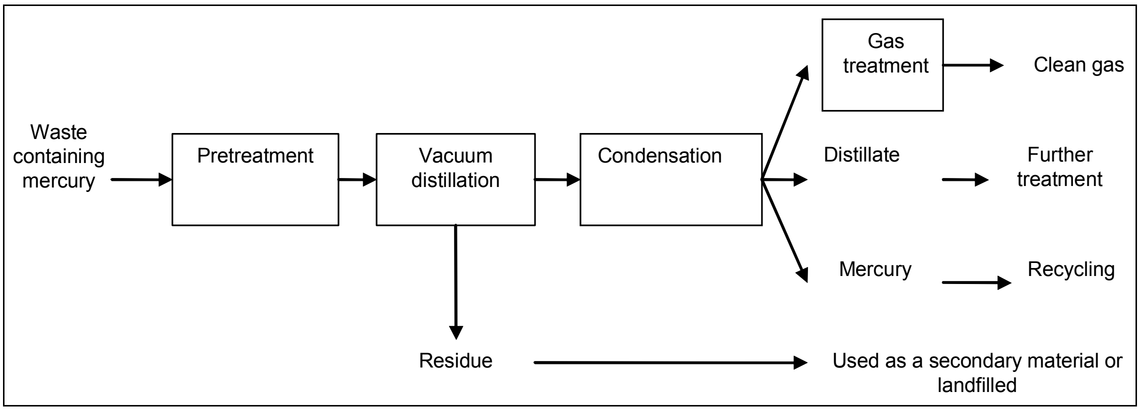


Figure 2.12: Vacuum distillation of waste containing mercury
[156, VROM, 2004]

<u>Users</u>
Used in Sweden, Netherlands and Belgium.

2.4 Treatments applied mainly to recover the materials from waste

This section includes those treatments and processes mainly designed to recover the materials or portions of materials contained in waste. Typically these processes are very dependent on the type of waste treated and the materials that are wanted or that need to be produced. The materials produced from these treatments are materials that can be re-used for the same purpose (e.g. lubricant oils) or recovery for other non-energy purposes (e.g. recovery of metals from catalysts). When the material is treated to be used subsequently as fuel, this is included in the Section 2.5.

'Regeneration' is the term used in this document to describe these treatments except in the case of regeneration of waste oils where the term 're-refining' is used. This is not an attempt to make any kind of definition. This should be taken only as a convention to aid reading this document.

2.4.1 The re-refining of waste oils

[5, Concawe, 1996], [7, Monier and Labouze, 2001], [11, Jacobs and Dijkmans, 2001], [13, Marshall, et al., 1999], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [96, Straetmans, 2003], [150, TWG, 2004], [152, TWG, 2004]

There are two main options for the treatment of waste oils. One is the treatment of the waste oil to produce a material that will be used mainly as fuel or for other uses (e.g. absorbant, mould release oil, flotation oil). These include treatments as cleaning of waste oil, thermal cracking and gasification for example and are covered in Section 2.5.2.4. The other way, is to treat the waste oil to reconvert it to a material that can be used as a base oil to produce lubricants. This latter way is referred to as 're-refining' in this document. This section details the different treatments that are actually applied to waste oils for clean-up and re-refining. As it is the case in the whole document, this classification has been adopted for this document and it is not intended to provide any attempt to define any of the 'R' codes from EC waste legislation.

A lot of treatment processes exist (or are currently under development) today in Europe. The most significant ones are listed below in Figure 2.13. This figure also gives an overview on how these treatments have been included in this document.

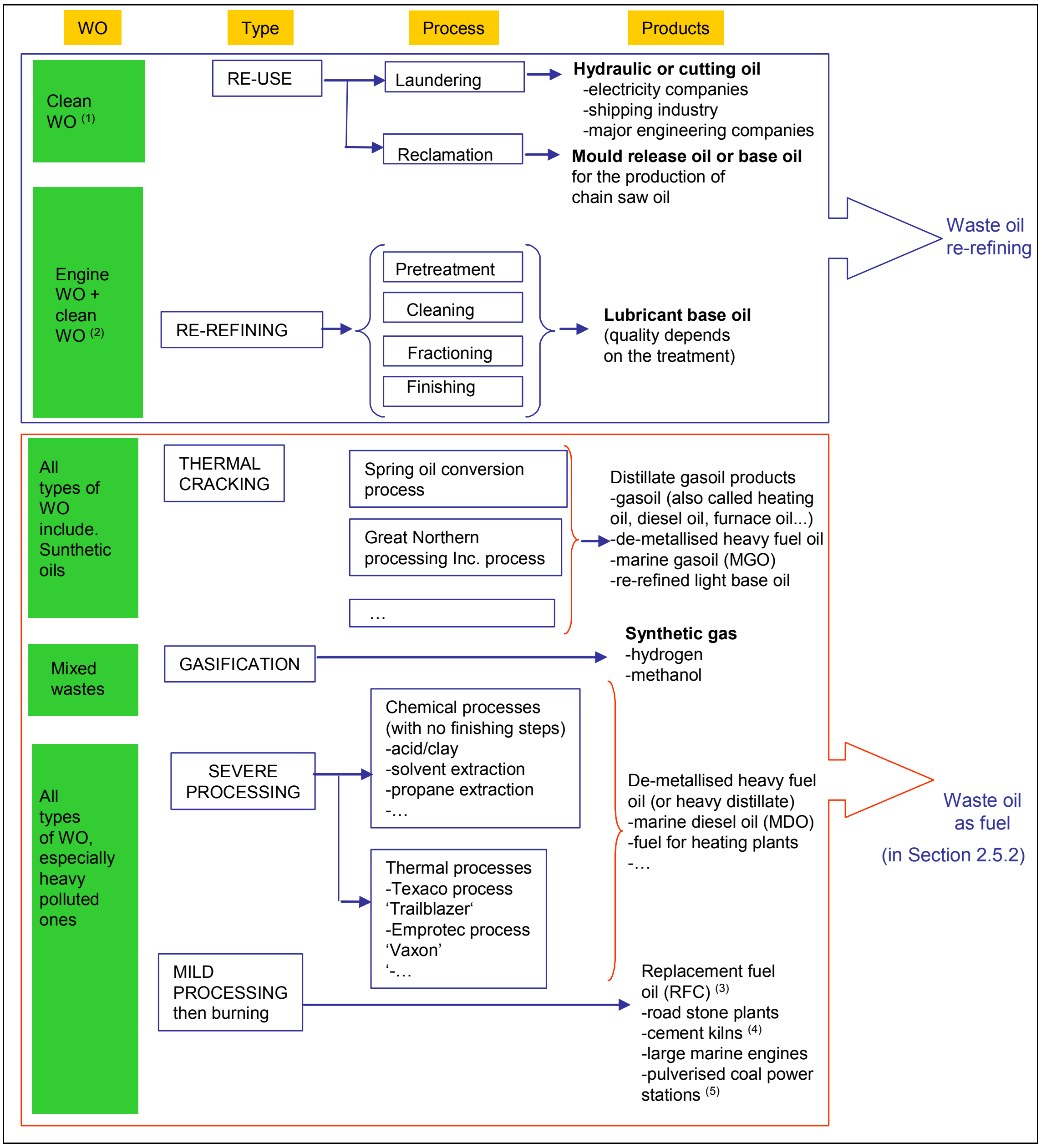


Figure 2.13: Waste oil treatments and division approach used in this document
[7, Monier and Labouze, 2001], [86, TWG, 2003], [150, TWG, 2004]
Note: (1) Especially hydraulic or cutting oil
(2) Engine oils without chlorine + hydraulic oils without chlorine + hydraulic mineral oils + mineral diathermic oils (according to the API classification)
(3) Treated oil still containing the heavy metals, halogen and sulphur contained in the original waste oil (WO)
(4) Substitutes other secondary liquid fuel (SLF) or heavy fuel or coal or petroleum coke
(5) As a furnace start up fuel

To re-use a waste oil to make a lubricant requires cleaning or re-refining in order to make it into a product suitable to be re-used as a base oil to produce a lubricant. These processes involve the removal of impurities, defects and any leftover products from its old use. Generally, this type of process removes all impurities and additives and only base oil then remains. Subsequently, lubricant producers add substances to attain the specifications of a virgin product.

The main processes used in oil recovery plants are shown in Figure 2.14. This is an amalgamation of unit operations. Not all operations are applied in every plant. In practice, most plants only use a few of the processes shown, and usually there are two or more parallel streams from each process.

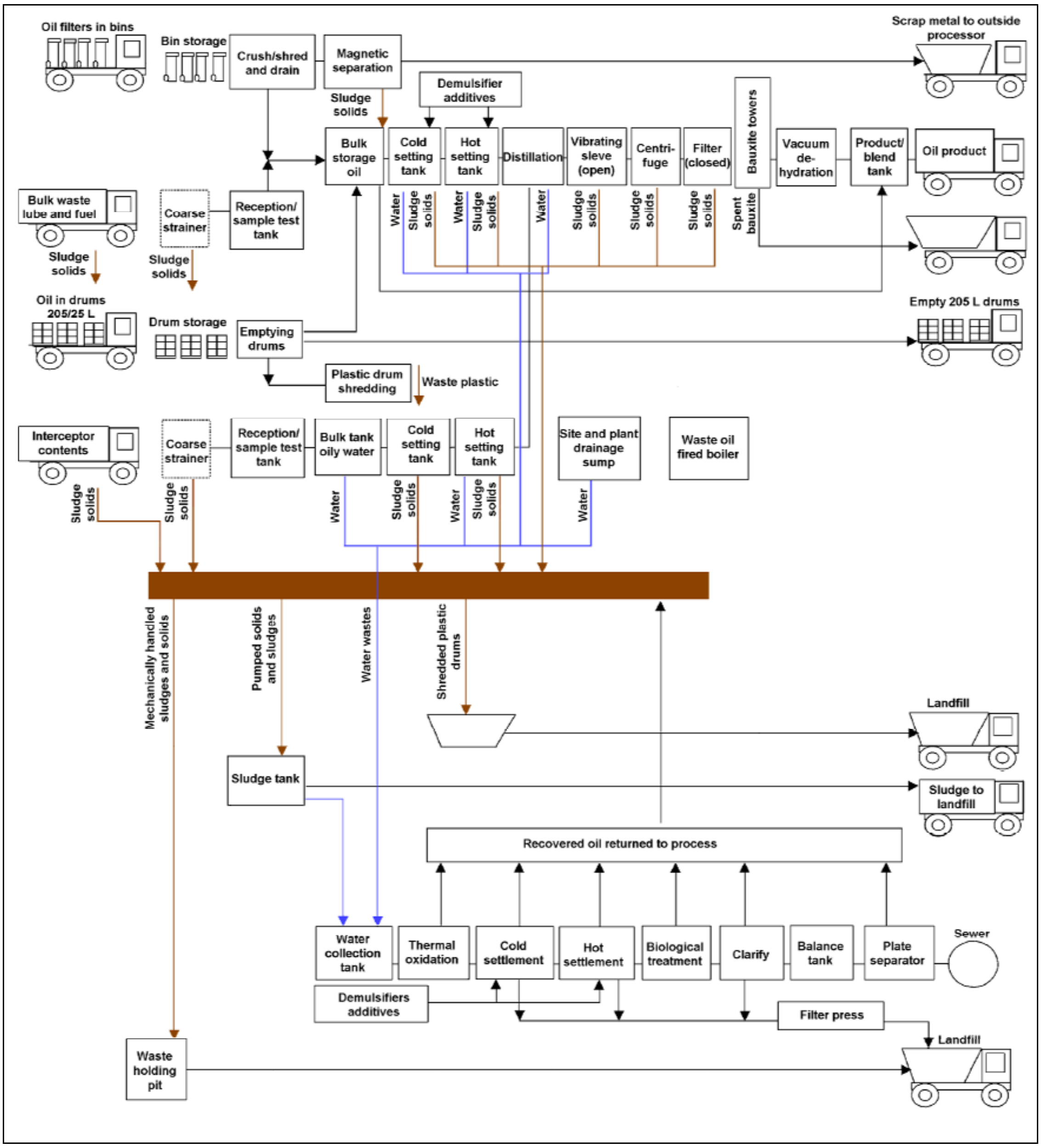


Figure 2.14: Generic flow diagram of waste oil treatment plant
Note: The diagram indicates common treatment elements. Some of these are alternatives and do not all occur in a single installation. Brown lines correspond to waste or sludges and blue lines to waste water.
Based on [56, Babtie Group Ltd, 2002]

Re-refining treatments may differ depending on the technology used for one or several of the following operations: pretreatment, cleaning, fractionation and finishing. Each of these processes are briefly described in the following sections.

2.4.1.1 Pretreatment of waste oil

Purpose
To dewater (removal of water), de-fuel (removal of light ends and fuel traces such as naphtha, etc.) and remove sediments. This pretreatment process is not compared with the other oil treatment systems because it does not yield an end-product, nor does it achieve the final aim of treatment.

Principle of operation
Water and sediments are removed from the waste oil by a simple physical/mechanical treatment. Settling is used in some cases to remove water and sludge from waste oil and in the effluent treatment systems for removing oil and solids from the effluent. Generally, settling takes place using the gravity effect in settling tanks, clarifiers or plate separators, but centrifuges or distillation can also be used.

Feed and output streams
The typical feed is collected waste oil. The product is cleaned waste oil. After this treatment the cleaned oil can be used in one of the options described below (Sections 2.4.1.2 to 2.4.1.4).

Process description
The main techniques used are settling, sedimentation, filtering and centrifuging.

Settling
A tank is filled and left until it settles, the upper oil strata is skimmed off and similarly the water layer is drawn off. Depending on how dirty the feedstock is, the sludge might be left at the bottom of the tank to accumulate over several settlement cycles before it is removed. The settling process is often aided by heating, to reduce the viscosity. In many cases, an interface layer of an oil/water emulsion remains. This can be encouraged to separate by the addition of heat and chemicals. Further settling processes applied to the 'water' layer can separate the oil/water phase even better.

Sedimentation

Filtering/straining
Particulates are removed by strainers, filters or sieves.

Centrifuging

Distillation
Water may be removed by this technique.

Users
Used in many of the waste oil re-refining technologies (see Table 2.12)

2.4.1.2 Cleaning of waste oil

Purpose
Cleaning includes deasphalting and the removal of asphaltic residues: heavy metals, polymers, additives, other degradation compounds.

Principle of operation
Distillation and the addition of acids are the most typical ways to achieve the above results.

Feed and output streams

Process description
Acid cleaning: additives, polymers, oxidation and degradation products are removed by contact with sulphuric acid or precipitated as sulphates (e.g. metals). Clay cleaning is also considered, where the clarified oil is mixed with clay by absorption to remove any polar and undesirable compounds still present.

Users
Used in many of the waste oil re-refining technologies (see Table 2.12).

2.4.1.3 Fractionation of waste oil

Purpose
This involves a separation of the base oils using their different boiling temperatures, to produce two or three cuts (distillation fractions).

Principle of operation
This physical separation process utilises the boiling point differences of components.

Feed and output streams
Typically pretreated waste oil.

Process description
Vacuum distillation units can range in complexity from a simple splitting column to a full fractional distillation column, as used in mineral oil refineries.

Users
Used in many waste oil re-refining technologies (see Table 2.12).

2.4.1.4 Finishing of waste oil

Purpose
Final cleaning of the different cuts (distillation fractions) is carried out to achieve specific product specifications (e.g. improve colour, smell, thermal and oxidation stability, viscosity, etc.). Finishing may also include the removal of PAHs in the case of a severe (high temperature and high pressure) hydrofinishing or solvent extraction (low temperature and low pressure).

Principle of operation and feed and output streams

Technique	Principle of operation	Feed and output streams
Alkali treatment	KOH or NaOH is used	Colour properties are enhanced.
Bleaching earth	This is a tertiary treatment, to remove the black colour from the oil (caused by the carbon breakdown from the additives), so it can visually be compared with virgin base oil.	The new goals, set up by the implementation of upcoming specifications for passenger car motor oils, cannot be achieved. In particular, the colour of the produced oils is darker than required.
Clay polishing	This is a process similar to the acid/clay process but acid is not used. Bentonite is the clay typically used. The clay is then separated from the oil using a filter press.	Generally, clay polishing does not produce the high quality base oils of solvent extraction or hydrotreatment.
Hydrotreatment	Chlorine and sulphur are removed from the waste oil fraction at a high temperature under a hydrogen atmosphere and in contact with a catalyst, being converted into HCl and H_2S. Phosphorus, lead and zinc are also removed in this process. PAHs can be removed by severe hydrofinishing (high temperature and with hydrogen under high pressure)	The quality of the distillates is very high and the petroleum fractions are immediately marketable. Hydrogen is needed for the process. Hydrogen sulphide is formed, which can later be reduced to sulphur.
Solvent cleaning	PAHs are removed from the base oils by extracting them into the solvent (into ppb range). The solvent extraction also improves the colour and viscosity index.	The feed into the extraction must be a good quality base oil with all heavy metals etc. removed and already fractioned into wanted cuts. The products are a high quality base oil, the used solvent which is regenerated, and a small stream of base oil (c. 3 % of the total base oil stream) with a high PAH concentration, which is used as a fuel product.

Table 2.11: Finishing techniques used for the treatment of waste oils
[7, Monier and Labouze, 2001], [86, TWG, 2003], [139, UBA, 2003]

Process description
The hydrotreatment process can be found in the Refinery BREF.

Users
Used in many waste oil re-refining technologies (see Table 2.12)

2.4.1.5 Technologies used for the re-refining of waste oils

Table 2.12 summarises the different technologies used for the regeneration of waste oil.

Technology	**Feed and output streams**	**Process description**			
		Pretreatment	**Cleaning**	**Fractionation**	**Finishing**
Laundering	Transformer oils, industrial lubricants (e.g. hydraulic and cutting). Product: clean industrial lubricant returned to users	Adsorption Heating Filtration Vacuum dewatering			
Reclamation	Industrial oils (especially hydraulic oils). Product: clean industrial lubricant returned to users	Centrifugation and/or filtering			
Clay processing	Product presents poor characteristics in terms of viscosity and volatility. It can only be employed in the formulation of a limited type of industrial lubricant	*Pre-flash unit* Atmospheric vacuum stripping	*Clay treatment* By contact with a large quantity of adsorption clay		
Acid/clay + distillation		*Atmospheric or vacuum flash stripping*	*Acid or clay treatment* Removal of waste oil contaminants by acid treatment (typically sulphuric acid) or clay treatment	*Distillation* The cleaned oil is then distilled to recover two or three cuts, plus an overhead gasoil	*Neutralisation and filtration* The lubricating oil cuts, along with the gasoil, are neutralised with calcium hydroxide and filtered
Acid surfactant flocculation					
Distillation/ chemical treatment or solvent extraction		*Vacuum distillation* The 1st stage removes the water, naphtha and light end. The 2nd stage removes the gasoil, spindle oil or light fuel oil	*Vacuum distillation* The 3rd/4th stages separate the different lubricating oil cuts from the residue (in which all the metals, additives and degradation products are concentrated)		*Chemical treatment is* carried out in a blocked operation, followed by a distillation/stripper to correct volatility and the flashpoint. Alternatively, a *solvent extraction stage* can be supplied to remove the PAHs
Distillation and solvent extraction (Vaxon process)			*Vacuum distillation*		*Solvent extraction*

Technology	**Feed and output streams**	**Process description**			
		Pretreatment	**Cleaning**	**Fractionation**	**Finishing**
Solvent extraction and distillation (Sener-Interline process)	The recovered base oils have a good quality.	*Chemical pretreatment*	*Extraction with propane.* Liquid propane extracts the base oils and rejects water, asphalt, additives, and other non soluble contaminants.	*Atmospheric and vacuum distillation* The extracted oil is firstly distilled in an atmospheric distillation column to separate light hydrocarbons and some propane. The remaining oil is fractioned in a vacuum distillation column to recover lubricant base oils.	
Propane deasphalting and hydrofinishing	The technology produces good quality base oils and an alphaltic residue (suitable as bitumen)	*Pre-flash* In a distillation column	*Extraction with propane* Propane deasphalting	*Atmospheric vacuum distillation*	*Hydrofinishing with a NiMo catalyst*
Distillation and alkali treatment (Vaxon - C.F.T. – Cator)	Motor and industrial waste oils, all types of synthetic lubricants except PAG water-soluble, silicon oils and some type of esters. Base oils and asphatic residue are the main products Impurities and sediments remain in the final solid waste, which has an asphaltic nature.	*Distillation* Throughout the process, pretreatment forms part of the same process, since the first phase produces a dewatering through whole distillation with all used oil types.			*Alkali treatment*
Thin film evaporators (TFE) and different finishing processes *	Heavy metals, polymers, additives and other degradation products are removed as an asphaltic residue.	*Pre-flash and chemical treatment (1st)* Water, light ends and fuel traces contained in the used oil are removed. Atmospheric vacuum stripping + chemical treatment (optional) to minimise the corrosion and fouling of downstream equipment.	*TFE(2nd)* Performed at very high temperatures and vacuums.	*Distillation (4th)* The lubricating oil fraction is separated into different oil cuts in a vacuum column.	*One of the following (3rd)* *a) Hydrotreatment* *b) Clay treatments* *c) Solvent extraction* *d) Solvent extraction + hydrotreatment*

Technology	**Feed and output streams**	**Process description**			
		Pretreatment	**Cleaning**	**Fractionation**	**Finishing**
Thermal de-asphalting process (TDA)		*Pre-flash* Atmospheric vacuum stripping + chemical treatment. The last treatment is used to minimise the corrosion and fouling of downstream equipment and to facilitate the subsequent deasphalting step.	*Settling + TDA* Deasphalted by settling. Residue removal is achieved by flashing at the bottom of the distillation column, which performs the fractionation of the different lubricating oil cuts.		*a)Clay* *b) Hydrotreatment*
Direct contact hydrogenation process (DCH)	Waste oil and hot hydrogen gas pass the process as a mixture It produces good quality base oils (group II)	*Pretreatment* Not necessary	*Guard hydrogenation reactor (1st)* Hydrogen and oil vapour is routed to a two stage fixed bed catalytic reactor. The guard reactor removes any trace metal contaminants, following by a cracking of any sulphur, nitrogen, halogen compounds in the conversion reactor.	*Fractionation (3rd)* The lubricating oil fraction is separated into different oil cuts in a vacuum column	*Hydrotreatment (2nd)* High pressure flash separator. Fixed bed catalytic reactor
Caustic soda and bleaching earth treatment (ENTRA)	Waste oil and caustic soda. The base oil produced is of good quality (group II) with good yields	*Pre-flash* Dewatering. Feed with the addition of caustic soda (3 % referred to dry used oils) and bleaching earth (2 % referred to dry used oil)	*Tubular reactor* Break-down of the undesired metallorganic, sulphur, nitrogen and halogen compounds takes place. An advanced control of temperature and retention time in a linear tubular reactor minimises the break-down of those organic molecules which are still viable as lubricating oil components	*Fractionation* The lubricating oil fraction is separated into different oil cuts in the linear tubular reactor	*Neutralisation* Neutralisation with acid, clay treatment
Integration in a base oil production of a refinery	Oil produced represents a good quality of re-refined base oil.	a) Pre-flash in a distillation column b) Atmospheric vacuum stripping.	*TFE*	*Aromatic extraction unit* of the refinery to remove PAHs and other undesirable compounds.	*Hydrofinishing*

Technology	Feed and output streams	Process description			
		Pretreatment	Cleaning	Fractionation	Finishing
Integration in a refinery after pretreatment	Waste oil is reprocessed in a refinery to allow blending into fuel products. Contaminants within waste oils normally preclude their use as catalytic cracker feedstock or in lubricant oil production.	Water and sediments are removed from the waste oil by a pre-flash step	The pre-flashed waste oil is directly blended with the regular atmospheric residue of a refinery.		
* *1st, 2nd, 3rd, 4th* stands for the sequence of when the operations are carried out within the process. When no such numbers are present, the sequence is the most common one, i.e. pretreatment, cleaning, fractionation and finishing.					

Table 2.12: Waste oil re-refining technologies
[5, Concawe, 1996], [7, Monier and Labouze, 2001], [86, TWG, 2003], [139, UBA, 2003], [150, TWG, 2004]

2.4.2 Regeneration of waste solvents

[53, LaGrega, et al., 1994], [83, Indaver, 2002], [129, Cruz-Gomez, 2002], [130, UBA, 2003], [150, TWG, 2004], [152, TWG, 2004], [156, VROM, 2004], [157, UBA, 2004]

Purpose

Once the waste solvent is passed to a waste manager, there are two main options for its treatment:

- utilisation of the calorific value by using them directly as a fuel or blended with other fuels. The use of the waste solvents as fuels is covered in Section 2.5.2.1
- treatment of the waste solvent to reconvert it to a material that can be re-used as solvent. This treatment is referred to in this document as ‘regeneration’. This section details different treatments that are actually applied to waste solvents for their clean-up and to regenerate them to produce solvents.

The solvents and organic acids can be treated to a degree such that they can be returned into the production cycle as secondary raw material.

Principle of operation

Clean-up is achieved by different types of distillations which are the main types of separation process used.

Feed and output streams

Solvent regeneration is common practice in many industries, with a wide range of solvents currently being regenerated, the more common of which are shown in Table 2.13.

Hydrocarbon family	Chemicals
Alcohols	Ethyl, isopropyl
Aliphatics	Hexane, heptane
Aromatics	Benzene, aromatic naphtha, toluene, xylene, turpentine
Chlorinated	Trichloroethylene, perchloroethylene, methylene chloride
Esters	Ethyl acetate, butyl acetate
Ketones	Methyl ethyl ketone, methyl iso-buthyl ketone
Mixtures of solvents	Toluene/xylene, ketones, alcohols, phenols, toluene/heptane

Table 2.13: Commonly regenerated waste solvents
[53, LaGrega, et al., 1994], [150, TWG, 2004], [152, TWG, 2004]

Process description

Figure 2.15 and Figure 2.16 give examples of flow diagrams of waste solvent regeneration plants.

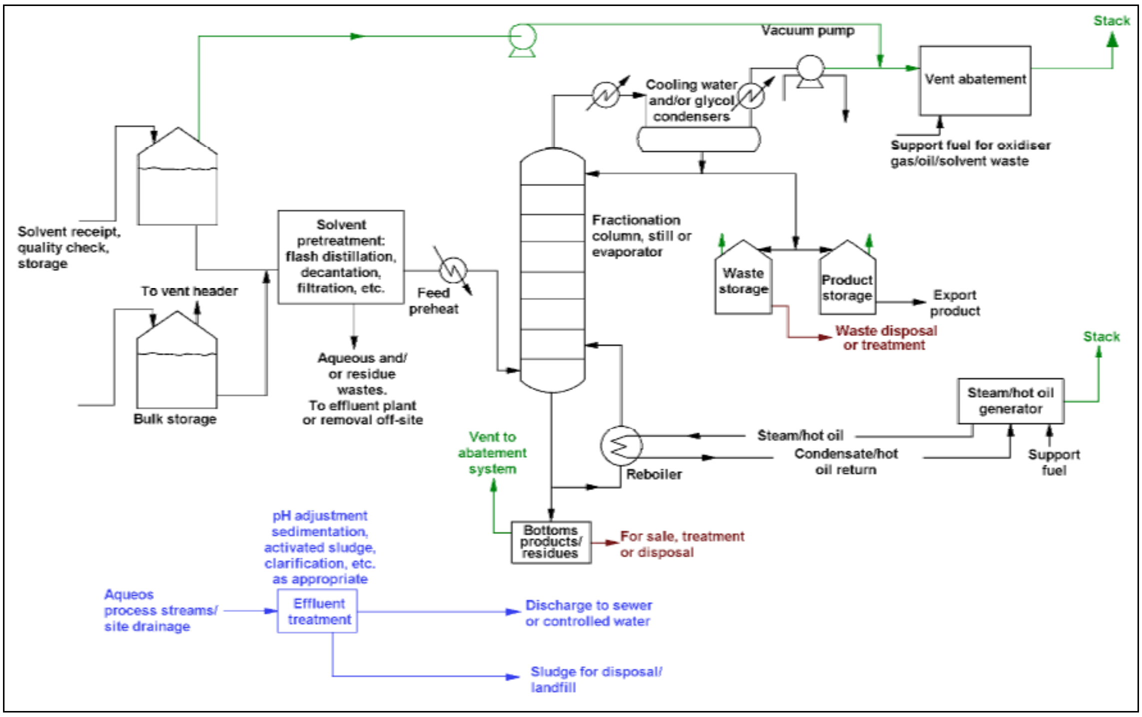


Figure 2.15: Example of waste solvent regeneration installation
[129, Cruz-Gomez, 2002]

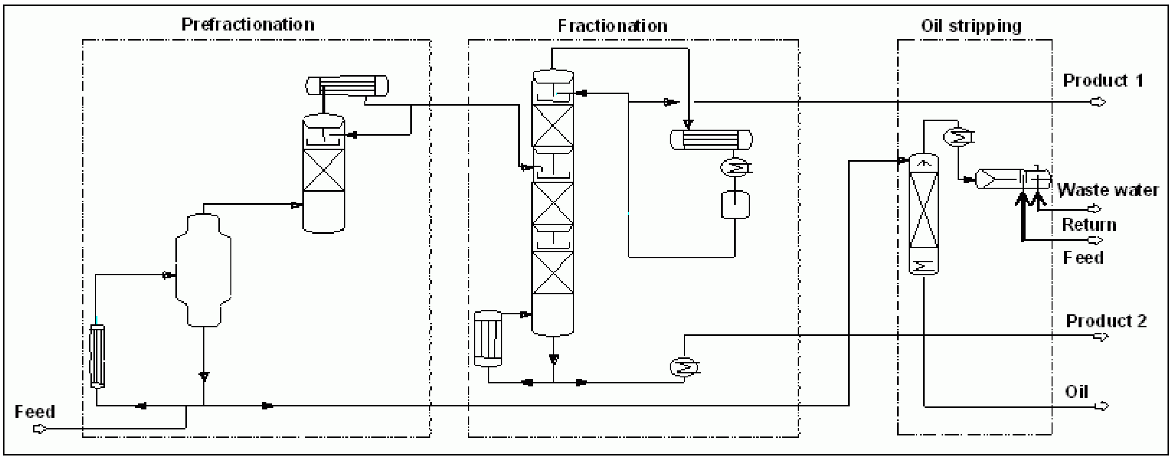


Figure 2.16: Example of chlorinated solvent regeneration flow diagram
[150, TWG, 2004]

Table 2.14 shows the techniques typically used for the regeneration of waste solvents.

Technique	Purpose and principle of operation	Users
Absorption	Transfer solvent from a gas to a liquid	
Adsorption	Recover solvent from solvent laden air	
Centrifugation	Removes suspended solid or separates two distinct (or insoluble) liquid phases, one phase is, for instance, the solvent being recovered	
Condensation	Eliminates solvent vapours from gas streams	
Decantation	Phase separation due to different densities. Separation of liquid solvent and water	
Distillation	Separation of liquid mixtures. Thin film evaporators. Rectification. Fractionation	The distillation of contaminated solvents for partial subsequent use as a fuel in boilers is one technique used (for reducing metal levels in the solvent), (some plants exist in Belgium, Italy, Spain)
Evaporation	Removal of solvent as a vapour form from a solution or slurry	
Filtration	Separation of solid particles from liquid solvent	
Liquid-liquid Extraction	Applied to liquid solvents	
Membrane separation	Recovery of solvents from liquid or gas streams	
Neutralisation	Applied to liquid solvents	
Salting out	Applied to liquid solvents	
Sedimentation	Applied to liquid solvents with a high level of solids	
Storage	See Section 2.1.4	
Stripping	Transfer of solvent from a liquid stream to a gas stream	

Table 2.14: Unit operations used for the regeneration of waste solvents
[129, Cruz-Gomez, 2002], [130, UBA, 2003], [150, TWG, 2004]

Users
This activity is carried out in the chemical, pharmaceutic and painting industries. Five plants are currently in the Netherlands. An example is described below:

The evaporation capacity depends on the specific evaporation heat of the distilled solvents and amounts to up to 1.3 t/h. The use of a reflux separator can further improve the separation; however, the flowrate is then reduced. Multiphase distillates are cooled and then separated in heavier and lighter phases which are then collected in different containers. Distillation can be performed both under ambient pressure and under vacuum. Furthermore, the facility can carry out other processes such as azeotrope solvent drying or azeotropic esterification. Additionally, organic acids may be treated in a specific ceramics bubble.

The input material containing solvents is pumped into the distillation containers. These containers are heated indirectly by fresh vapour of maximum 6 bar at approximately 158 ºC. For heavily contaminated solvents, distillation bubbles of steel are available which are equipped with stirrers for homogenising the contents. Waste solvent mixtures containing only small quantities of residues, or highly corrosive substances such as organic acids, can be distilled using enamelled bubbles. The resulting plumes are transported through a packed column and condensed at the pipes of the overhead cooler.

2.4.3 Regeneration of waste catalysts and recovery of components from abatement techniques

[86, TWG, 2003], [125, Ruiz, 2002], [150, TWG, 2004]

As mentioned in the Scope, this section covers the regeneration of waste catalysts and the recovery of components from abatement techniques. Alternative ways to regenerate spent catalysts exist, such as the recovery of the metals from catalysts (some precious metals recovery treatments are already covered with in the Non-Ferrous-Metals BREF), regeneration of catalysts (covered in this document) and the treatment of spent catalysts as raw materials for other processes, which are not covered in this document (e.g. the treatment of spent alumina-supported catalysts in the cement industry which is covered in the Cement and Lime BREF). This document only includes ex-situ regeneration installations. In-situ regeneration is typically part of a production process where a catalyst is used, thus is not covered in the scope of this document.

This section is intended as well to include information on the recovery of components from waste generated from abatement techniques (see also Section 1.2.8)

Purpose
Waste catalysts and waste from abatement techniques are typically disposed of. However, most catalysts used in abatement techniques (e.g. NO_x abatement) are regenerated.

Principle of operation
Regeneration of precious, platinum and noble metal catalysts to remove coke deposits can successfully restore the activity, selectivity, and stability performance of the original fresh catalyst. Coke deposits are removed by controlled combustion.

Feed and output streams
Catalysts from the refinery industry such as used in hydrotreating, hydrocracking, reforming and isomerisation are typically regenerated. Noble metal catalysts are also regenerated. The metals that are typically economically interesting to be recovered are Rh, Cd, Pt, Ir, the Nickel Raney and some petroleum catalysts with Ni-Co, Co-Mo, Co.

Process description
Ex-situ thermal regeneration is performed in specially designed equipment as well as in standard equipment, e.g. moving-bed belt calciners or rotary calciners.

The regeneration of precious, platinum and noble metal catalysts to remove coke deposits can successfully restore the activity, selectivity, and stability performance of the original fresh catalyst. Coke deposits are removed by controlled combustion.

As an example, after the coke is burned off, a catalyst containing platinum can be regenerated by chlorine treatment at an elevated temperature. The chlorine treatment causes redispersion of the platinum by converting it to a volatile platinum chloride, which is then transported through the gas phase and deposited on the pore walls, where it is treated in H_2 and reduced. The result is an increased dispersion of the platinum and a reactivated catalyst.

The common unit operations used in this sector are dryers, furnaces, leaching equipment and solvent extraction. Some end-of-pipe processes used to control air emissions are dust removal techniques (e.g. electrostatic precipitators, cyclones, fabric filters, ceramic filters, scrubbers, flares), gas scrubbing systems (e.g. scrubbers, dioxins capture systems, VOC abatement systems), and waste water treatments.

Users

There is a very precise process in France (Eurocat) which is applied to the recycling of one specific catalyst family (hydrotreatment) coming mainly from refineries. There is only one moving belt calciner process plant in the EU, which has been located in Luxembourg since 1979.

2.4.4 Regeneration of activated carbon

[29, UK Environment Agency, 1996], [41, UK, 1991], [42, UK, 1995], [150, TWG, 2004]

Purpose

To treat the spent activated carbon to produce a material with properties and qualities very similar to the original activated carbon.

Principle of operation

Thermal treatments are the main processes used for regeneration. During the process, drying, thermal desorption and heat treatment are carried out.

Feed and output streams

Activated carbon is commercially available in three forms: extruded, granular and powder. Since powdered carbon is extremely difficult to regenerate, this activity is not carried out on powdered carbon. Only the first two forms are therefore considered in this section.

Process description

Regeneration is normally carried out thermally and is typically composed of the following operations:

Receipt, handling and dewatering

Spent activated carbon is normally received on site as a drained solid in tankers. Water is added at the regeneration site in order to turn the carbon into slurry, which is fed to a tank where it is dewatered and charged into a kiln to be regenerated.

Thermal regeneration

After separation from the water, the moist carbon is fed into the furnace for regeneration. During thermal regeneration, drying, thermal desorption (i.e. removal of the organic chemicals) and high temperature (650 to 1000 °C) heat treatment in a slightly oxidising controlled atmosphere are carried out.

The types of equipment generally used are multiple hearth furnaces, directly fired rotary kiln furnaces and indirectly fired rotary kiln furnaces. Fluid bed furnaces and infrared furnaces may also be used.

Flue-gas treatment

Users

The most common use of these techniques is in the thermal regeneration of activated carbon, especially in facilities regenerating industrial or potable water/food grade carbons. This is because of the potential for carbons from a variety of sources to be contaminated with a range of organics. The other methods, such as steam regeneration, tend to be applied in specific areas and typically undertaken on-site.

Multiple hearth furnaces are used extensively worldwide. In conjunction with multiple hearth furnaces, rotary kilns (directly and indirectly fired) are one of the most common types of furnaces employed. Fluid bed furnaces are mainly used in Europe on potable water applications and also in North America for waste water and decolourising.

Other treatments are available as steam, chemical and biological regeneration. However they are only used for in-situ regeneration on-site and not at separate facilities. Steam regeneration is a non-destructive technique and is primarily used where the spent carbon contains highly volatile compounds. The resulting steam/VOC vapours are condensed. Chemical regeneration is a non-destructive technique that uses a variety of gaseous or liquid desorbants. There are numerous regenerant materials available, many of them highly specific to the individual application.

2.4.5 Regeneration of resins

[41, UK, 1991], [42, UK, 1995], [150, TWG, 2004]

Purpose
To regenerate ion exchange resins for their re-use.

Principle of operation
Thermal regeneration may be accomplished by using hot water or steam.

Feed and output streams
The feed corresponds to spent resin with the output of the process being regenerated resin. The attractive forces encountered in resin adsorption are usually weaker than those of granulated activated carbon adsorption. Due to this, regeneration of resins can be achieved by simple, nondestructive methods such as solvent washing, and the solute can be recovered. Thermal regeneration of resin adsorbents is generally not possible due to their temperature sensitivity, although in recent years some new products are becoming available that can be regenerated by hot water.

Process description

Steam regeneration
Steam regeneration is only possible if the temperature limits of the resins are within those of the available steam pressure. For example, styrene based polymeric adsorbents are usually stable to 200 °C, whilst acrylic based resins are only stable up to 150 °C. The adsorbed solvent and other organic constituents can cause the resin matrix to swell and weaken. It is important therefore, that removal of these constituents by steaming does not result in disruption and breakup of the resin matrix.

Hot water regeneration

Users
This technique is not widely used, but it may be applied to the desalination of brackish water for a cleaner process water usage. It would not be used for deionised water applications.

2.4.6 Regeneration of waste acids and bases

[40, Militon and Becaud, 1998], [86, TWG, 2003], [144, TWG, 2002], [150, TWG, 2004]

As described in Section 1.2.10, only waste sulphuric and hydrochloric acids are regenerated.

2.4.6.1 Regeneration of spent sulphuric acid

As mentioned in Section 1.2.10, two alternative methods for regenerating spent sulphuric acid exist. One is the thermal decomposition of spent sulphuric acids to give SO_2, achieved in a furnace at temperatures of around 1000 °C. The SO_2 produced is then used as a feedstock in the production of H_2SO_4. Both processes (thermal decomposition and SO_2 conversion to H_2SO_4) are covered in the LVIC-AAF BREF [62, EIPPCB, 2003]. There are some industrial processes where sulphuric acid is used (e.g. production of titanium dioxide). In such cases, the recycling of the spent sulphuric acid is an integral part of the process and will be covered in the BREF where that industrial process is covered. The second alternative process to regenerate spent sulphuric acid is based on the reconcentration of weak/spent/waste sulphuric acid, with or without a separation of the potential impurities (e.g. salts). This is also included in this BREF document.

Purpose
To re-use the spent sulphuric acid for the same purpose as it was originally used for or for a new use.

Principle of operation
Reconcentration of the weak sulphuric acid by evaporation.

Feed and output streams
Spent/weak sulphuric acid is concentrated to a stronger acid solution.

Process description
Concentrations close to 70 % H_2SO_4 have been achieved and the process consists of water evaporation, without too much H_2SO_4 in the vapour phase. The range of temperatures vary with the processes. There are many processes but the most common are based on the forced circulation evaporators, which allow a very stable operation; due to the big circulation, any solid in the acid will remain in the suspension and can be separated out in the concentrated acid, if necessary.

Because of the cost of the process is very dependent on energy, (medium pressure steam), a multiple effect evaporator can reduce the operating costs very much; vacuum operation allows lower operation temperatures and the use of more standard materials for equipment construction.

Another process for weak acid concentration uses hot gases (from sulphuric acid or any other process), by contacting hot gases and weak acid, the water will be evaporated towards the water saturation; the process takes place at atmospheric pressure but, due to the relatively high gas volume, some acid carry over must be prevented, by demisters or other similar devices.

Submerged combustion processes consist in the production of flue-gases at very high temperatures, (in excess of 1500 °C), directly over the spent acid level; the flue-gas passes through the spent acid allowing water evaporation from it, suffering an adiabatic cooling down to 150 – 250 °C; before being to discharged into the air, the gases need to be cooled and scrubbed out; in general, no especially high SO_2 emissions will be expected but NO_x levels should be important.

Other processes, such as Chemico, have been used for 70 years for sulphuric acid concentration; the principle is quite the same, except that the combustion does not take place within the vessel and the temperature is considerably lower (in the range of 600 °C).

Users
The metal industry.

2.4.6.2 Regeneration of spent hydrochloric acid

Most often, HCl is produced as a by-product from chlorination processes. HCl is generally produced in the gaseous phase and directly re-used in a chemical process. It can also be dissolved in water and used as a raw material for the production of other chemicals, such as water treatment product (e.g. $FeCl_3$) in electrolysis or as a neutralisation agent. HCl can be used in applications such as metal pickling or ion exchange regeneration.

Afterwards, spent hydrochloric acid is neutralised rather than regenerated. Then, reference to Sections 2.3.1 and 2.3.2 needs to be made. Some other regeneration treatments exists, for example, re-use as a picking acid. However, in this use, no treatment is carried out to these streams, so these are not covered in this BREF document.

2.4.7 Treatment of solid photographic waste

Purpose
Separate the waste in two main streams: one containing some valuable components (e.g. Ag) and the other to be used as fuel.

Principle of operation
The silver containing fixer is desilvered by means of electrolysis (see Section 2.4.8 on treatment of liquid photographic waste). The chemical reaction for dissolving silver from film is: $Ag + Fe^{3+} \leftrightarrow Ag^{+} + Fe^{2+}$.

Feed and output streams
Silver and energy.

Process description
The film waste is cut into little pieces by a shredder. The shreds are washed with a desilvering liquid and rinsed with water. Possible desilvering agents are desilvered bleach-fix (contains iron) or iron chloride. When desilvered bleach-fix is used, the consumption of raw materials is reduced. When iron chloride is used, silver chloride is separated and then dissolved again by means of a fixer. The plastic shreds are dried, after which they can be incinerated with energy recovery or used as a secondary fuel in a cement kiln.

Users
Photographic industries.

2.4.8 Treatment of liquid photographic waste

Purpose
Separate the waste stream into valuable components (e.g. Ag).

Principle of operation
Desilvered liquids and photo processing waste with a low silver content, such as developers, are treated by means of sulphide precipitation and membrane filtration. By adding a sodium sulphide solution, silver ions and other metals are precipitated. By pressing the solution through membranes the solid particles are filtered out. The permeate from membrane filtration undergoes further treatment. The silver contained in the sludge is recovered by means of pyrometallurgic treatment and refinement. These treatments are described in the Non Ferrous Metals Industries BREF. Photo processing liquid wastes with a low silver content are treated by chemical removal. By adding sodium borohydride, metallic silver is precipitated. The silver is recovered from the containing sediment. The desilvered liquid undergoes further treatment.

Feed and output streams
Silver.

Process description
The treatment of the desilvered liquid photo processing waste with a high silver content consists of the following steps:

- silver is removed from photo processing waste with a high silver content (>100 mg/l) by means of electrolysis. After refining, the silver is re-used
- for a concentration of concentration of silver of 5 to 100 mg/l, desilvering by electroflocculation or sulphide precipitation and membrane filtration is applied. The created sludge is sent for incineration
- colour processing waste water is, prior to further treatment, evaporated in a vacuum evaporator because of the presence of toxic and not easily degradable organic compounds
- treatment in an activated carbon filter, where large organic and metal containing complex agents are absorbed by the carbon. When the carbon is saturated, it is regenerated and re-used
- purification by means of flocculation and flotation
- biological treatment
- evaporation in a vacuum evaporator. The condensate can be used as processing water or discharged
- the sludge from the flocculation/flotation and biological treatment and the residue from the evaporator are incinerated or landfilled.

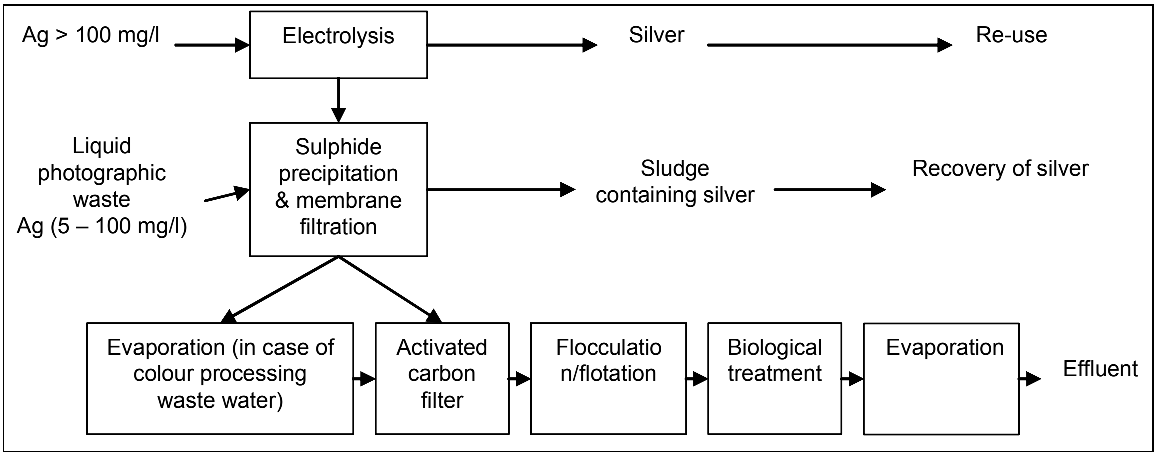


Figure 2.17: Treatment of liquid photographic waste
[156, VROM, 2004]

Users
Photographic industries.

2.5 Treatments primarily aimed at producing material to be used as fuel or for improving its energy recovery

[5, Concawe, 1996], [7, Monier and Labouze, 2001], [8, Krajenbrink, et al., 1999], [11, Jacobs and Dijkmans, 2001], [13, Marshall, et al., 1999], [21, Langenkamp and Nieman, 2001], [40, Militon and Becaud, 1998], [50, Scori, 2002], [52, Ecodeco, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [57, EIPPCB, 2001], [58, CEFIC, 2002], [59, Hogg, et al., 2002], [64, EIPPCB, 2003], [81, VDI and Dechema, 2002], [86, TWG, 2003], [114, Hogg, 2001], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004].

This section covers those treatments and processes which are mainly applied to obtain a material, prepared from waste, to be used as fuel or to change its physico-chemical properties to allow a better recovery of its calorific value. Some treatments may produce some outputs that may be used for other proposes other than as fuel. These processes are very similar and only depend on the physical properties of the starting waste and the physical properties that the waste OUT needs to have to be able to be burned in a combustion chamber. Discussion of the actual combustion of the waste is not in this document as it is covered in the individual sectorial BREFs (e.g. waste incineration, cement and lime, large combustion plants, iron and steel, etc.).

Waste which has some calorific value is currently used as a fuel in certain combustion processes, e.g. waste incineration, in cement or lime kilns, large combustion plants, heating plants, chemical works, industrial boilers, ceramic plants, brick production, iron and steel production, non-ferrous metal production. Some of the sectors using waste as a fuel are directly linked to the production of that waste. This implies that some wastes, produced in stable processes (therefore of a certain consistency), may not need any further preparation for their onward use in that sector and therefore they are often delivered directly to the plant where they will be used (e.g. used oils, used solvents). In these cases, no treatment is carried out on the waste, so consequently this activity is not included in the scope of this document (these ones represented in the following Figure 2.18 as brown arrows). The type of waste streams that are technically suitable for use in co-incineration plants is an issue that will be tackled in individual sectorial BREFs. This document considers and analyses the environmental issues involved in handling and transforming different types of waste into a material suitable to be used as fuel in different processes as represented by the blue arrows in Figure 2.18.

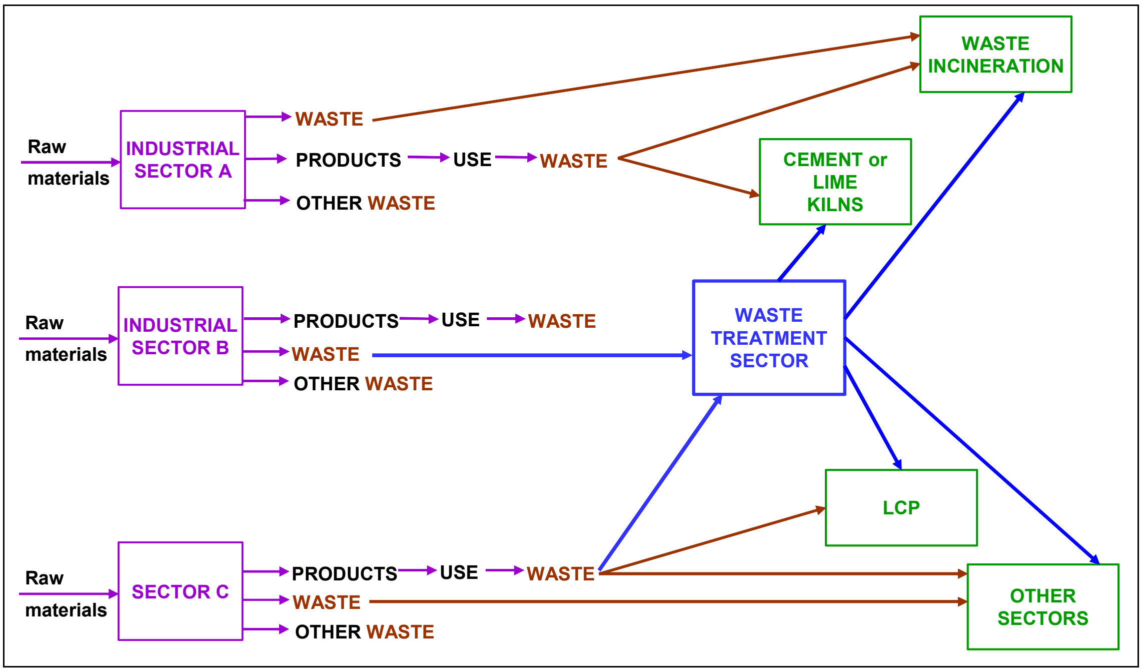


Figure 2.18: Some current possibilities for the use of waste as a fuel in different sectors
Note: This figure does not intend to show all the possibilities that may appear. Some options are not shown in the figure to increase its readability

To cite a few instances, the use of waste oil as a substitution fuel without any treatment is one option that is used across Europe, varying in popularity depending on local economic and legislative circumstances. Most national regulations allow the burning of waste oil in cement kilns. Waste oils are accepted under special conditions as cement kiln fuel in France, Germany, Italy, Spain and the UK, but seem to be banned for that use in the Netherlands, for instance. In other countries they are simply not used.

Common techniques used in the production of these materials for their use as a fuel are described in Section 2.1.

2.5.1 Preparation of solid waste fuel mainly from solid waste

2.5.1.1 Preparation of solid waste fuel by mechanical (and biological) treatment from non-hazardous wastes

Purpose
The main purpose is to prepare a combustible material out of municipal solid waste (MSW). Other purposes are mentioned in Section 2.2.2. The main function of the fuel preparation is to upgrade selected materials into a specified fuel. This section also covers the preparation of solid fuels by blending/mixing. Broadly, it is possible to distinguish two types of MBTs:

- ‘separation’ facilities -which seek to split residual waste into ‘biodegradable’ (that may be dried and used as fuel) and ‘high calorific’ fractions, and
- ‘dry stabilisation’ processes, which are less concerned with the splitting into fractions, and more aim towards the use of heat from a ‘composting’ process to dry the residual waste and increase its calorific value, therefore making it suitable for use as a fuel as well as to improve the separation of fractions.

Principle of operation
This type of fuel is manufactured by sorting wastes mainly to leave a combustible material, by mainly removing wet putrescibles and heavy inerts (stones, glass, scrap metals, etc.) from the wastes. Other operations used are for example sieving, separators, crushers, screening and picking.

Solid fuel preparation technologies vary considerably depending on the source and type of waste, and on the user requirements of the customer/combustion installation.

It is very important to bear in mind that waste is a heterogeneous mixture of materials, especially municipal solid wastes. Therefore, in producing the fuel, the producer makes a fuel more homogeneous by utilising preparation technology and specific waste processing.

Feed and output streams
See Section 2.2.2. This activity is commonly used for the treatment of non-hazardous waste. Solid fuel can arise from many different sources, such as pre-use of industrial residues, post-use of industrial waste, selected fractions from commerce and households, and from construction and demolition activities. The input to the process then may be either direct industrial waste or mixed waste (typically as the level of mixing increases, the need for waste preparation increases). Depending on the source, the composition and amount of contamination of the waste OUT will differ.

MSW, ‘commercial’ waste, and construction and demolition waste are the most common sources. The most common waste materials are paper, plastic, wood and textiles. Another type of waste typically used is the paper fraction (paper + plastic + rubber) from oil filters. This contains a high calorific value.

It is possible to distinguish two major fuel types: shredded or fluff-like material and densified fuels, such as pellets, cubes and briquettes. Densified recovered solid fuel can have lower heating values (LHV) i.e up to 30 MJ/kg depending on composition. The reported minimum calorific values vary from 3 to 40 MJ/kg. Other data report that the input, which may typically have a starting calorific value of c. 8.4 MJ/kg can increase its calorific value to c. 17 MJ/kg mainly by separating out the non-combustable fractions (e.g. inorganic materials and water).

Waste plastic can be substituted for other solid fuels, such as coal, peat, wood, petroleum coke, etc. There are a number of developments currently being carried out on fuel substitution, as well as some demonstration plants currently operating using solid waste plastic.

The treatment to produce solid waste fuel divides the MSW into two fractions. The calorific value and the composition of these fractions are different and also differs from the MSW treated. The fraction that remains after the extraction of the solid waste fuel may represent a high percentage of the MSW treated.

Process description

See Section 2.2.2. Depending on the source and the use, these wastes are shredded, separated, blended and pelletised. A typical example of a flow sheet is: input (waste), mechanical transport (e.g. conveyer belt), separation (e.g. by drum sieves, air classifiers, handpicking, magnets, dryers), size reduction (e.g. by crushing, shredding), size increasing (e.g. baling, pelletising), and finally output (fuel). Several examples applied in this process are known: reducing/removing/changing physical and/or chemical contaminants. Figure 2.19 only shows one main characteristic - automatic picking. Near infrared spectroscopy or metal separation also influences such properties as for example heavy metal contents. Figure 2.19 presents an overview of some common process units, which may be applied for solid waste fuel production. The number and kind of processing steps applied depend on the waste composition and the desired waste OUT qualities.

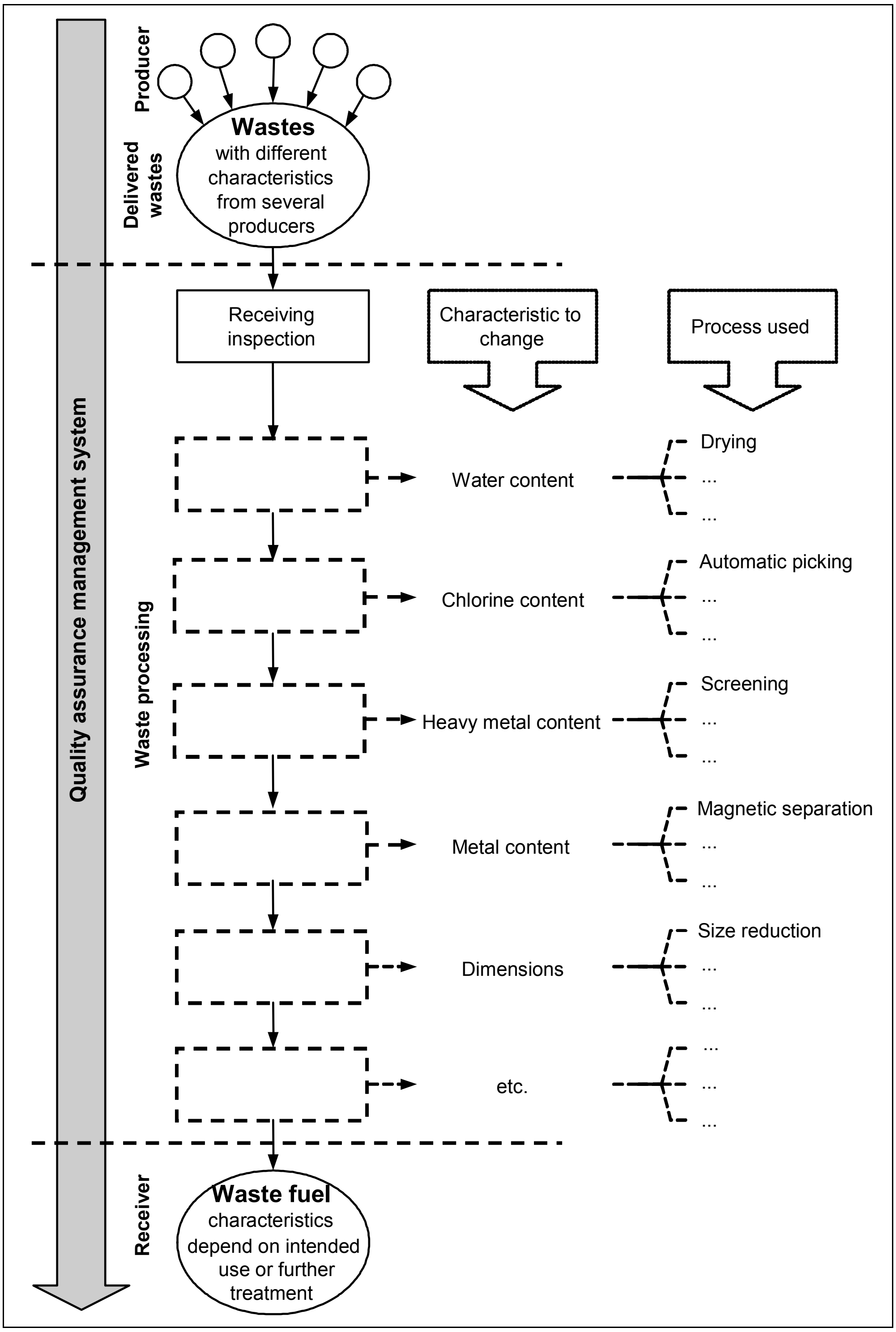


Figure 2.19: Process scheme of solid waste fuel production
[126, Pretz, et al., 2003]

Source selection may be the first action to take into account for monostreams. Preselection may be incorporated in the collection system for mixed commercial wastes. The waste receiving area is the first important facility with regard to the quality assurance management system and this is where a receiving inspection is carried out. All kinds of disturbance materials which might cause operational or quality problems, need to be sorted out at this early stage.

The production of solid waste fuel can be divided into several steps which are listed below. However, this list only presents an overview of possible techniques; each technique is not necessarily part of each process:

- receiving area/bunker
- presorting/contaminants selection
- feeding equipment - wheel loaders or cranes are usually applied for the feeding of the process
- size reduction - comminution can be achieve by hammer mills, shear shredders, single shaft shredders, rotary cutters, cam shaft shredders and cascade mills
- metal separation - to separate, for instance, ferrous metals out of the solid waste, it is possible to use a number of techniques based on the different properties of the material. The most important characteristics in waste treatment are density, shape, magnetic susceptibility and electric conductivity. The type of systems mostly used in this sector are magnetic separators (overband magnetic separators, magnetic drum separators, magnetic pulleys) or Eddy current separators (to separate out non-ferrous metals)
- classification - classification can be carried out by drum screens, linear and circular oscillating screens, flip-flop screens, flat screen, tumbler screens and moving grates. A very important processing step, within classification is the screening step, before and after grinding. Screens are applied to allow mass and volume division by particle size. It is noticeable that in small particle size mixtures, the content of hazardous substances accumulates compared to the amount found in the screen overflow. A classification with sieves is applied in waste treatment processing when:
    - materials from an upstream process need to undergo some kind of conversion to make them suitable for further processing steps, i.e. separation into defined size fractions
    - a separation of coarse or fine particle sizes is required
    - a comminution material has a high content of particles of the final particle size and only oversized particles should be reduced in size again
    - certain materials need to be concentrated. In this case, the processing is called sorting classification. This also includes separation of the small size fractions, which often contains a high content of heavy metals substances
- air classification (e.g. by air classifiers or aeroherds)
- near infrared spectroscopy
- automatic picking
- compacting/pelletising can be carried out by flat bed presses, ring die presses, or disc-agglomerators
- storage/storage area/hopper
- biological degradation/thermal drying - If the water content has to be reduced to increase the calorific value, a drying process step is necessary. This can be implemented as a thermal or biological drying step. It may be necessary to dry the waste in order to achieve higher sorting/classification ratios of waste
- exhaust gas collection and cleaning
- waste water treatment
- loading and transportation.

After the final processing step, a solid waste fuel is obtained. In some cases additional processing steps may be required to design the solid waste fuel according to the consumers' wishes. For example, further compacting or further size reduction may be requested. Table 2.15 shows the correlation between different fuel preparation processes and the end application for different purposes.

Prepared fuel in form of	Co-combustion process			
	Cement kiln	**Circulated fluidised bed**	**Pulverised coal power plant**	**Gasification and pulverised coal power plant**
Bales	Shredding (fluff), covered storage	Shredding (fluff), covered storage	Pelletising, storage, pulverisation	Shredding (fluff), covered storage
Soft pellets/fluff	Covered storage	Covered storage	Covered storage	Covered storage
Hard pellets	Covered storage, simple crushing	Covered storage	Covered storage, pulverisation	Covered storage
Chips				
Powder				

Table 2.15: Additional processing steps required according to the physical form, to deliver waste fuel to consumers' specifications
[126, Pretz, et al., 2003], [150, TWG, 2004]

Once the combustible material has been separated, it is then shredded and either sent to the customer, or pelletised before it is sent for combustion (this usually occurs when the material is burned off-site, as a densified fuel reduces transport costs).

Users
The combustible material is typically incinerated in dedicated facilities or co-incinerated in plants where a combustion process is carried out. The major fuel application is in cement/limestone production and power generation. Depending on the end application, there are different requirements for waste fuels.

This type of installation can be found in the Netherlands, Italy, Germany, Austria and Belgium, and constitutes a basic template for some 'integrated facilities' planned in the UK. The blending of large volumes of solid wastes is common practice in a number of EU states (e.g. Belgium, France, Germany, Denmark, etc.).

The processing of solid waste fuel is not a standardised process. The extent of processing carried out depends to a certain degree on the type of waste being received (input) and to the actual application of the solid waste fuel.

In mechanical biological treatment, the process used in the production of solid waste fuel is a kind of mechanical upstream facility, because the high calorific wastes are separated out before the rest of the material is fed into the biological degradation step to lower its organics content. In some cases, the biological degradation step is part of the production of solid waste fuel, with the main focus being on lowering the water content. In other cases, the biological degradation step is also arranged in the production of solid waste fuel, but the main focus may be on lowering the organics content, to maintain the respective disposal criteria for any material which is not part of the solid waste fuel and which needs to be disposed of. Depending on the applied process, different regulations for emissions may apply.

In some cases, the entire waste is dried by physical and biological processes for several days (e.g. in Germany, 7 days) under high aeration rates in a closed bio-reactor. Within this process, the organics content is reduced only slightly, and the separation behaviour is improved significantly. This is followed by a separation into a heavy and light fraction. The light fraction is used as RDF after further separation of the metals. The heavy fraction (about 15 %) is separated into metals, glass, batteries and mineral components for re-use.

2.5.1.2 Preparation of solid waste fuel mainly from liquids and semi-liquid hazardous waste

Purpose

The goal of the preparation of such fuel is to make a tailor-made, homogeneous, and free flowing waste fuel, which can be used in combustion processes and this may also make it easier for it to be traded/used.

Principle of operation

Mechanical preparation of solid waste fuel including, for instance, the impregnation of waste over a support (e.g. sawdust, crushed paper or cardboard, adsorbents).

Feed and output streams

The types of wastes used are pasty, powders and solid waste, mainly hazardous. In some specific cases, some liquid wastes may be used.

Process description

An example process of a layout for the production of solid waste fuel is presented in Figure 2.20. The design of the layout, as well as the selected installation, is chosen according to the type of waste, the availability of the waste, as well as the end specification of the waste fuel.

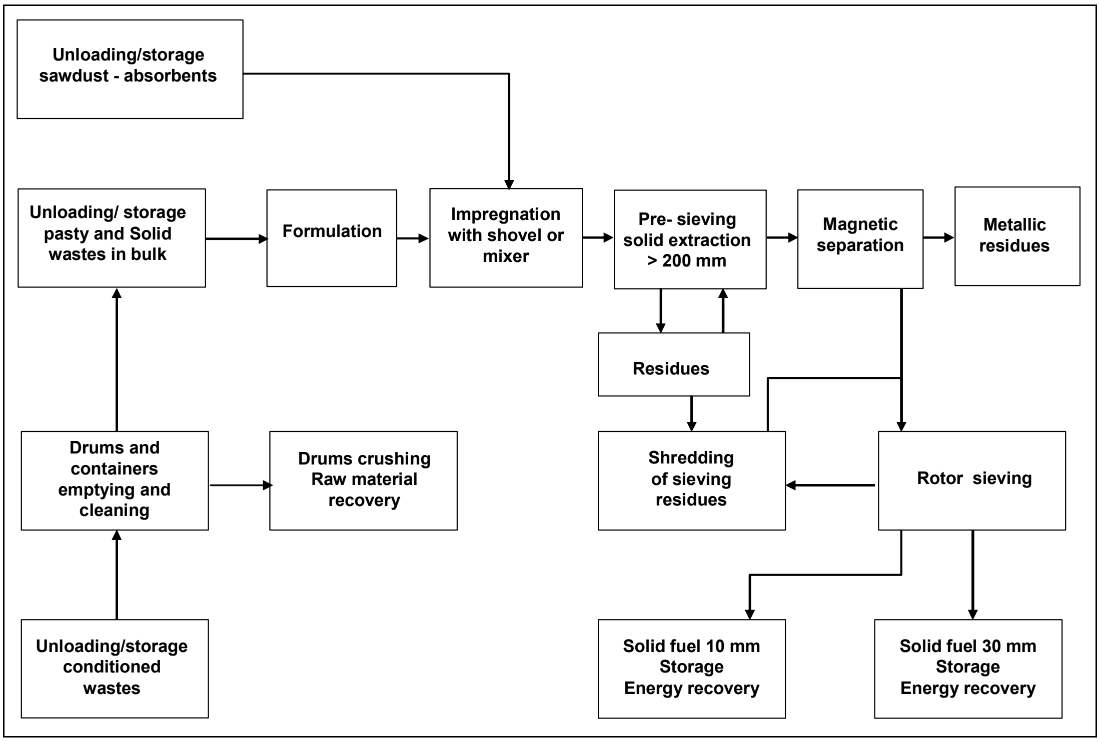


Figure 2.20: An example of the production of solid fuel from liquid or semi-liquid hazardous waste [122, Eucopro, 2003]

The main processes and production steps are:

- feeding of the waste from the storage to the production units. Pre-homogenisation of the incoming wastes is based on physico-chemical characteristics. This step is critical for ensuring the compliance of the waste fuel with the final users specifications
- shredding and/or sieving of coarse particles. Wastes that contain big particles need to be shredded or sieved before introduction into the mixing unit
- feeding of the mixing unit
- mixing operations. Materials can be fed directly or through a hopper to stabilise, regulate and control the quantity of waste introduced in the mixing unit. A conveyor belt is used after the mixing operation to transport the material to the sieve
- scrap extraction by magnetic separators or Foucault (Eddy) current systems to remove non-ferrous metals
- sieving operations by rotary or vibrating sieves. The dimensions, as well as the design of the sieve mesh depend on the granulometry specifications and the off-specification waste fuels (different fractions are possible on some installations, depending on the re-use possibilities of the big particles). Off-specification fractions can be reprocessed in the production, treated in a dedicated shredder, and/or treated in incineration or dedicated co-processing units
- storage of waste fuel before loading
- dispatch of the waste fuel. Loading of the trucks (or potentially trains or ships) is carried out by cranes, conveyor belts or bulldozers
- cryogenic crushing and separation of used packaging of paint, ink, and similar substances.

Users
Co-incineration plants (e.g. cement kilns).

2.5.1.3 Preparation of solid waste fuel by the carbonisation of contaminated wood

Purpose
Carbonisation of contaminated wood can be carried out to obtain a vegetal carbon to be used as fuel.

Principle of operation
Carbonisation of wood at a relatively low temperature (300 – 400 °C).

Feed and output streams
Contaminated wood is converted to coal, that can then be used as fuel. The metals are recovered and valorised in the metallurgic works.

Process description
The process is divided into three types of operations:

a. cutting of the wood in order to obtain a material with homogeneous granulometry and composition
b. carbonisation of the wood shavings in order to obtain a vegetable coal concentrating all of the metals. The carbonisation is carried out at temperatures between 300 and 400 °C in a low oxidant atmosphere. In this way, the organic compounds are gasified and the heavy metals are concentrated in the carboneous residue. This residue is then extracted from the oven and the gas is treated at 850 °C for two seconds
c. extraction of the heavy metals. This is an essential step to obtain pure carbon (with a calorific value of 27000 kJ/kg). A fine crushing is undertaken in order to separate the metal crystals of the carbon structure. The metals (3 w/w-%) are separated by centrifugation and the carbon is aspirated from the centre through a bag filter. The metals are recovered in metallurgic processes.

Users
One installation in France.

2.5.2 Preparation of liquid waste fuels

In this section, treatments carried out to prepare liquid fuels from liquid or semi-liquid materials are covered. The liquid waste fuel produced has properties enabling it to become fluid and move when a difference of pressure or gravity is applied. Some of the materials produced may be very viscous and can be very difficult and expensive to pump, however they still maintain fluid properties. The waste OUT of these treatments are referred to in this section as 'liquid waste fuel', regardless whether the fuel is semi-liquid or liquid. Those processes that start from liquid or semi-liquid waste and end up as a solid waste fuel are included in Section 2.5.1.2.

Typically, the materials prepared by these types of treatments are hazardous wastes. Several liquid waste fuels can be prepared according to the different wastes and market requirements:

- organic liquid preparation by blending
- fluidification
- emulsions
- sludges (the preparation of these types of waste is considered as an emerging technique).

The main processes used in the preparation of wastes to be used as fuel are:

- knowledge, controls, follow-up and traceability of wastes (a common technique as described in in Section 2.1)
- transport of wastes (a common technique as described in in Section 2.1)
- reception of wastes (a common technique as described in in Section 2.1)
- unloading of wastes (a common technique as described in in Section 2.1)
- storage units used before treatment
- reconditioning
- homogenisation and blending
- crushing
- sieving
- fluidification
- phase separation for liquid wastes: settling, centrifugation, extraction, …
- drying
- washing.

2.5.2.1 Preparation of organic liquid waste fuels by blending mainly hazardous wastes

Purpose
The aim of this operation is to blend and homogenise compatible wastes from several producers and/or sources. The purpose of this operation is to:

- provide a nearby service to producers with only small quantities of organic liquid wastes
- rationalise the logistic organisation (transports, etc.)
- develop an adapted solution for packed wastes with several phases (liquid/pasty or solid)
- separate the different phases (water, organic liquid, sludges or solid) from a composite waste in order to optimise the recovery
- prepare the homogeneous and stable wastes in accordance with specifications.

Principle of operation

These operations may involve the grouping of small quantities and/or pretreatment activities such as phase separation or settling. Blending and homogenisation are the main operations.

Feed and output streams

Liquid and semi-liquid waste with a high organic content. The wastes utilised include solvents, oils, oil sludges, emulsions, distillation residues, tank bottom sludges, oil emulsions from mechanical and metallurgy industries, wastes and sludges containing oil from petroleum refining and from the collection and storage of oil materials, waste from oil distillation and regeneration from production failure; pasty wastes such as grease, ink and adhesives wastes; pulverulent wastes such as paint powder, washing powder wastes, etc.

Process description

An example of a process layout for the preparation of liquid fuel from waste is presented in Figure 2.21.

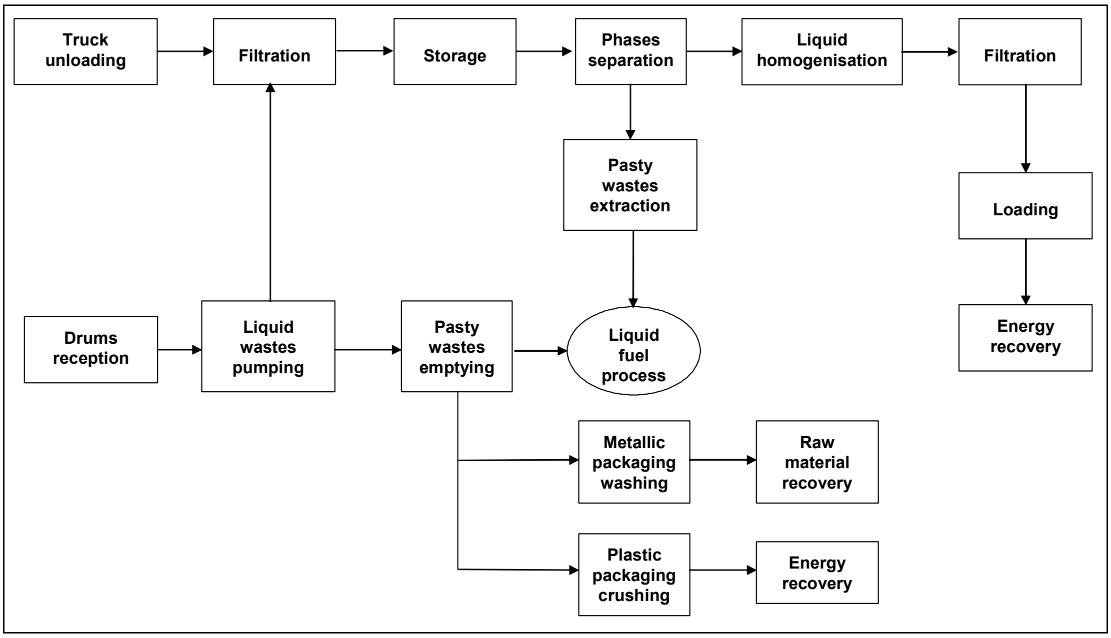


Figure 2.21: An example of the process layout for the preparation of organic liquid waste fuel [122, Eucopro, 2003], [150, TWG, 2004]
Note: 'Liquid fuel process' uses pasty waste to produce other liquid fuels

The main processes and production steps are:

Unloading and grouping

- liquid wastes in bulk. After filtration and/or settling, organic liquids are sent with a centrifuge or membrane pump to metallic cylindro-conical tanks equipped with a blending device in order to avoid settling or phase separation (consisting of a pendular mixer or pumping system which blends the top and the bottom of the tank by continuous circulation)
- packed wastes (drums, etc.). Before grouping, the packagings are emptied with techniques adapted to their physico-chemical characteristics. Generally, two phases exist: a liquid one and a pasty (and sometimes solid) one in the bottom of the drum.

Preparation

This step consists of operations such as settling, grinding, filtration and blending. A stirring propeller or a recirculation system is used in order to keep the wastes homogeneous. Sometimes, a grinding system is used with a recirculation technique in order to decrease the granulometry of any solid particles which may be in the liquid waste.

Dispatch

Before loading, the liquid preparation is filtered through a 3 mm filter. The loading of the trucks is carried out with all the security systems necessary.

Users

Co-incineration plants (e.g. cement kilns).

2.5.2.2 Preparation of liquid waste fuels by fluidification of hazardous wastes

Purpose

The aim of this operation is to blend and homogenise compatible wastes from several producers and/or sources.

Principle of operation

Fluidification means processes where liquid, pasty and solid wastes are homogenised and shredded together in order to produce a liquid fuel which can be used as fuel.

Feed and output streams

Typically hazardous waste such as oil residues, used solvents, residues from organic chemical synthesis, oil and grease, etc.

Process description

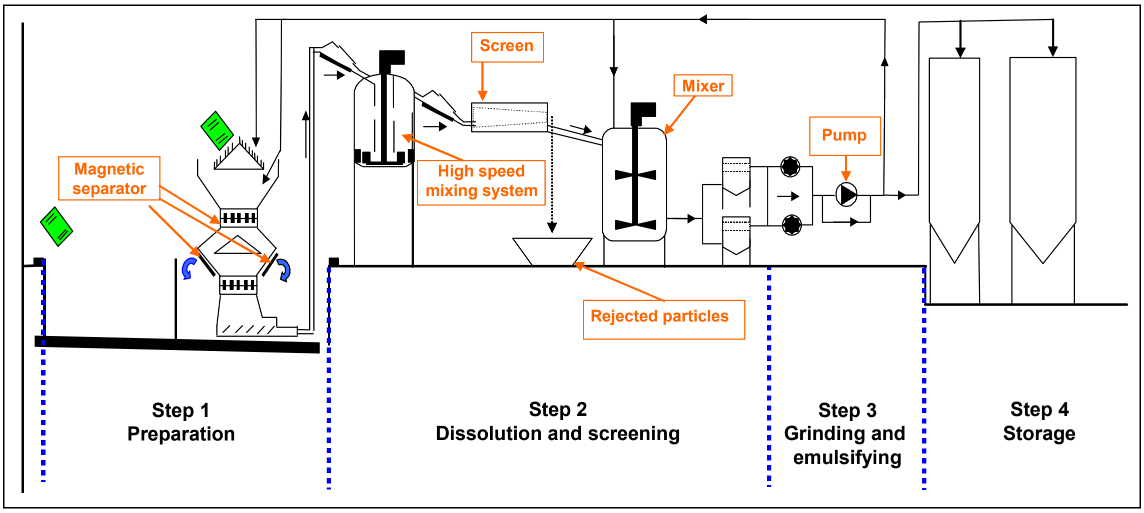


Figure 2.22: An example of the process layout for the production of liquid waste fuel by fluidification
[122, Eucopro, 2003]

The main processes and production steps are:

Pre-homogenisation

Pre-homogenisation of the incoming wastes is based on the physical-chemical characteristics. Pre-homogenisation consists of producing a premix with physical characteristics acceptable for the fluidification process. This step prevents different kinds of problems arising inside the process, such as blockages in the hoppers/pipes/machinery.

Feeding of the waste from the upstream storage facilities to the fluidification process

Solid wastes are handled with a mechanical shovel, hydraulic arm, crane bridge or hydraulic loader. They are transferred to the fluidification process with a screw conveyor or a reddler conveyor. Sludges are handled with hydraulic shovels, crane bridges and/or hydraulic piston pumps able to handle high viscosity materials. Liquid wastes are handled by pumps. Pumping technologies must be able to accept fluctuations in the quality and presence of particles in suspension.

Fluidification process

This is composed of four main steps:

'Calibration' of the pasty part

This step consists of shredding coarse particles, extracting any foreign metallic parts blended accidentally with chemical wastes and then transfering this pasty material into the mixing tank. The shredders used are slow motion shredders, used for flammable and low flashpoint wastes (e.g. mono-rotor or bi-rotor rotary shears) and dedicated shredders for specific wastes (e.g. cryogenic shredders). Technologies for the extraction of undesired solid portions include ferrous and non-ferrous metal separators for metals and vibrating sieves and/or static grates for bigger particles. The transfer of the material is carried out by screws and pumps (e.g. concrete pumps).

A simplified design is also possible for lower investments: this consists of a smaller capacity unit, which is dedicated to less difficult wastes (i.e. that free of coarse pieces). In this case, the material may be transferred into the mixing step by shredding. A rotary filter may be installed to remove large quantities of useless materials

Dissolution and screening

his second step dissolves and emulsifies the pasty parts into a solvent phase, to obtain a homogeneous material.

The dissolution of solid organic compounds in a liquid phase composed of solvents and/or waste water is carried out by special mixers, rotary screens and buffer tanks. The mixers must respond to the constraints of the sticky material containing strong and voluminous solids in suspension. They pulverise the solids between rotor and stator and blend them into the liquid phase. Next, the liquid mixture is admitted inside a rotary screen, which extracts the pieces of plastic lining fragmented by the shreddinig in the previous step. A buffer tank collects the material in the course of preparation at the end of this step

Grinding and emulsifying

This third step consists of finely grinding any solid particles remaining in suspension in the liquid phase. It also consists of making a fine emulsion between the aqueous phase and the hydrocarbons phase constituting the liquid waste fuel. The stability and the quality of combustion of the waste fuel depends directly on both its homogeneity and the size of fragmentation of the solids in suspension.

These criteria require high velocity technologies of grinding/emulsifying protected by magnetic separators and mechanical filters. The equipment must be flexible enough in order to accept fluctuations in viscosity, density and the nature of the solids in suspension.

The liquid waste fuel is controlled at this step, during the filling of the buffer tank. Some parameters such as pH and viscosity can be controlled continuously in process. Other parameters such as LHV, composition and flashpoint, are controlled from samples taken during the production. If the quality does not meet the specification, the fuel must be reprocessed before being transferred to the storage unit.

A simpler design is possible for small capacity units: here steps 2 and 3 may be carried out at the same time. In this case, the mixing and buffer tank will be the same and the grinding line will run into the mixing tank.

Storage and dispatching
Once a high level is reached inside the buffer tank, the material can be transferred by pump into the final storage. During this transfer, a latter adjustment of the quality of the fuel can be carried out by means of grinders and filters operating on the transfer line. The storage capacity is generally composed of vertical cylindrical-conical tanks with blending equipment. Two technologies of blending are appropriate to homogenise the liquid fuel:

- a long marine mixer installed on the roof of the tank
- a pumping system which blends the top and the bottom of the tank by loop circulation.

Dispatching to the customer is carried out by a truck loading station. This loading station is fed by the storage unit mentioned above.

Users
Co-incineration plants (e.g. cement kilns).

2.5.2.3 Preparation of emulsions from liquid/semi-liquid hazardous waste

Purpose
The aim is to produce a homogeneous and stable waste fuel from liquid and semi-liquid waste.

Principle of operation
This process is based on the control of blending by means of the addition of selected chemicals or tensides.

Feed and output streams
Emulsions are typically produced from hazardous wastes such as oils and emulsions from the mechanical and metallurgy industries, wastes and sludges containing oil from petroleum refining, production failure, etc.

Process description
Installations are similar in design and layout to those used for the pasty raw meal preparation for clinker production in cement kilns.

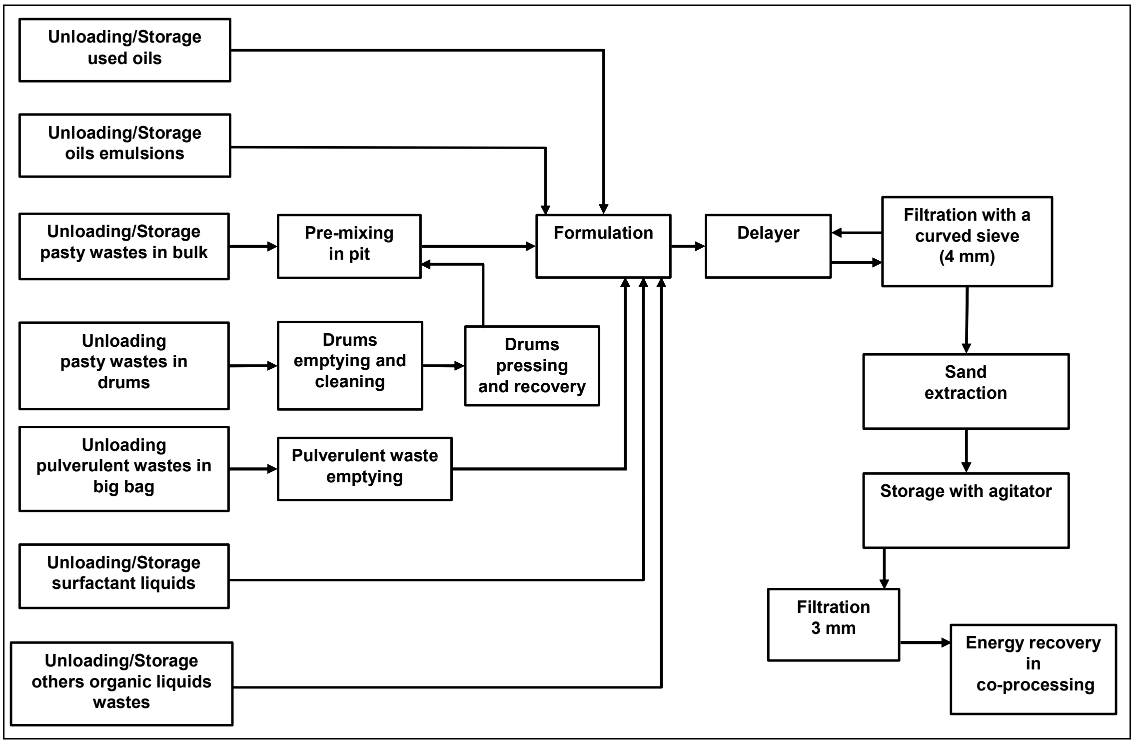


Figure 2.23: An example of the process layout out for the preparation of emulsions [122, Eucopro, 2003], [150, TWG, 2004]

The main processes and production steps are:

Feeding of the waste from the storage to the production units
Before introduction into the production process, wastes are deconditioned with equipment adapted to their physical characteristics. Pasty wastes extracted from drums are put in special pits. They are first handled by mean of a mechanical shovel to a homogenisation pit. Then, they are transferred to a hopper in order to be introduced to the production process by a screw conveyor or a concrete pump. Pulverulent wastes, such as paint and washing powder, are received in big bags. They are directly put into the production process with equipment adapted to capture dust emissions. Liquid wastes are handled by pump. Pumping technologies (centrifuge pump, volumetric pump with out-rotor, etc.) must be able to accept a viscosity fluctuation and the presence of particles in suspension

Formulation
According to the physical-chemical characteristics of the waste stored, the laboratory defines the specifications, including the nature and quantities of wastes, which can be put into the production processes. Compatibility tests are also developed. Such tests are carried out at any operation, in order to comply with the waste fuel specifications

Production process
The production process which is a batch process is carried out by special mixers (called ‘delayors’), closed in order to prevent VOC emissions. The different components are introduced in the mixer according to laboratory specifications. An agitator provides for stable emulsion production. During this step, several parameters are monitored, such as viscosity, pH, temperature and motor specification. One of the purposes of this monitoring is to detect any polymerisation reactions, as these could cause production problems

Screening
Once the emulsion is achieved, it is circulated again with a centrifuge pump to the mixer and through a curved screen providing particle retention above 4 mm

Sand extraction
When the mixer is emptied and before being sent to the storage capacity, the material is pumped to a concrete pit with a sedimentation area. The aim is to separate through density any mineral solid particles (e.g sand) which may be present in the material

Storage and dispatching
The material is transferred by centrifugal pump to storage. The capacity of the storage is generally composed of concrete or steel vertical cylindrical tanks with blending equipment.
Three technologies for blending are appropriate to keep the homogeneity:

- a submerged agitator
- a low agitator with a scraper in order to avoid sedimentation
- a pumping system which blends the top and the bottom of the tank with high flow (around 250 m^3/h) loop circulation.

The waste fuel quality is controlled in order to be sure that its characteristics comply with customer specifications. In some specific cases, the addition of waste with a high calorific value may be made if the calorific value is considered too low.

Dispatching to the co-processing factories is carried out by a truck loading station. A final screening (through a filter of 3 mm size) is undertaken whilst loading.

Users
Co-incineration plants (e.g. cement kilns).

2.5.2.4 Treatments of waste oil where waste OUT is basically used as a fuel

There are two main options for the treatment of waste oils (see Figure 2.13 in Section 2.4.1). One way is to treat the waste oil to reconvert it to a material that can be used as a base oil to produce lubricants. This is referred to as 're-refining' in this document and it is covered in Section 2.4.1. The other way is the treatment of the waste oil to produce a material that will be mainly used as fuel or for other uses (e.g. absorbant, mould release oil, flotation oil). These treatments are covered in this section. As is the case in the whole document, this classification has been adopted for this document and it is not intended to provide any attempt to define any of the R codes from EC waste legislation.

The calorific value of waste oils can be utilised. When used as a substitute fuel, principally for coal, diesel and light fuel oil, used oil has an economic value. A number of different burning applications for used oil exist, distinguishable partly by the temperature at which they burn, and partly by the control technology they use to reduce environmental effects. Before its use as fuel, several cleaning or transformation treatments may need to be applied. These are summarised in the Table 2.16.

Type of treatment	Changes that occur in the waste oils after treatment	Fuel use	Industrial sector use
No treatment. Used directly in a combustion process (Not covered in this document)	No change	Directly used as fuel in kilns, furnaces, etc.	Waste incinerators, Cement kilns, Space heaters (garages, green houses, workshops, etc.) [1], On-board ships (typically using marine oils), Quarry stone industries.
Mild re-processing	Removal of water and sediments	Waste fuel blend to fuel oil (replacement of fuel oil)	Cement kilns, Road stone plants, Large marine engines, Pulverised power plants
Severe reprocessing (chemical or thermal processes)	Demetallised heavy fuel oil (or heavy distillate)	Waste fuel blend to fuel oil (replacement of fuel oil)	Marine diesel oil, Fuel for heating plants
Thermal cracking	Demetallised and cracked material	Distillate gasoil	Gasoil (also called heating oil, diesel oil, furnace oil, etc.), Demetallised heavy fuel oil, Marine gasoil, Rerefined light base oil not used as fuel
Hydrogenation	Reduction of sulphur and PAH contents		
Gasification [2]	Converted to synthetic gas (H_2 + CO)	Fuel gas	Chemical production of methanol Large combustion plants (e.g. gas turbines)
[1] Forbidden in some MSs [2] More information in Section 2.5.3			

Table 2.16: Treatments applied to waste oils before their use as fuel
[5, Concawe, 1996], [7, Monier and Labouze, 2001], [86, TWG, 2003], [150, TWG, 2004]

2.5.2.4.1 Direct burning of waste oils

Burning waste oils without any treatment is one disposal/treatment option that is used across Europe, varying in popularity depending on local economic and legislative circumstances. There are four sectors identified where waste oils are directly burned: cement kilns (see Cement and Lime BREF); waste incinerators (see Waste Incineration BREF); as a reducing agent/fuel in blast furnaces (see Iron and Steel BREF), and in large combustion plants (see Large Combustion Plant BREF). As these are already covered in other BREFs, they will not be included under the scope of this document.

2.5.2.4.2 Mild reprocessing of waste oils

Purpose
To clean the waste oils to improve the physical properties, so that they can be used as a fuel by a wider variety of end users.

Principle of operation
The treatments involve the settling of solids and water, chemical demineralisation, centrifugation and membrane filtration.

Feed and output streams
Waste oils in general. A simple cleaning process is applied to waste oil destined for asphalt drying or for fuel blending before further use.

Process description

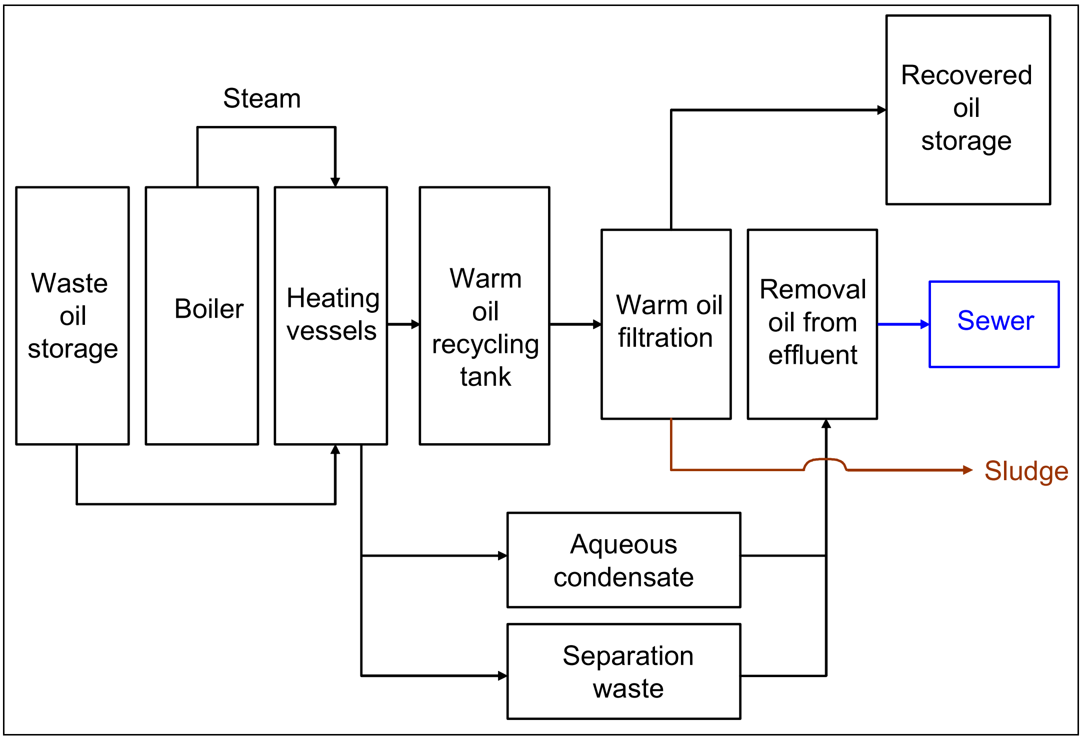


Figure 2.24: An example of a mild reprocessing of waste oil
[55, UK EA, 2001]

Settling

Water and sediments are settled in a tank after mixing the used oil with a demulsifier. Settling is facilitated by heating the tank up to 70/80 °C. If necessary, the clear oil is decanted and passed through a series of filters. The waste water and sediments are treated. A simple cleaning process to remove water and sediments (althought typically, this does not deal with the heavy metals, halogens and sulphur), is given before the further use of the waste oil as a replacement for fuel oil.

Chemical demineralisation

This process is used to clean metallic contaminants and additives. The chemical process relies on the precipitation of salts such as phosphates, oxalates and sulphates. The waste fuel is suitable for burning as ‘black oil’ and produces less air pollutants because of its pretreatment. Water is usually removed by demulsification and heating. The precipitate is removed by settling and filtration. Unfortunately, the chemicals and plant required are quite expensive when compared to the value added to the waste fuel produced. Also, a concentrated hazardous waste is generated.

Membrane filtration

Produces high grade recycled oil, a concentrated waste oil, and waste water.

Users

Used oil has been a substitute for light gasoil for several years. It provides a lowering of operational costs and useful a disposal route for used oil. Details of the extent of this route in Europe are unclear but it is likely that the combined fuel oil may be sold as bunker fuel, for use in asphalt plants and power stations. The material, after membrane filtration, is suitable for power station ignition fuel or as a diesel extender. Concentrated waste oil, after membrane filtration, can be used as coal spray, where contaminants are bound with silica compounds upon burning. Table 2.17 summarises some of the uses of waste oil after a mild reprocessing.

Sector where treated WOs is used	Comments	Countries where it is used
Road stone plants or asphalt mixing plants	Reprocessed WOs are burned to dry hard stone for the manufacture of road surfacing materials. The stones are dried, then sized, after which they are mixed with bitumen and filler	Common in Belgium and the UK. However, in Italy some environmental authorities do not permit this use
Dry limestone	Reprocessed WOs are burned to dry limestone. Some acid contaminants are likely to be captured by the solid material	
Blending into fuel oil	The processed oil may be blended into fuel oil. In this case, the maximum amount of processed used oil which may be blended with other heavy streams is limited by specifications on the ash content (generally about 0.1 % max.), and sulphur content and may be subject to meeting a viscosity range specification	
Power stations	Reprocessed WO is utilised in pulverised coal power stations, mainly as a furnace start up fuel, but it is also used sometimes as an addition to the main fuel where heat input is restricted. See the LCP BREF [64, EIPPCB, 2003]	
Burning used oil in space heaters	After a separate pretreatment step where water and sediments are removed, the cleaned waste oil (see Section 2.4.1.1) is burned in small space heaters in garages, workshops and greenhouses. Special standalone heaters are manufactured for this purpose. In this type of burner the exhaust gases are not usually scrubbed and emissions of harmful and polluting substances to air are likely. This route is usually carried out on a small scale (typically <10 MW_{th}). This use provides an economic heating source and the used oil is disposed of at the point of generation	Such burning is said to account for approximately 40 kt of used oil in the UK per year. In Belgium and Denmark it is illegal in most cases to use it in garages, workshops and greenhouses (it is necessary to have a permit to dispose of it as a hazardous waste)
On-board ships	Typically this involves used marine oils. The waste oil originating from shipping and from land sources is mixed in order to obtain better treatment and separation parameters. The oil is used as a finished waste fuel or as cutterstock, which means that different streams are blended in order to meet a viscosity range specification. The combined fuel oil is sold as bunker fuel. For the removal of the water the waste oil is decanted, if necessary demixing can be improved by adding emulsion breakers and/or raising the temperature. The oil is then filtered and centrifuged. The resulting oil goes to a storage tank and is sampled. Some cleaned waste oils are currently used in marine motors for electricity production	Some examples are in Spain

Table 2.17: Use of mild reprocessed waste oil (WO) as fuel
[55, UK EA, 2001], [86, TWG, 2003]

2.5.2.4.3 Severe reprocessing

Purpose
Burning after ‘severe’ reprocessing aims to separate the combustible WO portion from the less desirable bottoms fraction which contains the metals, the non-combustible ash, grit and dirt. The ‘severe’ reprocessing transforms the used oils into fuels which can be burned with similar conditions to those for burning other oil fuels.

Principle of operation

Uses of flash column and (vacuum) distillation columns to produce a cleaner waste fuel suitable to be used as fuel. Several commercial processes exists (see process description below).

Feed and output streams

The demetallised waste oil produced (also called heavy distillate or heavy fuel oil) is burnt as a marine diesel oil or as fuel for heating plants.

<u>Waste OUT from the 'Trailblazer' process (see process description below)</u>

- light hydrocarbons consisting of gasoline, kerosene, etc.
- vacuum distillates. These comprise ash-free hydrocarbons in the diesel range and meet the fuel oil specification for several applications, including for use as a marine diesel oil
- asphalt extender. This material is the residual bottoms from the vacuum tower. The metal, additives and degradation compounds are contained in the asphalt extender. The metal encapsulated in the finished asphalt material shows low leachability under a variety of tests.

<u>Waste OUT from the propane de-asphalting process (see description below)</u>

The base oil produced is only suitable as a diesel extender because they produce unfinished lube basestocks which are not marketable. The 'bottoms' produced are suitable as bitumen. This process yields more marketable materials than regeneration by chemical treatment or by hydrogenation. This is the reason why sometimes this process under certain operational conditions may be seen as a re-refining process because a high percentage of base oils are produced. More information can be found in Table 2.12.

Process description

Some chemical treatments exist (acid/clay, solvent extraction, propane extraction, etc., with no finishing step) as do thermal treatments ('Trailblazer' process, 'Vaxon' process, etc.). A short description of the processes currently available in the market follows:

<u>'Vaxon' process</u>

This consists of a series of vacuum cyclone evaporators, followed by a chemical treatment of the distillates obtained. There are several stages:

- the first stage removes water, naphtha and light ends
- the second stage removes gasoil, spindle oil or light fuel oil from the bulk of waste oil
- the third and fourth stages separate different distillate cuts from the residue (in which all the metals, additives, sediments, heavy hydrocarbons and degradation compounds are concentrated).

The resultant distillates are then available as good quality industrial fuel. This process has been modified to create re-refined base oils (see Table 2.12).

<u>'Trailblazer' process</u>

In this process the used oil is dehydrated in a flash tower, heat soaked and then processed by vacuum distillation to produce three output streams. The ash-free distillate oil yield with this process is 80 % on a dry basis.

<u>Propane de-asphalting process (PDA)</u>

Two types of process exist. These are called 'single-stage' and 'two-stages'. More information can be found in Table 2.12. Oil is mixed with liquid propane at a high pressure and ambient temperature in the de-asphalting unit for the separation of the residual asphaltic fraction. The components of waste oil that are not soluble in propane (i.e. the asphaltic fraction containing carbon, metallic additives, resins, additives, polymers, degradation compounds and asphalt), precipitate and can be removed via settling. The process consists of the steps shown in Table 2.18:

Dewatering and de-fuelling	Pre-flash. Water, light ends and fuel traces contained in the used oil are removed by atmospheric or mild vacuum stripping; one or two columns may be used for this operation
De-asphalting	PDA, fractionation and hydrotreating. Asphalt is separated by extracting the recoverable fractions of the used oil with liquid propane. Two versions exist: 1) single stage: downstream of the PDA extraction unit, the clarified oil is separated from the propane and fed to the hydrotreating. Finally, fractionation in a vacuum column produces the desired lubricating oil cuts 2) two-stages: the clarified oil coming from the first PDA unit is distilled and fractionated in a vacuum column. The bottom fraction, still containing impurities, is fed to a second PDA unit; the resulting asphaltic fraction is recycled back to the first PDA unit. The oil fractions coming from the side cuts of the vacuum column, along with the heavy cut clarified in the second PDA stage, are hydrogenated separately in the hydrotreatment. The two-stage process, compared to the single stage, provides an extended life for the hydrotreating catalyst, but has higher investment and operating costs
Fractionation	Vacuum distillation
Finishing	Clay or hydrotreatment: after the subsequent distillation steps, the chlorine content of the distillates is lowered by treatment with metallic sodium
Yield	74 % in dry basis for IFP process (97 % dewatering de-fueling, 80 % de-asphalting), 95 % hydrofinishing (medium pressure) 80 % in dry basis for the Snamprogetti. 5 % fuel, 9 % gasoil and 6 % residue
Common plant size	
Advantages	High yield and good waste fuel quality (if hydrotreated)
Drawbacks	More or less expensive according to the number of stages for the PDA. Significant amount of residues to be disposed of
Comment	Single-stage: IFP was the first company to apply this technology in 1968 at Pieve Fissiraga in Italy (Viscolube plant). One plant in Italy producing 57 kt/yr Two-stages: Snamprogetti installed this technology in 1982 at the Ceccano plant (Viscolube) in Italy.

Table 2.18: Information on the PDA process
[7, Monier and Labouze, 2001], [86, TWG, 2003]

Users
A 'trailblazer' process plant with a capacity of 150 kt/yr used oils is in operation in Louisiana, US. Some of those processes are similar to the ones used within refineries. The waste fuels of those processes are typically used as marine diesel oil or a fuel for heating plants.

2.5.2.4.4 Thermal cracking

Purpose and principle of operation
Thermal cracking uses heat to break down long-chain hydrocarbon molecules (e.g. the ones found in waste oils) into shorter ones thus generating lighter liquid fuels. In this way, larger molecules of more viscous and less valuable hydrocarbons are converted to less viscous and more valuable liquid fuels.

Feed and output streams
Thermal cracking can accept various types of hydrocarbon feedstock: waste oils, waste marine fuels, deep frying oils and, possibly with design considerations, waste plastics (e.g. waste oils returned in their original container). The strategy of thermal cracking is to crack viscous large molecules into more valuable shorter molecules ranging from demetallised heavy fuel oil to re-refined light industrial lube oil, including gasoil products as well as other materials for other uses. According to this, the thermal cracking can be configured to give the following set of outputs (Table 2.19).

Plant configuration	Outputs	%
1	Off-gases Naphtha Demetallised heavy fuel oil or marine gasoil Heavy residues	5 8 77 10
2	Off-gases Naphtha Gasoil (also called diesel fuels, heating oil, furnace oil) Light lube oil Heavy residues	10 15 65 Small fraction 10
3	Off-gases Naphtha Gasoil Re-refined light lube oil [1] Heavy residues	5 10 30 45 10

[1] Sometimes this configuration is enclosed as a re-refining process because of the high percentage of re-refined lube oil. Some cracked materials are used as flotation oil, mould release oil or as naphthalene absorbant in coke oven gas cleaning.

Table 2.19: An example of outputs under appropriate operating conditions
[7, Monier and Labouze, 2001], [86, TWG, 2003], [150, TWG, 2004]

If the configuration for gasoil production is desired, this is the most severe cracking mode and thus heat input is maximised and the throughput is at the design capacity. If demetallised heavy fuel oil or light lube oil is preferred as the primary output from the plant, the process operating conditions can be changed to achieve this. Due to these variability facts, thermal cracking offers a big opportunity to adapt to fluctuations in the market values of products.

Process description

The process operates at very high temperatures (thus evaporating all the water present). After removal of the water, much of the heavy metal content is removed as a sludge or via an acid treatment prior to the cracking step. The pretreated waste oil is thermally cracked at 420 °C at low pressure (without a catalyst). The subsequent distillation and stabilising steps yield a marketable fuel (gasoil). Depending on the intensity of the cracking, the material may either be a fuel oil, a fuel suitable for blending with diesel (diesel-extender) or materials used as light lube oil and for other uses. Several processes exist today, such as:

SOC processes

- SOC1: dewatering is followed by thermal cracking, performed in fired heater coils with soaking drums or heated kettles. This process is suitable to small plants, in the 6 to 15 kt/yr range but it has only a limited feed acceptance
- SOC2: dewatering is followed by thermal cracking, performed in an indirectly fired rotary kiln. This process is suitable for large capacities and can also process more refractory oils than thermal cracking (such as synthetic oils) and higher carbon residues (bunker fuels, etc.).

GNP processes

This thermal cracking of waste oils, utilising ‘refinery calibre’ systems and equipment, is a relatively recent development. The process consists of a screening and dewatering stage; followed by a thermal cracking stage; a separation or distillation stage, depending on the output mix desired; and finally a purification and stabilisation stage. This technology is characterised by large operational and output flexibility and adaptability to the changing market values of materials. It can also be manipulated to maintain output quality even with wide feed variability. As a matter of fact, the process operational conditions (temperature, pressure, residence time, etc.) can be varied to produce a primary output (be it heavy fuel oil, gasoil or base oil) that can be maximised, whilst minimising the secondary output streams (consumed in the process for calorific value or sold).

Thermally cracked gasoil is unstable if not further processed. It can discolour rapidly and precipitate gums and tars. A stabilisation and purification operation supplementing the thermal cracking can produce a gasoil which is not odorous, meets regulatory and consumer colour criteria, minimises the formation of gums and tars during storage and which is not highly acidic. For this, several methods are available:

- the 'Robysth' process
- several chemical stabilisation methods (clay absorption, solvent extraction)
- hydrotreatment. Except for a standalone WO thermal cracking plant, this treatment might not be feasible due to the very high capital costs and the requirement for hydrogen gas.

The typical yield for thermal cracking is 71 %, this resulting from the partial yields in the processes of 95 % dewatering, 90 % thermal cracking, 83 % distillation and 99.5 % purification/stabilisation.

Users
Thermal cracking is a common mineral oil refinery process that is well known and proven. At least two plants exist in Europe. One is a 40 kt/yr plant in Belgium and another a 20 kt/yr facility operating in Spain. The latter one mixes all the light and heavy fractions obtained to feed a thermal engine producing electricity. More than seven plants are in operation in the US, with a total capacity of more than 160 kt/yr. The plant size for this technology ranges from 7 - 40 kt/yr.

2.5.2.4.5 Hydrotreatment

Hydrotreatment is a dedicated name for catalytic hydrogenation in the mineral oil industry. For waste oils, the main purpose is essentially to remove PAHs. It also reduces the sulphur content in the oil (this is a potentially useful characteristic if diesel and diesel extender is the intended output).

2.5.2.5 Production of biodiesel from vegetable waste oils

Purpose
To produce biodiesel from vegetable waste oil.

Principle of operation
Involves cleaning of the waste oils.

Feed and output streams
The types of waste oils treated are collected in waste transfer facilities and from the restaurant sector. The outputs are mainly biodiesel, which are used for transport and glycerine.

Process description
First the waste oils are filtrated and water is removed. The waste oil is then separated by distillation to obtain the outputs.

Users
At least two plants exist in the EU (in Spain and Austria) and one is planned to be constructed in Portugal.

2.5.3 Preparation of gaseous fuel from waste

Purpose
To prepare a gaseous fuel from a liquid or solid waste.

Principle of operation
Two ways of producing fuels from waste exists and these are:

- gasification of the waste at high temperatures by partial oxidation and then conversion of materials containing carbon into synthesis gas (mainly H_2 and CO)
- production of biogas (mainly methane) by the anaerobic digestion of waste (covered under biological treatments in Section 2.2.1).

Feed and output streams
Used oil can be fed, alone or in combination with other feedstocks, to gasification plants for the conversion of materials containing carbon to synthesis gas (H_2 and CO). This process can also use mixed wastes that cannot be economically separated; for example, oil and plastic which may be found together when used oil is returned in its original container.

Process description
See the Refinery and the WI BREFs.

Users
Gasification technology has been used worldwide for a long time in more than 100 plants and it provides a well used option for the re-use of waste oil as well as other types of wastes. This option is typically used when gas fuel has a use on site. In Greve (close to Florence in Italy), a gasifier operates using the RDF pellets from Florence. Here, they use the gas fuel for two purposes. The first purpose is to produce electricity in a gas boiler plant for the national grid. The second purpose is to deliver gas to a cement kiln located close to the gasifier. The synthetic gas can also be used for the production of methanol.

2.6 Techniques for the abatement of emissions

[126, Pretz, et al., 2003], [150, TWG, 2004]

There are many non-production techniques in use in the WT sector. In particular, techniques used to control and abate emissions to air, water and soil are also relevant for this document. Descriptions of many of these techniques can be found in the BREF on Waste Gas and Waste Water in the Chemical Industry and in Chapter 4 of this document (Sections 4.6 to 4.8) as well as in other BREFs (e.g. Waste Incineration). These techniques are not described in this section because they are typically techniques that might be considered in the determination of BAT, and consequently will be described and analysed in Chapter 4.

3 CURRENT CONSUMPTION AND EMISSION LEVELS

This chapter provides data and information about current consumption and emission levels in existing installations at the time of writing. Because it covers many types and sizes of waste treatment installations, data is very wide-ranging. The aim of this chapter is to bring together, as far as possible, consumption and emission levels for different waste treatment installations as a whole and as far as possible from each specific process/activity. The data quoted should, in most cases, enable estimates to be made of the concentration and loads of emissions from WT sites. This will in turn help a competent authority issuing a permit to verify the information provided by the applicant in the permit application.

The structure of this chapter is similar to that of Chapter 2, with the sections being divided into:

- Section 3.1: an overview of the emissions and consumptions from common waste treatment processes/activities
- Sections 3.2 to 3.5: the emissions and consumptions from the different processes/activities covered by this document. Again, such structure/classification should not be interpreted as any attempt to interpret IPPC Directive or any EC waste legislation
- Section 3.6: the emissions and consumptions generated by the techniques used to abate emissions
- Section 3.7: the monitoring systems typically applied in waste treatment installations.

Sections 3.1 to 3.6 follow the order laid out in Chapter 2 so as to make it easier to cross reference between chapters. In addition, each of these sections have been structured in the same way following the material flow logical steps, i.e. waste IN (input), consumptions (input), emissions (output) and finally waste OUT (output). Table 3.1 explains this layout further.

Section	Title of the section	Information included
3.X.1	Waste IN	Description of the type of wastes that may be treated as well as their physico-chemical properties. This section is important because the type of waste input is relevant for the determination of eventual emissions, residual wastes and the composition of the waste outputs
3.X.2	Consumptions	Consumption of energy (i.e. fuel, heat, electricity) and chemicals (i.e. water, air, additives, catalysts)
3.X.3	Emissions	This includes emissions to air and water of any component as a result of the process operation or related to the waste input. Residues (also waste in many cases) related to the type of process are also covered in this section
3.X.4	Waste OUT	When the outcome of a certain process is to be used as input into another process, it is also important to know the physico-chemical properties of the output. In some cases, this detail is not important and is then omitted
X being from 1 to 6: 1 Common techniques, 2 Biological treatments, 3 Physico-chemical treatments, 4 Regeneration treatments, 5 Preparation of waste fuel and 6 Abatement techniques.		

Table 3.1: Structure of each section of Chapter 3

Figure 3.1 shows a diagram of the mass/energy balance of a typical operation/process/activity. A waste input (called in this document waste IN) is treated in an installation, producing a processed/treated output (called in this document waste OUT). To change the physico-chemical properties of the waste IN, it is necessary to provide to the system, energy and chemicals (e.g. water, air, acids, etc.) as required to support the particular treatment. Application/operation of the waste treatment then generates emissions to air and water, as well as a unusable waste and possibly a usable waste OUT. The unusable waste (e.g. waste lime, bottoms of storage tanks, sludges) is generated by the process/operations and is different from the target waste OUT. The reason for differentiating between the wastes is that the waste OUT may be used for different purposes, but process generated waste/residues is typically not re-used.

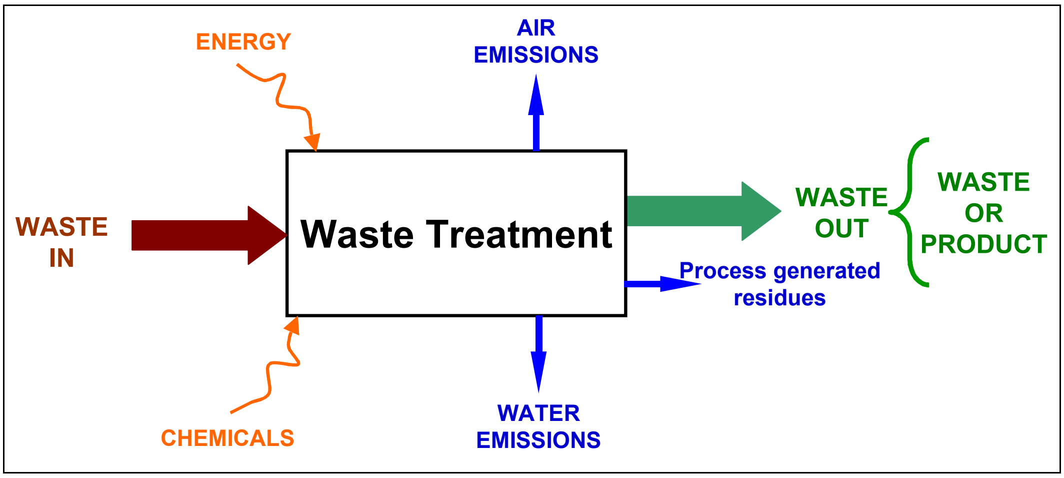


Figure 3.1: Inputs and outputs in a waste treatment operation
Note: Sections 3.X.1: Analysis of the waste to be treated, brown arrow; Sections 3.X.2: Analysis of the consumptions, orange arrows; Sections 3.X.3: Analysis of the emissions, blue arrows; Sections 3.X.4: Analysis of the waste treated, green arrow

Table 3.2 shows a summary of the main releases to the environment generated by WT activities.

	Substances released										
Source	**Particulates**	**NO_x, SO_x, HCl**	**NH_3,Amines**	**H_2S**	**HCN**	**VOCs**	**Odours**	**Other organics**	**Metals**	**Suspended solids**	**COD**
Common activities											
Acceptance (sampling/vehicle waiting)	A,W,L	A	A			A	A				
Transfer (pipework/pumps/valves)		A	A	A	A	A	A	W,L	W,L	W	W
Storage of solids (e.g. lime)	A,W,L										
Drum storage, bulk liquid storage and treatment vessels		A	A			A	A	A	W	W	W
Transfer and storage of wastes	A,W,L					A	A	A	A,W,L	W	W
Charging and mixing of treatment vessels	A,W,L					A	A	A	A,W,L	W	W
Removal of solid residues from vessel	A,W,L					A	A	A	A,W,L	W	W
Biological			A	A		A	A		W	W	W
Physico-chemical											
Precipitation/settlement and dewatering	W						A	W	W	W	W
Acid neutralisation		A	A$^{(1)}$	A		A$^{(2)}$	A$^{(2)}$	A$^{(2)}$ W	W		W
Alkali neutralisation			A				A	W	W		W
Chromic acid neutralisation									W		
Cyanide treatment					A		A				
Stabilisation	A,W,L		A			A	A			W	W
Waste oil treatment						A	A	A			W

Notes: (1) There is a specific problem with the treatment of sulphuric acid that has been used to scrub an amine release
(2) Conventional treatment of acidic wastes contaminated with solvents
KEY: To air (A) To water (W) To land (L)

Table 3.2: Summary of typical releases to the environment generated by waste treatment activities
[55, UK EA, 2001], [86, TWG, 2003], [150, TWG, 2004]

In order to complement the information directly provided by the TWG on emissions and consumptions of WT installations, a questionnaire was prepared and sent to TWG members (see Annex II). This was then forwarded by TWG members to WT facilities all over Europe. As a result more than 70 'filled-in' questionnaires were returned to the EIPPCB. A compilation of the data arising from this survey has been incorporated in this chapter and it has been referred as [66, TWG, 2003]. The consolidated analysis of the survey does not identify names, companies or specific figures or even identify individual comments from any specific company/site provider. Thus, data have been used in such a way so as to maintain confidentiality of the providers and preventing identification to any particular source.

3.1 Emissions and consumptions from common waste treatment processes/activities

[29, UK Environment Agency, 1996], [42, UK, 1995], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [116, Irish EPA, 2003], [150, TWG, 2004], [156, VROM, 2004], [157, UBA, 2004]

This section contains emissions and consumptions data for the pretreatments/activities and post-treatments/activities commonly used in the WT sector. It contains those emissions and consumptions related to the waste treatment processes described in Section 2.1. This covers those sites that transfer, bulk and store wastes.

3.1.1 Waste IN in common treatments

The type of wastes that may be involved in these processes is very wide especially for hazardous waste. Table 3.3 gives the percentages of sites that process a certain type of waste at hazardous waste transfer stations in the UK. Non-hazardous waste transfer stations cover municipal solid waste, etc.

Waste streams	% of sites processing each waste stream
Non-chlorinated solvent	67
Scrap metal	53
Scrap metal (drums)	47
Chlorinated solvent	40
General inorganic liquid/sludge	40
General organic	40
Waste for incineration	40
Contaminated waste for landfill	40
Drums/IBCs	33
Non-hazardous waste for landfill	33
Oil	33
Batteries	27
Asbestos	13
Fluorescent tubes	7
Oil filters	7
Oil/water mixtures	
Acids and alkalis	

Table 3.3: Common waste streams processed at hazardous waste transfer stations in the UK
[56, Babtie Group Ltd, 2002]

Some examples of waste IN for some common techniques are reported below:

Computer-controlled high rack storage areas for hazardous wastes
More than 600 different types (fluid, paste-like and solid hazardous wastes) of waste are treated.

Treatment of small quantities

This typically includes treatment, sorting and packing of hazardous wastes from private households, universities, laboratories, business enterprises and other customers. Additionally, the system can offer the possibility to condition inorganic material for underground disposal.

Shredding

The treatment is used for hazardous and non-hazardous waste. The wastes treated are solid and paste-like wastes, non-pumpable wastes like print and lacquer sludge, oil and other machining sludge.

3.1.2 Consumptions of common treatments

Although a number of sites run entirely on electricity, some have mobile or stationary plants that use diesel or fuel oils, or they have their own power plants that use gas (natural or biogas) or gasoil. Some common equipment that use fossil fuels are fork-lift trucks, small boilers, shredders and grinders. These take a mixture of standard vehicle diesel, and a range of fuel oils. Some waste plants in the UK have quantified their fuel use as ~200 tonnes per year. The proportion of raw materials (i.e. purchased reagents) used is relatively low as, in the first instance, wastes are used to treat other wastes. However, some new raw materials are used, as summarised in Table 3.4.

Raw material	Application	Principal environmental characteristics
Calcium hydroxide (lime)	Usually purchased in powder form for acid treatment	• hazardous substance • powder difficult to handle • produces large sludge volumes • for example, the treatment of sulphuric acid results in a large net production of calcium sulphate sludge
Sodium hydroxide (caustic soda) solution	Abatement reagent, typically used in wet scrubbing systems to control acid gases or as a scrubbing liquor in oil reprocessing	• hazardous substance • very low levels of mercury may be found in some grades of caustic soda, and these may be transferred to the installation effluent (see Section 4.1.3.5)
Ferric chloride solution	Additive to aid precipitation of metals and as a conditioning agent for sludge formation (as it helps with floc formation)	• strongly coloured in the event of a spillage or incident
Sodium hypochlorite	Used in the treatment and abatement for cyanide wastes scrubbing and odour control	• strong oxidising agent • stored away from potentially incompatible substances
De-emulsifiers	Used to 'crack' emulsified oil water mixtures in oil recovery processes	• high oxygen demand risk, if released to water in the event of an accident

Table 3.4: Examples of commonly used raw materials in waste treatments
[55, UK EA, 2001], [150, TWG, 2004]

3.1.3 Emissions from common treatments

Following the same structure as followed in Section 2.1, some individual sections on common treatments are discussed. At the end, the other common treatments not described before are covered in a tabulated form.

Energy systems
The use of fuels is a source of air emissions during combustion, and possibly of emissions to land as well due to spillage and leaks. The air emissions are predominantly CO_2 (carbon dioxide) and water from the combustion process, but can also include NO_x, SO_x, PM_{10}, PAHs, VOCs and CO (carbon monoxide). The emissions are related to the fuel specification and the age and use of the equipment (e.g. vehicles, biogas engines). Other pollutants that may appear are halogens (e.g. HCl and HF when waste is used as fuel within the installation) and metals.

The following table suggests a set of data that could be used to estimate the emissions. Data have been collected for three types of sources:

- line sources, including roads and railways (g/km)
- area sources, including emissions from agricultural and other land, and low intensity emissions from sources such as building heating systems
- point sources, including emissions from industrial plants.

The type of fuel used to fire in the energy system (e.g. furnaces, boilers, afterburner) will determine the nature of pollutants present.

	Type of fuel		
	Distillate	**Residual fuel**	**Diesel**
Air emissions			
CO_2[1]	3142	3112	3036 – 3142
PM			2.564
PM_{10}[1]	0.2	2.85	2.83
NO_x[1]	3.46	7.54	33.9 – 48.8
N_2O			0.041 – 1.3
CH_4			0.17 – 0.336
NM-VOC[1]	0.09	0.12	7.08 – 10.898
CO[1]	0.06	0.5	15.8 – 26.548
SO_2[1]	3.6	47.4	0.8 – 10.106
SO_x	19.56 x S[2]	20.42 x S[2]	
PAH[@](g)	0.15	0.151	4.07
Ni (g)	Tiny	1.1	
Cu (g)			1.7
Zn (g)			1
HCl			0.038
HF			0.038
Water emissions			
BOD			0.038
COD			0.038
Suspended solids			0.038
TOC			0.415
Phenol			0.038
Total metals			0.038
Cl			0.038
F			0.038

Units: kg (unless specified) per tonne of fuel

[1] Data sourced from the UK Emission Factors Database; gasoil (other sources) and Fuel Oil (other sources), from Australian National Pollution Inventory (converted from kg emissions per m^3 fuel) and European Environment Agency

[2] S is the % of sulphur in the fuel

[@] as benzo (a) pyrene

Table 3.5: Summary of data for small boilers using a distillate (gas), a residual oil (fuel oils 5,6) or diesel engines
[56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [65, EEA, 2003], [150, TWG, 2004]

Storage and handling

The main air emissions from the storage and transfer of waste are VOC emissions. According to the type of waste, dust may also be important. These comprise the major issues arising from handling wastes at transfer and treatment sites. The principal emissions arise from transfer and bulking activities since, in the majority of cases, any remaining residues in containers that may contain solvents will be vented to the air. General releases of VOCs from tanks due to thermal effects and releases from pipes and pumping systems can also occur but depend on the system installed in the plant structure.

Most of the fugitive emissions to air are from the transport, storage and bulking of organic wastes, primarily solvent wastes. Similar emissions are also expected from the transfer of ammonia wastes and from strong acid wastes.

The main emissions from decanting and bulking processes are to the air and may be related to the following although some of the practices mentioned below may be considered bad practices. If a practice is mentioned here, it does not mean that it occurs at the majority of sites):

- caps on the receiving containers, these may be open during the working day and give a continuous emission, albeit through a small aperture, of volatile components. This emission is particularly related to the displacement of saturated vapour from within the container with each new addition of liquid
- emissions directly from the liquids being transferred as the transfer takes place
- empty containers (drums, or bottles) which contain a measurable amount of waste materials, which, through rinsing out, is discharged to the on-site treatment process or to the sumps for disposal later. In some cases, these containers are placed in a skip for disposal to landfill or, when the contents are volatile, left to evaporate to air either with or without shredding. Such practice is actually not in accordance with the Landfill directive. Where the sites handle a large amount of solvents, drum-crushing systems can be used to squeeze and collect additional waste solvent from the drums
- the potential problem of leaks occurs during transfer, during displacement of the product in the headspace above the liquid layer, and when venting the residues from the original container. Where the material is held in storage tanks, there is an issue of outbreathing in response to atmospheric temperature and pressure. The problem is most acute with solvent transfers, but is also relevant to strong acids and wastes containing ammonia. Such practice is not considered to be a good environmental practice
- the transfer of materials from tankers to storage tanks, which are therefore controlled on a number of sites, particularly when this involves low boiling point solvent waste. The weakest link and subsequently the main source of spillage during transfer from the vehicle to storage arises from the transfer hoses
- although the volume lost during routine operations due to ill fitting or damaged hoses may be relatively small, persistent spillages may have a cumulative effect on the surface of the area, which in the long term may damage the surface and lead to a fugitive emission
- spillages may also be a source of odour
- the manual transfer of materials from small containers to 205 litre drums and IBCs. Typically this transfer has no control on emissions and it is common practice for the empty containers (containing perhaps 1 %, or up to 0.5 litres, of the original content) to be vented to the air prior to landfill. Such practice is actually not in accordance with the Landfill Directive

- with regard to monitoring and other activities on site, it is worth noting that:
    - most sites have little or no monitoring data for calculating emissions to the air and some kind of rough estimation method is needed to relate potential air emissions to the number of tankers or containers emptied or filled at the site
    - discharges to sewer or surface waters tend to have limited monitoring data as well, but the actual discharges are minimised by operational practices at the sites, such as bunding
    - transfer stations also undertake a range of other practices that can create emissions. These include the evaporation of solvents to the air from tank cleaning, from industrial wipes and from solvent sludges.

The range of emissions is very large and dependent on the type of activity (e.g. differences are particularly notable between physico-chemical treatment plants and oil re-processing plants). Each transfer of waste, and processing of the original container can generate liquid and vapour emissions. Some emissions generated by this activity are:

- tank bottoms from storage tanks
- air emissions generated by bulking in tanks loading and in unloading tankers due to displacement to the air (note: some transfer stations have very well equipped systems for balancing tanker emissions and controlling the discharges from tanks)
- evaporation emissions during decanting (e.g. VOCs) and bulking, also evaporation from wastes left in containers
- general spillages during decanting and handling. Spillages are typically retained in the bunded area or discharged to the interceptor
- air emissions generated by wiping cloths impregnated with solvents. In some installations, these are collected in sealed bin liners and then laid out to dry by evaporation to dryness prior to landfill. This is considered a bad environmental practice
- VOCs from the venting of empty drums being washed out (washings to underground storage tanks prior to landfill) and, from the evaporation of blanket wash solvents washed to the underground tanks
- emissions caused by bulking laboratory smalls. Emissions only typically occur in the event of spillages and are recorded in site diaries. General discussions at sites suggest that the number of substandard containers and badly labelled containers in this category are now minimal and that spillage and emissions due to poor containers is in fact rare
- accidental breakage of waste containers
- from storage tanks in the open, on hard-standing and bunded areas, and for which although the connections are over the bunded area, there is no system to deal with leaks from the collection/delivery systems and so the whole bunded area can become very contaminated. Rainwater in the bunded area will also become contaminated. On some sites, there is no provision to control displacement of air in the tanks during loading and unloading; others have very good control systems for both tanks and tankers. Air emissions are less well controlled. Tanks tend to have valve systems to regulate tank pressure and to allow inbreathing/outbreathing of headspace vapours. Emissions to the air can occur during tank charging or due to changes in atmospheric conditions. Small emissions will also occur during sampling and inspections. There is a potential for one-off larger emissions during tank cleaning
- non-evaporated liquids and solids, which may end up being landfilled or drained to sewer. This is considered a bad environmental practice
- fugitive air emissions from transfer operations between processes, especially with non-pumped systems. Also leaks from containers and from pressure/vacuum relief valves
- solid/liquid and gaseous emissions due to a possible container break in handling (accidental damage), depending on the waste material. Because the accident is reported in the site diary, the emissions can be estimated when the material is known
- in the case of the storage of waste oils, releases to the air come from condenser vents on hot oil storage tanks. On the storage tank, vents measurements for hydrocarbons are taken using Draeger tubes and typical values may be 10 to 20 mg/Nm^3 and peaking at 100 mg/Nm^3

- investigations into the microbiological pollution of waste sorting plants revealed mould fungi concentrations in the air at the workplace of up to more than 106 cfu/m^3 (colony-forming units).

Complementary to the information above, next Table 3.6 shows potential emissions from transfer stations, bulking processes and storage.

Activity	Description of release [1]	Release type	Release to
Filling of bulk storage tanks or IBCs by road tankers	Displaced air	VOCs	Air
	Losses from transfers	VOCs	Air
		Liquids	Soil
		Liquids	Water
Storage in bulk tanks	Vented material	VOCs	Air
	Tank bottoms	Waste	
Releases from pipes and pumping systems	All losses	VOCs	Air
		Liquids	Water
		Liquids	Soil
Gravity and vacuum emptying of drums, IBCs and other containers to bulk tanks	Displaced air	VOCs	Air
	Losses from transfers	VOCs	Air
		Liquids	Soil
		Liquids	Water
Storage and handling of empty IBCs	Washing	Liquids	Water
	Storage	VOCs	Air
	Disposal	Liquids/solids	Landfill
Storage and handling of empty drums and other similar containers	Crushing	VOCs	Air
		Liquids/solids	Water
		Liquids/solids	Soil
	Washing	Liquids/solids	Water
	Disposal	Liquids/solids	Landfill
	Storage	VOCs	Air
Maintenance of equipment	Tank cleaning/washing	Liquid/solid	Soil
		Liquid/solid	Water
		VOCs	Air
Planned evaporation of volatile liquids	Evaporation	VOCs	Air

[1] The wide range of possible emissions to air and sewer/controlled waters has to be estimated in relation to the range of activities and wastes handled at a particular site.

Table 3.6: Potential emissions from transfer stations, bulking processes and storage [56, Babtie Group Ltd, 2002], [86, TWG, 2003]

Emissions from some other common waste treatments

Table 3.7 summarises the most frequent activities/equipment found in common waste treatment processes and the emissions that may be generated.

Process/activity	Compounds found in WT processes that may lead to emissions
Air stripping columns	May cause a discharge of ammonia into the air which can be calculated by mass balance
Cleaning wastes or aqueous organic wastes from the chemical industry	These can contain a range of volatile compounds, chlorinated compounds and phenolic compounds. The solid and muddy residues produced during cleaning are disposed of as waste. If necessary, the waste is conditioned according to the acceptance criteria of the waste disposal facility
Crushing of oil filters	Waste contained in oil filters are particulate matter containing combustion products, including high PAHs/metal fragments, etc. 'stuck' together with oil. The solids from these operations tend to go into the oil water separation system for treatment plants, and leave with the bottom sludge. PAHs escape into the air with the oil mist produced during crushing or may be retained in the oil, or remain on the solids components of the filter. The PAH emissions to the air are potentially carcinogenic
Cutting	During drum cutting operations, the former contents of the drum and any residues that may be still present can be a cause of emissions
Washing of containers and vehicles	Fugitive emissions occur to air and water. Typically, a contaminated effluent is generated as well
Crushing and shredding	Regardless of the technique employed, there is typically no provision for environmental control and the emissions depend on the composition of the waste held within the drum. In the shredding process, the temperature of the shredded items may reach several hundred degrees. Shredding will cause emissions to the air, depending on the efficiency of the scrubber or other kind of air cleaning equipment. Fluids still present in the waste (e.g. solvents, mercury) may be released to the interior of the plant and may either evaporate or leak to the ground or may be collected as sludge. Dust from the plant will be spread to the surroundings. Other outlets from a shredding plant include a magnetic metal fraction, non-magnetic metal fractions, sludge from the washing process, and a fluff fraction which is a mixture of plastics, insulation materials, paper, soil, etc. The fluff fraction may be disposed of for incineration but sometimes is landfilled (not considered a good practice). A quite significant amount of heavy metals follows the fluff fraction. In the middle of the nineties Danish shredder plants shredded about 300000 tonnes waste. The fluff from the operation was estimated to contain about 0.15 tonne mercury, 200 – 1000 tonnes lead, and 0.5 - 2.5 tonnes of cadmium. The emission of mercury to air from the operations was estimated at <0.05 tonne
Drum and road tanker cleaning	Cleaning operations which specialise in cleaning drums that previously contained solvent and oil wastes may release large percentages of waste to the air since the solvent wastes are flushed to the air occasionally and in certain locations, during the cleaning process. This appears to be a similar issue to the evaporation of solvents to the air during decanting at certain transfer stations. The presence of any former content or any residue in drums may cause emissions during cleaning/washing operations. At some sites, unwashed drums might go directly to landfill along with the associated residues. A site processing drums contaminated with oil and organic materials estimated a 40 t/yr solvent discharge to the air. Part of this emission is due to the standard transfer station practice of venting 'empty' drums to the air. A site recycling drums from the inorganic sector had a high metals level in the discharge to sewer, but was able to calculate the discharge from regular analyses. Most treatment plants incorporate a washing out facility to enable the removal of residues from vehicle tanker barrels. In some cases, vapours may become trapped within the sludges and appropriate actions need to be taken to avoid any uncontrolled releases

Table 3.7: Activities/equipment that may lead to emissions from some common waste treatments [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [113, COWI A/S, 2002], [116, Irish EPA, 2003], [121, Schmidt and Institute for environmental and waste management, 2002]

Shredding

Parameter	Concentration	Unit
Dust	0.1	mg/Nm^3
SO_2	<0.06	mg/Nm^3
NO_x	8	mg/Nm^3
TOC	5	mg/Nm^3
CO	4	mg/Nm^3
HCl	13.8	mg/Nm^3
PCDD/PCDF	0.001	ngTEQ/Nm^3
Odour	85	GE/m^3
Cl	<0.1	mg/Nm^3
The flows of the exhaust air are 8028000 and 5628000 m^3/yr for the can shredder and the bin shredder respectively.		

Table 3.8: Exhaust air from shredding treatment of solid hazardous waste [157, UBA, 2004]

Emissions occurring due to accidents

The most significant environmental risks associated with waste treatment operations are the storage of hazardous wastes. This can involve emissions resulting from wastes reacting together, either from leaks and spillages or from treatment processes going out of control.

Procedure	Hazard	Hazardous event	Cause/possible initiating event
Sampling/ analysis	Toxic vapours	Chemical spray Blow-out Chemical spillage	Container under pressure Transfer from sampling vessel and withdrawal of sample (barrel-sampler) Waste not as expected
	Fire	Flammable materials ignite	Flammable vapour at point of sampling
General handling/ treatment	Toxic gases	Incompatible wastes mixed	Inadequate/incorrect information on wastes
		Waste spillage	Operator not working according to safe practices No safe operating procedures established Inadequate facility engineering Inadequate supervision Accidental discharge
Drum handling/ storage	Direct chemical contact	Blow-out	Contents under pressure
	Toxic gases Dusts	Spillages	Contents spilt during emptying/decanting Corroding/leaking drum Manual removal of contents
	Reaction Toxic gases	Mixing of incompatible wastes	Spillages/corroded drums Bulking up drums Wastes not conforming to labelling Wastes not adequately analysed
	Fire/ explosion	Flammable materials ignited	Unexpected flammable materials present Spark in taking lid off/flammable headspace Use of cutting tools to open drum Fire produces toxic degradation products

Procedure	Hazard	Hazardous event	Cause/possible initiating event
Unloading tankers	Toxic gases	Release as liquid/gas spray	Incompatible/reactive wastes mixed together Container under pressure/blow-out Unloading into wrong storage vessel Waste materials received 'hot' due to viscosity – solidification/thickening difficulties Gross failure of tanker Vehicle impact Spillage on coupling/uncoupling, failure of coupling
	Fire/ explosion	Flammable/ explosive mixture ignited	Flammable atmosphere in 'empty tanker'
Waste storage tank farm	Fire/ explosion	Flammable liquid or vapours ignite	Flammable vapour vented-off Vapour release from spills Pipeline failure Flammable vapour in tank headspace
	Reaction	Incompatible wastes mixed	Wastes react in storage vessels pipeline or conveyor failure
	Toxic gases	Non-compatible or reactive waste mixed in store or reagent spillage	Inadequate information on waste Waste does not conform to process specification
		Significant levels of toxic gases/fumes evolved	Inadequate venting of tanks, etc. Poor materials handling practices
Physico-chemical treatment	Toxic gases	Uncontrolled release during reaction	Failure of protective systems Incompatible waste mixed Wrong reagent added Too much/too little of reagents added Failure of pH control
Effluent dewatering from physico-chemical treatment	Toxic gases	Mixing incompatible effluents	Reaction not complete Residual contamination in effluents
Biological treatment		Fire	Biological degradation processes may cause self heating and auto-ignition. This does not only affects the biological treatment system. Auto-ignition may also occur in the bunker. In some cases fires can appear in the product storage area. A second reason for fires in solid waste fuel processing plants are particles that are still glowing.

Table 3.9: Example of most frequent accidents that may occur in WT installations
[80, Petts and Eduljee, 1994], [126, Pretz, et al., 2003], [150, TWG, 2004]

Generic air emissions from common waste treatments

VOC

There are no real data available at present on VOC emissions. The vast majority of sites that undertake air monitoring, undertake it on an irregular basis and are unlikely to take a sample at the times of maximum discharge. Air emissions are particularly difficult to monitor from these sites as operations are generally in the open air and gases are not always controlled. VOC emissions at a site may be due to:

- a deliberate process activity at some sites carried out in order to reduce the flammability of wastes going to landfill. The quantities may be very small per unit of waste, but the operation takes place across a large number of sites and the accumulated effect may be very large. This practice is not common in the sector and is considered a bad practice so is now obsolete
- the agitation or heating of mixed materials left to settle in contact with the atmosphere. Oil treatment tanks are one obvious example, but chemical treatment tanks or sludge mixing tanks are also sources
- emissions of semi-volatile PAHs from crushing and sieving operations, particularly from the handling of oil filters at transfer stations
- the transfer of liquids to bulking containers, with a subsequent displacement of the product headspace above the liquid layer
- the venting of residues from original storage containers; and also from storage tanks outbreathing in response to atmospheric temperature changes.

There are example plants in the WT sector with no controls on discharges of volatile compounds into the air, indeed few processes have ever been designed to discharge pollutants to the air.

Acid emissions

The most serious air emissions are likely to arise from solvent transfer and storage activities, but they can also arise from chemicals such as strong acids and ammonia.

Ammonia emissions

Ammonia is detected in some WT sites. There is a general problem with ammonia emissions. However, this is usually easy to spot on site visits and by operators due to the low threshold concentration for odour detection, although it is harder to quantify. Locations where ammonia emissions have been detected are:

- in solvent transfer and storage
- in the pressing and storage of effluent sludge at several chemical treatment plants. This is an area that is rarely within the exhaust systems for the site and therefore emissions do not pass through the plant scrubbers. Furthermore, the scrubbing systems are usually caustic scrubbers
- from strong ammoniacal solutions directly to the air after an air stripping at one site, although the site monitoring (only annual monitoring carried out) says that background atmospheric levels are minimal
- effluent treatment plants
- acid treatment of waste oils
- wastes from the photographic industry are an example of a waste stream with a high concentration of ammonium salts and, although discharges to the air are not identified, this is a potential problem during transfer processes, giving rise to air emissions and potential contamination of water discharges.

Fugitive and diffuse emissions

In many installations, fugitive and diffuse emissions may be more significant than point source or channelled emissions. Common examples of the sources are:

- open vessels (for example, the effluent treatment plant)
- sampling activities
- storage areas (for example, bays, stockpiles, lagoons, etc.)
- the loading and unloading of containers
- transferring/bulking up of material from one vessel to another
- conveyor systems
- pipework and ductwork systems (for example, pumps, valves, flanges, catchpots, drains, inspection hatches, etc.)
- poor building containment and extraction
- potential bypass of abatement equipment (to air or water)
- spillages
- accidental loss of containment from failed plant and equipment
- tankers and vessels, manhole openings and other access points
- displaced vapours in receiving tanks
- cleaning or replacing of filters
- drum cutting
- waste water storage
- drum storage
- tank cleaning
- tanker washing/cleaning.

Particulate emissions

Sites handling powders and wastes giving rise to dusts (e.g. fly ashes) often have particulates to emit to the air.

Noise and vibration

‘Noise’ refers to ‘noise and/or vibration’ typically detectable beyond the site boundary.

Odour emissions

Emissions to air tend only to be checked subjectively by using the sense of smell. Odour emissions are associated with point sources as well as fugitive sources. In addition to ammonia previously discussed, the handling of any substance that is or may contain a VOC (or other odorous substances, for example, mercaptans or other compounds containing sulphur) will potentially lead to odour noticeable in and beyond the installation boundary. Odours may arise from:

- storage
- the transfer or bulking up of wastes containing VOCs or other odorous substances
- a failure to adequately inspect and maintain plant and equipment, which may lead to fugitive emissions, e.g. leaks from pumps.

Generic water emissions from common waste treatments

A distinction can be made between installations conducting ‘dry’ or solid phase operations, e.g. transfer or stabilisation, which do not produce a distinct liquid effluent; and those conducting liquid phase treatment, e.g. acid neutralisation and oil water separation.

‘Dry’ processes typically only produce effluents from activities such as from rainwater collection and incidents such as spills and leakages. In general terms, the strength of this effluent in terms of metals and COD levels will be relatively low. ‘Wet’ processes, in addition to the general effluent arising from yard drainage, etc., produce an effluent from the reaction, precipitation, settlement and dewatering processes.

Waste water may be generated in the installations due to:

- unplanned discharges to drain (e.g. emergency control, fire)
- spillage from storage
- discharge to storm drain
- discharge of bund and secondary containment contents
- process waste water (each case is covered from Section 3.2 to 3.5).

Many transfer stations are associated with adjacent treatment plants and all run-off goes into that treatment system where is treated. Others collect the run-off and tanker this to landfill. Again there is no discharge to receiving waters or sewer. The remainder of the installations discharge either to surface water (unusual option) or to sewer. In the vast majority of EU countries, it is not permitted to make direct discharges to sewer or to controlled waters. A security storage is then needed in order to control or treat the water before discharge. Some typical emissions are summarised in Table 3.10:

Emission to	Unit process or activity
Sewer	Physico-chemical treatment. Final effluent from acid/alkali neutralisation and the precipitation of metals
	Oil reprocessing. Effluent treatment to remove oil from condensate and yard drainage
	Cleaning
Watercourse	Rainwater collection
	Yard drainage

Table 3.10: Point source emissions to water
[55, UK EA, 2001]

In principle, there will always be small quantities of every material decanted at the site discharged to sewer, due to drips and splashes even if there are no spills recorded. The most common materials to be bulked at transfer stations are dilute acids (often from metal treatment), caustic solutions, oils, non-halogenated solvents and aqueous organic wastes. The discharge is almost certain to contain organic carbons, nitrogen compounds (total nitrogen), chloride, some metals and, when bulking non-halogenated solvents, xylene. Discharges to sewer may reach COD levels of several thousand milligrams per litre. The nature of the discharge depends on the wastes being handled at the installation, which invariably involves a wide variety of substances, thereby resulting in a complex effluent.

Emissions to water also occur from washing containers and tanks if this occurs in the WT plant. Liquid discharges may arise from the washing and processing of containers prior to their re-processing, or from the washing of road tankers. One approach of estimating these emissions is to assume that the residual material in each type of container after emptying is 0.5 % of the volume, and that all of this material is washed to sewer. In general, volatile residues from containers of solvent waste are evaporated directly to the air rather than being washed to sewer.

General leaks and spills can occur in waste transfer stations. Most sites are on hard standing and liquid and solid spills are eventually washed away to the main interceptors and then to sewer or to an adjacent treatment plant.

Generic releases to soil and process generated waste from common techniques

Most sites will have a continuous, but small, discharge of waste to the site base-ground due to drips, splashes, crushing residues, pipe connections, oil leaks, etc. and these may be washed to the surface water collection points by rainwater and site cleaning. Tank bottoms are another typical waste when storing waste.

Example of inventory of emissions from a waste transfer station

<table>
<tr><th>Operation</th><th>Emissions to air (kg/yr)</th><th>Emissions to sewer (kg/yr)</th></tr>
<tr><td>Repacking and labelling of laboratory chemicals</td><td>0</td><td>0</td></tr>
<tr><td>Breakage/leaks during loading and storage</td><td>VOC as TRI 20.3</td><td>Small amounts of oil, but these will be picked up in weekly monitoring data and not doubly counted here</td></tr>
<tr><td>Decanting into IBCs</td><td>Dichloromethane 360
Ethanal 48
Trichloroethylene 60
VOC as TRI 60
VOC 1320
Xylene 360</td><td>All solvent species
Total nitrogen
Total phosphorus
Chloride
TOC
Metals</td></tr>
<tr><td>Transfer from IBCs to solvent storage tanks</td><td>ethanal 76
VOCs 1330
xylene 570</td><td>Xylene
TOC</td></tr>
<tr><td>Fuel use for fork lifts (Use of 5 tonnes of diesel per year)</td><td>CO 79
CO_2 15710
NM-VOC 35.4
NO_2 244
PM_{10} 14.15
SO_2 4</td><td>TOC</td></tr>
<tr><td>Sewer discharges</td><td>0</td><td>TOC 5980
NH_3-N 14
Cu 0.5
Ni 0.5
Zn 0.5
Oil 150
Xylene, toluene, TRI, trichloroethylene, Cl, P trace discharges</td></tr>
<tr><td>Totals</td><td>CO 79
CO_2 15710
Dichloromethane 360
Ethanal 124
NO_2 244
PM_{10} 14.15
SO_2 4
TRI 80.3
Trichloroethylene 60
VOC 2706
Xylene 930</td><td>TOC 5980
NH_3-N 14
(assumed cannot reach limit for nitrogen)
Cu 0.5
Ni 0.5
Zn 0.5
Oil 150
Xylene, toluene, TRI, trichloroethylene, Cl, P</td></tr>
<tr><td colspan="3">Overview of the installation
The above data correspond to a hazardous waste transfer station fitted with an impermeable base. It has bulking areas with blind sumps and a roof. The solvent storage tanks are in a separately bunded area with activated carbon filters on vents. Thermal out-breathings and head space displacement losses due to charging the storage tanks, are scrubbed prior to be discharged into the air. Loading, unloading and drum storage areas of the site are in the open and drain to the interceptor, hence to the sewer. There is a continual monitoring of pH and flowrate, and a weekly monitoring of COD, metals, oil, ammoniacal nitrogen and suspended solids on the sewer discharge. Packaging materials and old contaminated containers are sent to landfill.
The site handles a very wide range of materials, but mainly the following streams:
• halogenated solvents comprising on average 80 % solvent; 20 % solids. Of the solvent fraction, 10 % is trichloroethylene; 10 % 1,1,1 trichloroethane; and 60 % dichloromethane
• non-halogenated solvents, on average 70 % solvent, 30 % solids and water, with the solvents comprising 10 % toluene; 30 % xylenes; 10 % acetone, 20 % others, mainly MEK, ethanol, ethanal, methanol and aliphatic C_{10}-C_{12} hydrocarbons
• the other major waste streams are dilute hydrochloric acid and zinc, sulphuric acid and phosphoric acid from metal processing, soluble oils, dilute caustic soda, dilute ammonia solutions from photographic processes, aqueous paint residues, aqueous adhesive residues and ethylene glycol. All of these are bulked prior to onward transfer or storage.
Waste OUT produced is 120 tonnes of waste fuel and 60 tonnes of halogenated materials per year. The installation handles 120 tonnes of waste from IBCs filled at the site and a further 260 tonnes of waste that arrives in IBCs.</td></tr>
</table>

Table 3.11: Example of total estimated emissions from a waste transfer facility
[56, Babtie Group Ltd, 2002], [86, TWG, 2003]

Emissions from specific waste treatments

Specific waste treatments	Air	Water	Waste
Aerosol destructor - crusher	In some cases, propellants are discharged to the air via the exhaust fan	A mass balance suggests that emissions to water could be as much as 250 t/yr, but there is insufficient detail on the tonnage of liquid waste produced at present to make an accurate calculation	Liquids from the crushing process are collected and sprayed onto the adjacent landfill
	The active ingredients and carrier solvents can include materials such as paint thinners, alcohols, and possibly some pesticides		
CFC recovery treatments	The oil waste will contain some CFCs that evaporate in the air. A small additional discharge will occur during routine sampling	Discharges can be estimated	CFC refrigerants are recovered for re-use and generate a small stream of oil, that is sent for further treatment. A tiny amount of used dessicant (contaminated with oil) goes to landfill each year
Delivery storage and transfer of materials	VOCs, acids or ammonia wastes		
Glass crushing	There are large problems with particles, despite the presence of extractor fans, with dust settling on equipment, the plant and on the finished product. Abatement equipment is not fitted		
PCB cleaning	A monitoring programme typically covers PCB discharges to the air, to surface waters and to the land in the vicinity of the installation. The trichloroethylene (TCE) is distilled on site for re-use, and the residual sludge is sent for incineration.		
Cleaning of transformers containing PCBs	Decontamination of PCB transformers is never completely applied to all components, and this means that a residue remains which must be incinerated. In the best case this will be just the porous parts (wood and paper), unless the solvent technique is applied for long process times, and a product will finally be obtained which can be sent for land-filling if the residual PCB levels are legally acceptable. There is potential for fugitive emissions of PCB via the formation of aerosols.		

Table 3.12: Emissions from specific waste treatment processes
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [100, UNEP, 2000], [150, TWG, 2004]

3.1.4 Waste OUT from common waste treatments

Depending on the type of operation of the treatment technique, the physical and/or chemical properties of wastes may change when common techniques are applied. However, it is found that some common techniques (e.g. storage, acceptance, reception) do not change the chemical or the physical properties of the waste IN. On the other hand, others such as, for example, blending, mixing, crushing, shredding, change the properties of the waste IN.

3.2 Emissions and consumptions from biological treatments

[33, ETSU, 1998], [51, Inertec, et al., 2002], [54, Vrancken, et al., 2001], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [66, TWG, 2003], [76, EEA, 2003], [81, VDI and Dechema, 2002], [86, TWG, 2003], [113, COWI A/S, 2002], [138, Lanfranchi, 2003], [150, TWG, 2004]

This section discusses the emissions and consumptions of the biological treatments mentioned in Section 2.2. Each section of this Section 3.2 is structured in the same way as Section 2.2, namely the treatments follow the order of: emissions and consumptions of anaerobic digestion, mechanical biological treatments and lastly biological treatments applied to contaminated soil. Emissions associated with an ancillary treatment, e.g. transfer station operation, are covered in Section 3.1.

3.2.1 Waste IN in biological treatments

Generally successful biotreatment only occurs when the waste is non-toxic (although micro-organisms can acclimatise to some extent and to certain wastes), within the relatively narrow pH range of pH 4 – 8, and with a C:N:P ratio of around 100:5:1. Biological treatment is, if well prepared, able to be adapted to a great variety of organic compounds which can be found in wastes or contaminated ground.

Anaerobic digestion

Anaerobic digestion may be used to treat liquid or solid wastes directly (e.g. MSW), or to treat the biological sludge generated by an earlier aerobic stage. There are a number of possible feedstocks which can be used in anaerobic digestion. These include the following: source separated food waste, sludge (e.g. sewage sludge from municipal waste water treatment), agro-industrial by-products, manure, slurries, some fractions of the MSW, and yard waste.

Anaerobic digestion (AD) is better suited to waste with a higher moisture content than aerobic digestion. The process of AD can occur between 60 and 99 % moisture content. Moisture content is also important. A low value increases both the ammonium inhibition of the AD process and the salt toxicity. Therefore, kitchen waste and other putrescible wastes, which by themselves may be too wet and lacking in structure for aerobic digestion, can provide an excellent feedstock for AD. Liquids are often added to the AD processes (either water or recycled effluent) to maintain a high moisture content.

The characteristics of the feedstock have very important effects on the AD process. A high quality feedstock will increase the quality of the digestate. High heavy metal concentrations in the feedstock can be toxic to methanogenic bacteria, in the following order (of increasing severity): iron<cadmium<zinc<chromium<lead<copper<nickel. The volatile solids content will affect the extent to which the process needs to be monitored to avoid the damaging effect of overloading.

The type of waste accepted in this type of treatment is, principally, source separated biodegradable waste, since matter and nutrients are to be recovered with minimal contamination, composting of residual waste or separated fractions thereof is becoming increasingly uncommon. Therefore, the types of waste typically used are the wet organic fractions from kitchen waste and from hotels and restaurants. Garden and park waste and paper and board are not usually processed. Some waste fractions excluded are metals, plastic, glass, animal waste, which is undesirable at plants without hygienisation due to the degradation of lignin which requires post-digestion composting.

There are two main alternatives for waste separation. The choice between them has an important bearing on the anaerobic digestion feedstock quality:

- source separation (not covered under the scope of this document) – this is actively encouraged in a number of Member States. It includes separation of the putrescible organic fraction (biowaste). It is generally accepted that source separation provides the best quality feedstock for both AD and composting, offering both a maximum organic content and a minimum contamination with heavy metals, glass and plastics. After digestion of this source separated waste in a reliable process, the end result will be the formation of a quality digestate and a high volume of biogas
- centralised separation – this is is the only route for obtaining a digestible fraction from residual waste. The techniques involved include mechanical processing, optical processing and hand-picking. The digestible fraction obtained tends to be more contaminated than source separated biowaste, with inevitable consequences for the digestate's ultimate utilisation (there is some evidence that where pulping is used as a pre-process sorting phase, liquid separation can lead to the removal of some more hazardous elements). There is also the risk of larger non-separated components of the waste being carried over and then causing physical damage to treatment plants further downstream (by abrasion, blockages or tangling).

Mechanical biological treatments

The types of waste that may be accepted by this treatment are non-source separated municipal waste, sludge (e.g. sewage sludge from municipal waste water treatment plants) and commercial solid waste. Technically speaking, there is no restriction in also treating a wet organic fraction (e.g. kitchen wastes), garden and park waste, organic waste from hotels and restaurants or paper and board. However typically these last types of waste are not usually treated by these treatments.

The moisture content of intake waste is extremely variable, but it would be expected that green wastes and household wastes have a moisture content of at least 40 – 50 %.

Biological treatments applied to contaminated soil

Characteristic	Desired range
Organic content	0.025 – 25 w/w-%
Solid content	10 – 40 w/w-%
Water content	60 – 90 w/w-%
Solids particle size	<0.635 cm. diameter
Feed temperature	15 – 35 °C
Feed pH	4.5 – 8.8

Table 3.13: Desired inlet feed characteristics for slurry biodegradation processes for soil decontamination
[30, Eklund, et al., 1997]

The effectiveness of slurry biodegradation for certain general contaminant groups is shown in Table 3.14.

Contaminant	Applicability
Organic contaminants:	
Halogenated semivolatiles	2
Non-halogenated semivolatiles	2
Pesticides	2
Halogenated volatiles	1
Non-halogenated volatiles	1
Organic cyanides	1
PCBs	1
Dioxins/furans	0
Organic corrosives	0
Inorganic contaminants:	
Inorganic cyanides	1
Asbestos	0
Inorganic corrosives	0
Non-volatile metals	0
Radioactive materials	0
Volatile metals	0
Reactive contaminants:	
Oxidisers	0
Reducers	0
KEY: 0 = No expected effectiveness - expert opinion is that the technology will not work 1 = Potential effectiveness - expert opinion is that the technology will work 2 = Demonstrated effectiveness - successful treatability test at some scale has been completed	

Table 3.14: Applicability of slurry biodegradation for treatment of contaminants in soil, sediments, and sludges
[30, Eklund, et al., 1997]

3.2.2 Consumptions of biological treatments

Anaerobic digestion
The consumptions of a mechanical-biological treatment (MBT) containing separation and anaerobic digestion are typically: water, auxiliary materials and energy:

Water
The total water consumption for treatment of 1 tonne of waste is 78 litres. This treatment uses either tap or groundwater. Water is consumed in the following process steps:

- steam production: 22 litres per tonne waste
- production of polymer solution: 56 litres per tonne waste.

Auxiliary materials
The following products (delivered by truck) are used as auxiliary materials:

- anionic polymeric flocculants (polyacrylamide powder): 60 grams per tonne waste
- iron chloride solution (40 w/w-%): 3 kilograms per tonne waste
- anti-foaming products (polyalkylene glycol solution in water): 50 grams per tonne waste.

Energy

The only energy source which is used during the normal operation of the installation, is electricity, which could be generated on-site, and heat, which may be needed for possible drying processes and for heating the buildings. The electricity use per tonne of waste is 55 kWh_e. This electricity could be generated at the installation itself by the combustion of biogas in a biogas engine (efficiency: 35 %). The biogas consumption for electricity production is 29.1 Nm^3 biogas containing 55 vol-% CH_4 (i.e. 37 kg). The electricity production and the energy use is given in the Table 3.15.

Energy type	kWh per tonne MSW	Source
Electricity input	50 – 55	Own production (biogas engine)

Table 3.15: Electricity consumption and production
[54, Vrancken, et al., 2001], [59, Hogg, et al., 2002], [66, TWG, 2003]

Up to one third of the biogas produced is needed to heat the digester itself, since the process requires warm conditions.

Estimates concerning the utilisation of electricity by the plant vary a great deal. In rural AD plants, approximately 20 % of the electricity produced in the process is required for the plant operation, while urban plants may utilise 2/3 of the electricity produced.

Mechanical biological treatments

MBT technique	Aeration rate (Nm^3 air/(m^3 of waste.h)
Tunnel:	40 – 60
Moving heap pre-degradation after degradation	 5 – 10 1 – 5
Heap	10

Table 3.16: Aeration rates
[132, UBA, 2003]

In quasi-dynamic biological systems the major part of organic waste contents is degraded within the first four weeks of biological degradation. During this period, the highest aeration rates are needed and up to 60 or 70 % of the total heap air supply is consumed. In the case of process interruptions in the pre-biological degradation, biological degradation is deferred towards the later biological degradation phases/aeration fields. The same holds for static processes without turnover. In the case of upstream fermentation, the intensive degradation of the easily degradable organic components occurs in the closed fermenter. Thus the exhaust gas quantities from the after-degradation are strongly reduced compared to fully aerobic degradation processes.

Energy

Aerobic process	Electricity (kWh/t)	Diesel oil (kJ/kg)
Enclosed aerobic digestion	27 – 65 [2]	5
Windrows	0	15
Range[1]	4 – 72 [2]	5 – 132 [3]

[1] Range contains different types of installations with more or less sophisticated gas treatments and without gas treatments
[2] Higher end of the range typically corresponds to process with advanced purification of exhaust gases
[3] Higher diesel consumptions are associated with a lower electricity consumptions

Table 3.17: Specific energy consumptions of aerobic digestion processes
[59, Hogg, et al., 2002], [66, TWG, 2003], [150, TWG, 2004]

Water
MBT plants sometimes add water to the windrows, as moisture is lost during the aerobic digestion, which could otherwise lead to a shortage of water and halt the aerobic digestion process. This typically occurs during summer and winter months.

In some cases, there is no net water consumption in the process. In the drying process, water is produced (350 litres -in vapour form- per tonne waste). During the aerobic digestion, temperatures of 50 – 60 °C are reached. Thus, water lost from the feedstock becomes water vapour (about 90 %) and is typically released to the air. However, in some cases, some of this water is condensed. The treatment of this condensation water is quite complex.The purified waste water (permeate) is used as process water in the cooling circuit. It is evaporated in the cooling tower. Tap water is only used in the cooling tower as make-up water (10 litres per tonne of waste). However, other sources reported that the water consumption range from 260 - 470 litres per tonne of waste treated.

Auxiliary products
As reported, no auxiliary materials are used in the process, except for the plastic foil used to bale the waste solid fuel.

Biological treatment of contaminated soils
Most often, organic pollutants are used as a source of carbon and energy by micro-organisms. Also, the concentration of nutrients like nitrogen and phosphorus must be adjusted to support microbial growth. Usually, an ammonium salt like NH_4Cl is used for nitrogen addition and phosphorus as phosphate salt. However, micro-organism growth needs lots of elements like vitamins and some metals (Fe, Mg, Cu, etc.). These elements can be naturally present in soil but improvement can be sometimes necessary. C/N/P ratios are sometimes used to determine the total quantity of nutrient necessary. In fact, a regular control of nutrient concentration in soil must be achieved. Polluted soil is sometimes mixed with compost to optimise biological treatment. Compost addition is most often included between 10 and 30 % and never exceeds 40 %. Water is sometimes also used in order to increase the moisture content in the soil.

Oxygen and nutrients (N and P) are added to the contaminated soil to biostimulate the biodegradation. Increasing the micro-organisms flora with specific organisms (e.g. bacteria, fungus), increases the biodegradability of the contaminants.

3.2.3 Emissions from biological treatments

The specific emissions from biological treatments depend on:

1. volatile components already being a content of the feedstock,
2. the amount and type of waste being treated and
3. on the type of treatment.

For example, wastes derived from biological sources (such as rendering or food industry effluents) are less likely to produce high emission loads. Thus, e.g. the emissions (loads of TOC, methane, N_2O, ammonia, etc.) from the biological treatment of separately collected biowaste (not covered in this document) are comparable to the emissions from the biological treatment of MSW and sludge except for some volatile VOC ingredients from MSW (e.g. fluorinated chlorinated hydrocarbons).

heavy metals in the original material will be well mixed with the rest of the material, by dissolution, extraction or simply by being torn into small pieces during the operation.

A common characteristic of the biological treatment is that heavy metals and other non-biodegradable components are subjected to dilution by mixing, dissolution in the aqueous phase, become part of the body of the micro-organisms, concentration by loss of moisture and weight and so on. In general, heavy metal compounds are not selectively separated from the waste and not selectively concentrated to a target output material.
Volatile chemical constituents are the most likely to result in fugitive air emissions, together with ammonia. Municipal wastes tend to produce metals in the effluent or sludge.

Anaerobic digestion
Figure 3.2 shows the relevant emissions from anaerobic digestion processes.

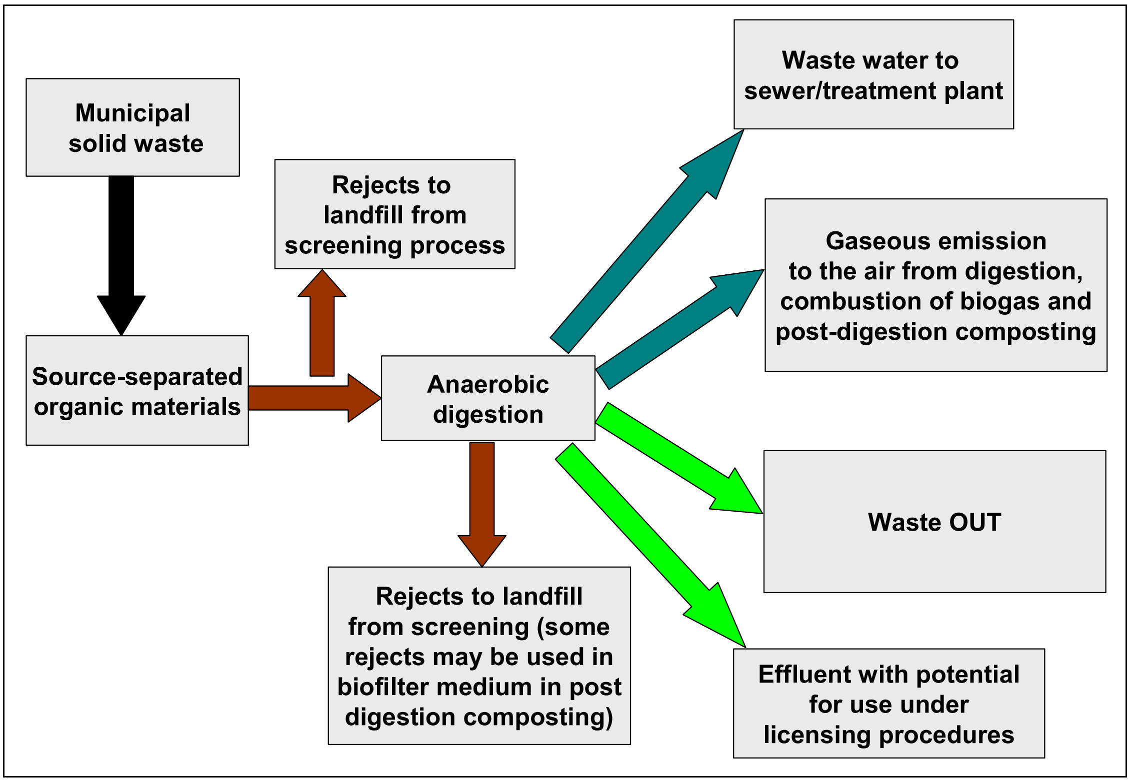


Figure 3.2: Schematic representation of anaerobic digestion inputs and outputs
Note: Brown arrows represent solid materials
Blue Arrows represent emissions
Green Arrows represent waste OUT with some use
[59, Hogg, et al., 2002], [150, TWG, 2004]

<u>Air emissions</u>
This process is enclosed and air emissions are unlikely to occur except during transfer to and from the digester. Anaerobic systems generate less emissions than aerobic systems per kilogram of waste, since the principal gaseous emission (methane) is a desired product. However emissions related to the delivery of waste and mechanical treatment may cause emissions of odours and dust and the aerobic digestion of the digestate may cause a significant odour problem if not properly treated. The emissions generated by the combustion of the biogas are typically higher than the emissions generated during the biogas production process.

A simple mass balance would suggest that, if the input material has a moisture content of 70 %, and if the volatiles solids content of the remainder is 80 %, then the input waste must contain 240 kg of volatile solids. Unscreened stabilised biomass might account for 40 % of the initial weight, of which 40 % might be moisture with the remainder having a volatile solid content of 40 %. This implies a loss of 144 kg, volatile solids, if the incoming material has a moisture content of 70 %.

As already stated, since the digestion process is enclosed, air emissions are unlikely, except during transfer to and from the digester. However, fugitive emissions of biogas are possible from emergency vent valves and from poorly sealed water traps. This can result in a range of hazards, including the risk of fire or explosion, as well as toxicity from contaminant gases such as H_2S and mercaptans (generating odour). Nitrogen gases also are possible.
Particulate emissions are also less likely than from aerobic digestion because the process is enclosed, but there will probably be some waste preparation units which may have larger particulate emissions.

Component	Emissions concentration	Unit	Specific emission (g/tonne of waste)	Specific emissions (g/MJ of methane)
Flue-gas				11000 Nm^3/t
Methane	Fugitive	vol-%	0 – 411	0.1
CO_2	31 – 35.2	vol-%	181000 – 520000	85
CO			72.3	0.25
NO_x			10 – 72.3	
NH_3	Fugitive			
N_2O			0	0.2
SO_x			2.5 – 30	0.15
H_2S	284 – 289	mg/Nm^3	0.033	
TOC (VOC)			0.0023	
PM (e.g. bioaerosol)				
Odour	626	GE/Nm^3		
Chloroform	2	$\mu g/Nm^3$		
Benzene	50 – 70	$\mu g/Nm^3$		
Toluene	220 – 250	$\mu g/Nm^3$		
Ethylbenzene	610 – 630	$\mu g/Nm^3$		
m+p+o xylene	290 – 360	$\mu g/Nm^3$		
Halogenated HC and PCBs			0.00073	
Dioxins/furans (TEQ)			$(0.4 – 4) \cdot 10^{-8}$	
Total chlorine	1.5	$\mu g/Nm^3$		
HCl			0.011	
HF			0.0021	
Cd			$9.4.10^{-7}$	
Cr			$1.1.10^{-7}$	
Hg			$6.9.10^{-7}$	
Pb			$8.5.10^{-7}$	
Zn			$1.3.10^{-7}$	
Fugitive means that fugitive emissions of these components occur but no data have been provided to quantify it				

Table 3.18: Examples of gaseous emissions from anaerobic plants
[33, ETSU, 1998], [54, Vrancken, et al., 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [150, TWG, 2004]

Water emissions

Although anaerobic systems can be operated in stages to reduce the overall COD in the effluent, they are generally operated for efficient methane production, and the liquid effluent thus tends to be more concentrated than the effluent from aerobic systems.

The emission species will be similar to those from aerobic systems, but the volume of liquid is much higher and measurements will be needed to calculate emissions (e.g. TOC). The aqueous fraction may be discharged to sewer, or it may go through an aerobic waste water treatment prior to discharge. TOC, total nitrogen, total phosphorus and chloride levels will need to be monitored at the plant inlet and outlet to optimise plant performance, and are probably the most relevant indicators for such optimum performance.

Those units processing biological wastes from the food industries or agriculture are unlikely to produce metals in the liquid emissions. Moreover, the metal content in a discharge may be lower than for an equivalent aerobic system because metal compounds are precipitated and leave with the solid fraction. However, a small amount can appear in the liquid effluent as suspended solids.

The quantity of waste, or excess water generated depends upon a number of factors (extent of biodegradation, moisture content of input wastes and the extent to which the process water is recirculated, the way in which digestate is used -in some cases it is directly applied to land as slurry- and the degree to which steam is used to heat the biomass). Most processes seek to extract excess water from the digestate prior to aerobic digestion of the remaining biomass. In some countries, however, little or no attempt is made to do this and the digestate is used on land as a soil conditioner. Some site studies state 100 – 500 kg per tonne of waste (wet weight). The excess waters are likely to be more polluted from dry systems, since more water is recirculated in the wet systems. Figures for wet and dry systems are given in Table 3.19. The figures on dry and wet systems in Table 3.19 relate to the waste water before removal of the suspended solids. In the post-treatment phase, the liquor from the digestate may be subjected to a process of denitrification, or filtered and/or fed to a decanter, with solids potentially being added to the digestate and the excess water being delivered to sewer.

Components	Units	Dry systems	Wet systems	Amount (g) [1]
Waste water flow	m^3/t			0.47
COD	mg O_2/l	20000 – 40000	6000 – 24000	20 - 530
BOD	mg O_2/l	5000 – 10000	2500 – 5000	
Ammonia				1 – 160
Nitrate				1 – 10
Total N	mg N/l	2000 – 4000	800 – 1200	
Total P				
Cl				
Sulphate				1 – 5
As				
Cd				
Cr				
Cu				
Hg				
Ni				
Pb				
Zn				

[1] Based on 261 litres of waste water/tonne waste (possibly to be reduced to 211 litres by means of a partial re-use of the water used for the production of polymer solution). The range depends on the type of waste water treatment applied

Table 3.19: Typical waste water characteristics from anaerobic digestion
[59, Hogg, et al., 2002], [33, ETSU, 1998], [56, Babtie Group Ltd, 2002], [66, TWG, 2003]

Digested matter and waste

Concerning anaerobic digestion, the sludge or digestate is usually dewatered. The content of heavy metals may be leached out to soil or washed off into watercourses if the digestate is used as a compost, a soil cover or landfilled. In the event the content of heavy metals is too high to allow a land application, the compost/sludge may be used for daily covering at landfills. In this aspect, the groundwater Directive may be applied.

As the resulting anaerobic sludges are generated in a reducing environment, such sludges may concentrate some compounds such as metal sulphides and some organics (e.g. non-soluble intractable organics). The sludges processed from MSW or sewage sludge with an industrial feed will have a metal content in the waste intake, which will be deposited in the sludge.

The sludge cake, generated in the waste water treatment plant can go for a further chemical purification. If no purification is carried out, the sludge cake needs to be disposed of by landfill or can be (co-)incinerated. The residue of the sand washing is probably not suitable for thermal treatment, due to its low calorific value, and thus is disposed of by landfill.

Mechanical biological treatments
The loss of weight during the aerobic process is about 10 – 20 % of dry substance matter of input waste, equivalent to 30 – 40 % loss referred to the total weight. However, these data do not differentiate between moisture loss and carbon dioxide production. Aerobic systems operated in the open are more likely to create a wide range of emissions because the temperature and moisture content of the process is harder to control. There is much more chance that the material will saturate and produce a liquid emission, and a higher chance of the process turning anaerobic with subsequent emissions of methane.

Various companies co-digested hazardous organic waste streams with municipal or green wastes and low concentration of halogenated organics with aqueous organic wastes. In both cases, it is reasonable to expect the biomass to adapt to a new food source, but it is also reasonable to expect that the temperature rise in composting, or agitation of the tanks in activated sludge systems, will create a discharge to the air of new species.

By contrast to composting plants treating green waste and separately collected biowaste, the material treated in MBT plants may exhibit a broad range of emissions (municipal waste). MBT exhaust gas may contain fluorinated chlorinated hydrocarbons, ammonia, mercury, methane, N_2O and other compounds.

The MBT exhaust gas is partially produced during the mechanical treatment, but mostly is related to the biological process in which heat is released. Depending on the process, management temperatures from 30 up to 90 °C may be reached. Thus a great part of the moisture contained in the waste is driven out. Furthermore, the remains of solvents and of mineral oil carbohydrates can be driven out. Under these boundary conditions, the MBT exhaust gas contains at least the following material groups:

- water in the form of water vapour saturated process exhaust air which is not likely to be below saturation unless unsaturated hall air is added
- degradation products of organic decomposition which are also known from alcoholic fermentation, such as acetone, acetaldehyde, ethanol, methanol, butanol and other short-chained compounds
- solvents, especially benzene, toluole, xylene
- odorous terpenes, mainly limonene and alpha- and beta-pinene
- traces of mineral oil carbohydrates.

Air emissions
There is a limited amount of information available on emissions from aerobic operations. The emissions of air pollutants and odorous substances of MBT plants are:

- waste specific (type, composition, age)
- treatment specific (aerobic degradation, fermentation)
- process specific (type of aeration)
- dependent on operational management
- influenced meteorlogically (weather conditions) in the case of open reactors.

In addition to the release of odorous substances at delivery and during mechanical treatment, the emissions of the plant are mainly determined by the following sources:

- aerobic degradation
- fermentation
- exhaust air/exhaust gas treatment.

Microbiological degradation releases are from 30 to 50 MJ of heat per kg of organic substance in the waste. This heat leads to the desired self-warming of the material. The surplus heat that exceeds the quantity necessary for maintaining the process temperature is dissipated through evaporation of the water. The water thus fulfils the important function of the heat carrier.

Capacity MBT	**Part of the facility**	**Air renewal, temperature[1], process conditions**	**TOC (FID)**	**Concentration of odour**		**Odour**
kt/yr			**mg/m^3 and g/t respect**	**spectrum GE/m^3**	**average GE/m^3**	**10^6 GE/h**
30	Mechanical treatment and low bunker	Forced ventilation, approx. 2-fold air renewal, 5 – 10 °C during the measurement	40 mg/m^3 20 – 25 g/t	-	-	-
200	Mechanical treatment and low bunker	Forced ventilation, approx. 1.5-fold air renewal, 10 – 13 °C during the measurement	15 – 25 mg/m^3 25 – 55 g/t	150 - 630	390	38
30	Total exhaust air of MBT (2 weeks biological degradation)	Mixture of exhaust air from halls and heaps, approx. 3-fold air renewal, 25 – 30 °C during the measurement	60 – 130 mg/m^3 500 – 720 g/t without methane 10 - 30 mg/m^3 approx. 700 g/t methane			
50	Total exhaust air of MBT (16 weeks biological degradation)	Mixture of exhaust air from halls and heaps, approx. 1-fold air renewal, 20 – 30 °C during the measurement	700 – 880 g/t 200 – 700 mg/m^3 up to 12000 g/t methane			
70	Exhaust air from biological degradation (fermentation with 8 weeks of biological degradation)	Mixture of exhaust air from halls and heaps, approx. single air renewal, 25 – 30 °C during the measurement	50 – 180 mg/m^3 590 – 720 g/t without methane approx. 80 mg/m^3 approx. 1100 g/t methane	8000 – 20000	15000	1200 to bio-filter

[1] There are some systems (air suction systems) where temperatures can reach up to 40 °C

Table 3.20: Examples of air parameters from some MBT
[132, UBA, 2003], [150, TWG, 2004]

Some data on air emissions from aerobic operations is shown in Table 3.21 below.

Parameters/ pollutants	Emission to air (values in g/tonne of waste digested) [6]
Flow	Exhaust air: 2500 – 30000 Nm^3/t
Ammonia[3]	5 – 3700 Other data: 0.12 times intake tonnage[1] 20 – 40 mg/Nm^3 [4]
Carbon dioxide	98 – 563 kg/tonne of MSW 482 – 566 kg/tonne of MSW if machinery, energy system and construction are included Other data: 10 – 20 % intake tonnage of waste x 1000 20 % of the intake dry solids
N_2O	11 – 110
NO_x	100
Methane	411 – 2000
Particulate matter[2]	163 – 186
PM_{10}s	e.g. bioaerosols
Odour	50 – 500 GE/m^3
TOC (VOC)[5]	0.7 – 600
AOX	
CFC	
Dioxins/furans	0.1 ng/m^3
Microbes	
Mercury	

[1] Reduce emission factor by 50 % if the system uses forced air or another method to ensure aerobic conditions throughout; increased emission factor if high nitrogen wastes received.

[2] Filter systems on the exit air will reduce general particulate emissions, but not PM_{10}.

[3] If treatment process conditions move away from the range of pH 4 – 8 and with a C:N:P ratio of out of 100:5:1, then larger quantities of other gases may evolve; larger quantities of ammonia may become particularly prevalent if there is too much nitrogen in the feedstock.

[4] Equals 545 – 1090 grams per tonne before any abatement of ammonia (e.g. biofilter).

[5] Methane may represent 1/6 of the TOC amount.

[6] In some cases several ways of calculation or different types of emission data are presented.

Table 3.21: Relevant emissions for MBT operations
[54, Vrancken, et al., 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [66, TWG, 2003], [75, UNECE,], [81, VDI and Dechema, 2002], [132, UBA, 2003], [150, TWG, 2004]

Ammonia emissions

Nitrogen in the waste can easily be converted to ammonia, and this is more likely to happen if the C:N ratios are unbalanced (too much nitrogen), or the mass becomes anoxic. For green wastes, this is more likely in the summer months with high levels of grass mowings in the waste and insufficient woody material as a bulking agent. Enclosed aerobic digestion or biodegradation systems with a high forced air injection providing an excess of oxygen produce less ammonia than standard windrows. The ammonia load of the crude gas of MBT plants amounts to between 10 to 560 mg/Nm^3 depending on the process variant, specific exhaust air quantity, etc. With upstream fermentation, up to 1000 mg/Nm^3 may be found in the pre-biological degradation. In addition to its effect of polluting the air, a high ammonia concentration in the crude gas damages the biofilters often used in MBT plants. Therefore, the aim has to be to keep the ammonia load of the crude gas prior to entry into the biofilter as low as possible. Upstream pH controlled acid scrubbers can reliably keep NH_3 concentrations below 10 mg/Nm^3.

Sites undertake a range of riddling, sieving, grinding and turning operations. *Particulate* emissions occur, but there are no data to quantify them. It is known that most aerobic digestion operations generate a range of fungi, particularly aspergillus. Filters on the exit air will minimise particulate emissions. PM_{10} emissions are a possibility.

Bioaerosols

These are micro-organisms and other tiny biological particles that are suspended in air. They are respirable and generally invisible. Bioaerosols can be produced by the aerobic process. Surveys have drawn particular attention to a fungus called Aspergillus fumigatus. It is found all over the world, especially in soils and in forest litter. It is particularly associated with the aerobic digestion process as it is capable of degrading cellulose (a carbohydrate found in plant material) and is capable of surviving at high temperatures (up to 65 °C). As part of its lifecycle, Aspergillus fumigatus produces tiny spores.

Odour emissions

They may come from anaerobic conditions. Odours are emitted from the surface of open piles, windrows, maturation piles, storage piles and stockpiles. Exhaust gases from controlled aeration systems also contain odourous compounds. Typically the most problematic odorous compounds at aerobic digestion facilities include ammonia, hydrogen sulphide, mercaptans, alkyl sulphides such as dimethyl sulphide, dimethyl disulphide and terpenes. These compounds are present in many feedstocks or are formed during the process through aerobic or anaerobic actions.

Some pesticide

They may be broken down by photolysis, plant metabolisms or microbial action. Others are persistent.

Methane

Methane will also be an issue, although the plant will usually be run in such a way so as to minimise this production. Methane emissions may range from 10 to 2000 mg/Nm^3.

VOCs

Any volatiles in the feedstock will tend to be emitted to the air due to the temperature rises. The crude gas from MBT plants contains a large number of single organic compounds in relatively high but fluctuating concentrations. The TOC concentration (total organic carbon) that records all organic contents is a parameter suitable for monitoring. The MBT crude gas contains TOC concentrations of between 10 to 2000 mg/Nm^3, but up to 7500 mg/Nm^3 have been measured. Open-air heaps have TOC-concentrations above 1000 mg/m^3 due to inevitable anaerobic conditions within the core of the heap. Carbon concentrations of more than 10000 mg/Nm^3 have been recorded at the surface of non-aerated open-air heaps especially with anaerobic conditions within the heap. The main outflow of the TOC occurs during the first hot biological degradation phase, i.e. in the first one or two weeks of biological degradation. Next Table 3.22 shows the list of organic compounds identified in MBTs.

Alkanes		
1,1-dimethylcyclopentane	4-methylnonane	n-dodecane
1,3-dimethylcyclohexane	5 ratified alkane	n-heptane
1,4-dimethylcyclohexane	5-methylundecane	n-hexane
10 ratified alkane	6 alkylcyclohexane	n-nonane
11 ratified alkane	butylcyclohexane	n-pentadecane
2 ratified ektane	2 C_3-cyclohexane	n-pentane
2 ratified undecane	C_4 –cyclohexane	n-tetradecane
2,3-dimethylpentane	cyclohexane	n-tridecane
2,4-diphenyl-4-methyl-2-pentene	decane	n-undecane
2-methyldekane	dimethylcyclohexane	nonadecane
2-methylheptane	dodecane	propylcyclohexane
2-methylhexane	ethylcyclohexane	tridecane
2-methylnonane	ethylcyclopentane	trimethylbenzol
2-methylundecane	hexadecane	trimethylcyclohexane
3-methyldecane	methylcyclopentane	undecane
3-methylheptane	methylbutane	3 ratified heptane
3-methylhexane	methylcyclohexane	7 ratified nonane
3-methylnonane	methyloctane	2 ratified octane
4-methylheptane	n-decane	ratified dodecane
PAHs		
1,2,3,4-tetrahydromethyl-naphthaline	naphthaline	acenaphthene
1,2,3,4-tetrahydronaphthaline (tetraline)	dimethylnaphthaline	methyldecaline
ethylnaphthaline (vinylnaphthaline)	1-methylnaphthaline	2 -methylnaphthaline
decahydromethyl- naphthaline	methyltetraline	
Acids and esters		
2-butene acidethylester	butyric acidmethylester	hexanal
2-methylbutyric acidethylester	2 carbonacidester	hexanacidethylester
3-methylbutyric acidethylester	6 carbonacid	fattyacidethylester
alkanacidethylester	acetic acid	myristinacidisopropylester
alkanacidethylester (acid >C_7)	2 alkanacid	pentanacidmethylester
aceticacid -1-methylethylester	aceticacidalkylester	propanacidethylester
benzoacid	aceticacidbutylester	propanacidmethylester
benzoacidbenzylester	aceticacidethylester	hetradecane acid
butyricacid	aceticacidmethylester	hexadecane acid
butyricacidethylester		
Terpene		
α-pinene	β-pinene	β-myrcene
pinene	D-limonene	3-carene
myrcene	camphor	
Aldehydes/ketones		
1,2-diphenylethanone	3-buten-2-one	hexanal
2,3-butandione	3-hydroxy-2-butanone	methyl-2-butanone
5 2-alkanone	3-pentanone	methylisobutylketone
2-butanone	Acetaldehyde	nonanal
2-heptanone	Acetone	octanol
2-hexanone	acetophenone	pentanal
2-methylpropanal	decanal	ramified 2-heptanone
2-pentanone	diphenylethandione	dodecanal
2-undecanone		
Alcohols		
1-butanol	2-methyl-1-propanol	isopropanol
1-pentanol	2-methylbutanol	ramified alcanol
2-butanol	3-Methyl-1-butanol	ramified pentanol
2-ethyl-1-hexanol	butanol	ethanol
2-methyl-1-butanol		

Benzenes/alkylbenzenes		
benzene	2 C_6-benzene	methylpropylbenzene
5 C_3-benzene	3-dimethylethylbenzene	propylbenzene
C_4-benzene	ethylbenzene	styrol
1-methylpropylbenzene	ethylmethylbenzene	toluene
15 C_4-benzene	o/m/p-xylene	3-trimethylbenzoene
7 C_5-benzene	methylisopropylbenzole	
Halogenic compounds		
1,1,1-trichlorethane	dichlormethane	tetrachlorethylene
dichlorbenzene	fluorethylene	trichlorethylene
Sulphur compounds		
2-butanthiol	dimethylsulphide	sulphur dioxide
dimethyldisulphide	methanthiol	carbon disulphide
Siloxanes		
cyclohexasiloxane	cyclotetrasiloxane	cyclosiloxane
cyclopentasiloxane	hexamethyldisiloxane	siloxane
octamethylcyclotetra-disiloxane		
Phthalates		
diethylphthalate	dimethylphthalate	
Ethers		
tetrahydrofurane		

Table 3.22: Organic compounds which were verified within the scope of four screening inquiries of exhaust air (three aerobic tests with intensive and after-biological degradation, one anaerobic plant)
[132, UBA, 2003]

Chlorofluorocarbons (CFC)
The few available data shows that in MBT plants CFC loads of more than 10 grams per tonne input material may be released depending on the processed waste type (Table 3.23). Leading substances are CFC R11 (trichlorofluoromethane) and R12 (dichlorofluoromethane) which were used frequently in the past.

Parameter (g/tonne)	**Facility A (exhaust air from tunnel)**	**Facility B (exhaust air from biological degradation trommel)**	**Facility B (exhaust air from biological degradation trommel)**	**Facility B (exhaust air from halls)**	**Facility C (exhaust air from biological degradation module)**
Probe spring	Winter	Summer	Winter	Summer	(estimated)
R11	n.d.	8.5	4.1	0.4	2.2 – 2.3
R12	n.d.	11.3	0.2	0.4	1.3 – 1.4
R21	n.d.	n.d.	-	n.d.	n.d.
R113	n.d.	n.d.	<0.05	n.d.	1.9
R114	n.d.	n.d.	0.2	0.4	1.2 – 1.4
n.d. = not detectable					

Table 3.23: CFC emissions from MBT (raw gas)
[132, UBA, 2003]

Waste water
Sites are unlikely to produce a surplus of liquid because the aerobic digestion process emits large volumes of water to the air and generally requires additional liquids as ‘top-ups’. If they do, then these will be occasional intermittent flows. Although it is known that some sites have had problems with waste water, the quantities of liquid emissions are likely to be small since aerobic digestion is an exothermic process.

Water parameter	Specific emissions (kg/tonne of MSW)	Concentration of the waste water (mg/l)
Waste water flow	260 – 470	
TOC		40
COD	0.457	120 – 200
BOD_5		20 – 25
HC		10 – 20
BTEX		0.1
AOX		0.5
Chloride	0.152	
Total N		70
Total P		1 – 3
CN	$7.28 \cdot 10^{-5}$	0.2
Sulphide		0.1 – 1
Cd	0	
Cr	0	0.5
Cr (VI)		0.1
Cu	0	
Hg	0	
Mg	0	
Ni	$7.94 \cdot 10^{-4}$	
Pb	$5.96 \cdot 10^{-4}$	
Zn	$2.38 \cdot 10^{-4}$	
Copper and zinc would be expected in any aerobic digestion leachate as they are plant micronutrients. There is a possibility of toxic metals in the effluent although most metals will remain in the aerobic digestion product.		

Table 3.24: Leachate from aerobic digestion
[54, Vrancken, et al., 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [66, TWG, 2003], [75, UNECE,], [81, VDI and Dechema, 2002], [132, UBA, 2003], [150, TWG, 2004]

Emissions to land
Aerobic digestion sites should make certain whether or not there are liquid emissions to land, even if they have a concrete base underneath the windrows, as the concrete basement may not be non-continuous, and part of the operation may be on a permeable surface. If the base is impermeable, then there will be a discharge to surface waters or sewer or a collection in sumps. If the aerobic digestion sites are on the landfill, liquid discharges will go to the landfill treatment plant.

There is also a possible problem if excess rainwater falling on the windrows is not evaporated by the heat of the aerobic digestion process. Surplus water would pick up fatty acids and humic acids and solids from the aerobic digestion process and then transfer the discharge to land, surface water or sewer.

Sludge and/or digestate for onward disposal to landfill typically have organic compounds, nitrogen and phosphorous compounds, chloride and chromium.

Biological treatments applied to contaminated soil

Air emission due to *ex situ* biodegradation
Little information exists on volatile losses from *ex situ* bioremediation processes. Table 3.25 summarises the data available for both slurry-phase and biopile systems. Although these data are limited, volatilisation appears to be a small component of the overall removal of hydrocarbons in these processes.

Contaminants	Emission rate	Total emissions	Biodegradation/ Volatilisation	Notes
Slurry-phase bioremediation				
Creosote	0.07 – 6.3 g HC/h	n.a.	n.a.	Off-gas concentrations peaked during day 1 and decreased to near baseline by day 5
Petroleum sludge	n.a.	910 kg HC	n.a.	425000 kg of soils were treated. Emissions reduced to background by day 6
Petroleum sludge	n.a.	10 - 20 kg/yr; 1.5 kg dredging 30 kg storage tank; 4 kg pond	n.a.	A full-scale system is estimated to have 500 to 2000 kg of VOC emissions
Biopile				
Gasoline	n.a.	n.a.	99 %/1 %	Air emissions measured for the stockpiling/handling, mixing, and curing operations. Mixing component accounted for 96 % of contaminants lost. 73 % of VOCs lost were trapped in carbon units
Petroleum	0.01 kg/hr HC once through; 0.03 kg/hr HC after treatment (carbon)	n.a.	n.a.	Off-gas was also recycled back to the biopiles to further reduce emissions
Petroleum	16 ppb BTEX start-up; 5 ppb BTEX (day 8); <1 ppb BTEX (day 35)	n.a.	>99 %/<1 %	
HC: Total hydrocarbons				

Table 3.25: Summary of emission data for ex-situ bioremediation systems
[30, Eklund, et al., 1997]

In open lagoons and in aerobic digestion and land treatment processes, the primary environmental factors which influence air emissions, in addition to the biodegradability and volatility of the waste, are process temperature and wind speed. Emissions tend to increase with an increase in surface turbulence due to wind or mechanical agitation. The temperature affects emissions through its influence on microbial growth. At temperatures outside the band for optimal microbial activity, volatilisation will increase. Emissions from self-contained reactors are also determined by reactor design parameters such as the amount of air or oxygen used to aerate the slurry. Higher gas flows will strip more volatiles out of solution and increase air emissions.

3.2.4 Waste OUT from biological treatments

The structure given to this section corresponds to the same one that has been given to Section 2.2, and describes the waste (or products) generated by the biological treatments of waste (the Waste OUT, according to the definition in Table 3.1).

Anaerobic digestion
An overview of the expected waste OUT (based on the source separated MSW input) is given in Table 3.26.

Fractions suitable for energy recovery	Specific amounts (kg per tonne MSW)	Heating value (MJ/kg)	
		Lower	Higher
Biogas [1]	117.5 (75 – 364 Nm^3)	15.4	16.8
Light residue	37.3	12.4	21.5
RDF	257.2	17	25.8
Wood-like fraction	14	4.9	10.0

[1] This lower yield is mainly explained by the higher content of non-degradable material (sand). Yields may vary from season to season (higher yields during autumn/winter).

Table 3.26: Expected waste OUT (based on the standard composition of waste) from the installation
[54, Vrancken, et al., 2001], [59, Hogg, et al., 2002]

Biogas

In the biogas, there are also other constituents in smaller concentrations including carbon monoxide, hydrogen, nitrogen and oxygen. A larger proportion of inorganics and polluting substances in the process will lead to smaller amounts of a ‘dirtier’ biogas. The constituents of biogas (other than carbon dioxide and methane) can be quite important in its end-use. Table 3.27 shows such the typical composition of a biogas generated by anaerobic digestion.

Component	Biogas concentration (vol-%)	Specific production (g/tonne of waste)	Specific emissions (g/MJ of methane)
CO_2	25 – 50	181000 – 520000	85
Methane	50 – 75	0 – 411	0.1
Water (biogas)	6 – 6.5		
O_2	0.9 – 1.1		
N_2	3.9 – 4.1		
H_2			
H_2S	<0.1 – 0.8		
Ammonia	<0.1 – 1		
Mercaptane	In spores		
Low molecular fatty acids			
Higher molecular substances	traces		

Table 3.27: Composition of biogas generated by anaerobic digestion
[33, ETSU, 1998], [54, Vrancken, et al., 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [132, UBA, 2003]

The biogas may be partly used for the production of power and/or heat (e.g. electricity, building heating, vehicles powered with biogas) by combusting it in a biogas engine. When biogas is used to generate energy, it is possible to generate from 20 to near to 300 kWh of net energy per tonne of waste. Several references have been enclosed in Table 3.28.

Study/process	Net energy production (kWh/tonne of waste)		
	Minimum*	Average*	Maximum*
AN-Anaerob	38	49	60
DBA	45	53	60
Kompo	85	88	90
NOVEM	21	88	154
Plaunener-Verfahren	85	98	110
Waterman BBT		100	
DHV study		102	
White et al		110	
Prethane-Biopaq	80	110	140
IEA Bioenergy	75	113	150
BTA	100	115	130
Dranco	105	131	157
Vrancken		140	
WAASA	120	145	170
IWM	100	150	200
Schwarting-UHDE		154	
D.U.T	254	273	292
* If only one figure is quoted, the reference in question did not provide a range			

Table 3.28: Net energy production figures from different sources [59, Hogg, et al., 2002], [54, Vrancken, et al., 2001], [150, TWG, 2004]

Solid waste fuel to be used as fuel

More information on this matter can be found in Section 3.5.4.1. The solid fuel prepared is a presorted mixture of paper and plastics. Washing of the digestion product yields two additional streams a residue and a wood-like fraction, with a residual calorific value that allows thermal treatment. The three streams added together give 308.5 kg solid fuel mix for thermal valorisation. The solid fuel mix has a lower heating value of 16.5 MJ/kg and a dry solids content of 66 %.

Type of waste	%
Organic waste	45
Others	31
Paper/cardboard	13
Plastics	9
Textile	2

Table 3.29: Composition of the solid waste prepared [54, Vrancken, et al., 2001], [150, TWG, 2004]

Digestate

The amount of digestate generated ranges from 100 – 500 kilograms per tonne of waste IN. This range is due to an extention of biodegradation, the moisture content of waste IN, the extent of process water recirculation, the way in which the digestate is used and the degree to which steam is used to heat biomass. The composition varies as shown in Table 3.30:

Feedstock	Units	N	P	K	Mg	Ca
Biowaste/RDF	% of TS	1.2	0.68	0.74		0
Source sep. MSW	% of DM	1.90	0.66	0.63	-	-
Source sep. MSW	ppm	20.0	11.9	14.7	11.6	49.7
Source sep. MSW	ppm	11	8	10	-	-
Organic fraction MSW	ppm	1 – 1.3	6 – 12	8 – 12	17 – 26	60 – 110
Fruit/veg from market	ppm	21.9	9.5	10.5	4.7	-
Unsorted MSW	ppm	11	8	10	-	-
Unsorted MSW	ppm	19	13	15	3.67	-

Table 3.30: Chemical characteristics of anaerobic digestate [59, Hogg, et al., 2002], [150, TWG, 2004]

Other products/waste

Recovered product	Specific production (tonnes per tonne of waste treated)
Nutrient recovery	4.0 – 4.5 kg N/tonne 0.5 – 1 kg P/tonne 2.5 – 3 kg K/tonne
Energy recovery	0.4 – 0.9 MJ electricity per tonne of waste. In addition, CHP plants may generate a similar quantity of heat
Total solid residuals depending on waste	0.3 – 0.6
Quality products for recycling (recovery)	Fibres (0.07 – 0.3) (for composting)
Other residuals possible for re-use with restrictions	Fluids (0.6) Inerts (0.05) Sand (0.08)
Residuals for landfilling or other waste treatment	Overflow sieving (0.02 – 0.1)
Metals (containing ferrous)	0.043
Ferrous metals	0.032
The separation and washing of the digested material yields fractions of inert materials, sand and a fibrous fraction. The inert materials and the sand fraction can be used as a building material. Another output corresponds to the fibrous fraction.	

Table 3.31: Overview of anaerobic technology for the treatment of biodegradable municipal waste [59, Hogg, et al., 2002], [54, Vrancken, et al., 2001]

Mechanical biological treatments

The aerobic treatments reduce the tonnage of input materials by the conversion of part of the biomass to carbon dioxide and water through microbial actions.

Fractions suitable for energy recovery	Specific amount (kg per tonne MSW)	Heating value (MJ/kg)	
		lower	higher
RDF	300 – 460	16.6	19.9
Fractions not suitable for energy recovery		**Destination and properties**	
Ferrous	32 – 40: 24 ferrous 1 8 ferrous 2	Scrap trade (2 fractions) Pre-separation Post-separation	
Inerts	48.6 <40 glass	Re-use	
Non-ferrous	8 – 10	Recovery	
Organic rich material (to biological treatment)	550 - process losses 200 - treated waste for landfilling 350	TOC 18 w/w-% Upper heating value of 6 MJ/kg Density >1.5 t/m^3 (wet) Hydraulic conductivity $k_f<10^{-8}$ m/s	

Table 3.32: Waste OUT from MBT
[54, Vrancken, et al., 2001], [59, Hogg, et al., 2002], [81, VDI and Dechema, 2002]

Grey compost

Copper and zinc can be expected to be found in any compost as they are plant micronutrients. Other heavy metals will be associated with whole aerobic digestion only, or by the addition of, hazardous waste streams. In general, metals will be retained in the solid fraction. Metals will bioaccumulate in the compost fraction. Some products recovered by this treatment are shown in the Table 3.33.

Recovered product	Value (tonnes/tonne of waste treated)
Nutrient recovery	2.5 – 10 kg N/tonne of biowaste recovered 0.5 – 1 kg P/tonne of biowaste recovered 1 – 2 kg K/tonne biowaste recovered
Energy recovery	Likely (e.g. through dry stabilisation/separation processes to manufacture RDF). Depending on the configuration, RDF may be (typically) 0.2 – 0.5 tonnes, with a calorific value of around 15 – 20 MJ/kg (sometimes higher). In addition, in some configurations, digestion processes can recover energy from degradation of the biodegradable fraction (can be >100 kWh depending on composition)
Total solid residuals depending on waste (tonnes/tonnes waste)	0.7 – 0.9
Quality products for recycling (recovery)	Metals (0.05)
Other residuals possible for re-use with restrictions	RDF (0.3 – 0.4) Stabilised organic fraction (0.07 – 0.2) ▪ respiration activity (AT_4): <5 – 7 mg O_2/g TS ▪ gas formation: GB21 <20 mg/g TS
Residuals for landfilling or other waste treatment	Heavy and light rejects (0.2 – 0.4)

Table 3.33: Overview of MBT outputs for the treatment of biodegradable municipal waste [59, Hogg, et al., 2002], [150, TWG, 2004]

The characteristics of the aerobic digested product has the following characteristics: one kilogram of treated waste potentially releases a total load of 1 – 3 g of COD, 0.5 – 1.5 g TOC and 0.1 – 0.2 g NH_4-N into the leachates. The real numbers clearly depend on the intensity respective and the duration of the treatment. Table 3.34 shows the potential emissions from grey compost by gas and leachate.

Emission potential	Unit	Untreated MSW	Mechanical-biological treated MSW
by gas: carbon	litre/kg of dry matter	134 – 233	12 – 50
	g C_{org}/kg dry matter	71.7 – 124.7	6.4 – 26.8
by leachate: TOC	g/kg of dry matter	8 – 16	0.3 – 3.3
N	g/kg of dry matter	4 – 6	0.6 – 2.4
Cl	g/kg of dry matter	4 – 5	4 – 6
Note: Minimum values represent the stabilisation degree reached by more modern MBTs			

Table 3.34: Range of organic carbon, nitrogen and chlorine transfer by gas and leachate [81, VDI and Dechema, 2002]

Biological treatments applied to contaminated soil

	Initial concentration		Final concentration		Removal[(a)]	
Compound	**Solids (mg/kg)**	**Slurry (mg/kg)**	**Solids (mg/kg)**	**Slurry (mg/kg)**	**Solids (%)**	**Slurry (%)**
Phenol	14.6	1.4	0.7	<0.1	95.2	92.8
Pentachlorophenol	687	64	12.3	0.8	98.2	92.8
Naphthalene	3670	343	23	1.6	99.3	99.5
Phenanthrene and anthracene	30700	2870	200	13.7	99.3	99.5
Fluoranthene	5470	511	67	4.6	98.8	99.1
Carbazole	1490	139	4.9	0.3	99.7	99.8
Note: Treatment carried out using a 190 m^3 reactor (a) Includes the combined effect of volatilisation and biodegradation						

Table 3.35: Performance of a slurry biodegradation process treating wood preserving wastes [30, Eklund, et al., 1997]

3.3 Emissions and consumptions from physico-chemical treatments

[30, Eklund, et al., 1997], [51, Inertec, et al., 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [89, Germany, 2003], [94, USA DoE, 2002], [99, Fons-Esteve, et al., 2002], [100, UNEP, 2000], [101, Greenpeace, 1998], [121, Schmidt and Institute for environmental and waste management, 2002], [123, Perseo, 2003], [134, UBA, 2003], [147, UBA, 2003], [150, TWG, 2004], [152, TWG, 2004], [154, UNEP, 2004], [156, VROM, 2004], [157, UBA, 2004]

This section contains the emissions and consumptions of physico-chemical (Ph-c) treatments discussed in Section 2.3. Chemical treatment processes cover a wide range of unit operations and a wide range of wastes. This section also applies to chemical treatment plants operating neutralisation processes. The following sections highlight information available to site operators from their current record systems and the areas where emissions are likely to occur. Most sites are on a totally enclosed base with all liquids entering or generated on-site (including rainfall) returned to the process. This sector is very diverse, but also one of the best monitored sectors, as was observed in site visits.

The structure of each of the following sections in this section is the same as the one followed in Section 2.3. Emissions associated with an ancillary treatment, e.g. transfer station operation are covered in Section 3.1.

3.3.1 Waste IN in physico-chemical treatments

Waste waters

The waste waters treated by physico-chemical treatments are:

- the core waste streams – these are inorganic acids and alkalis and their rinse-waters, together with cleaning, washing and interceptor wastes from a range of processes
- chemical industry wastes – these may include aqueous alcohol/glycol streams and process wash-waters
- (possibly) cleaning wastes with low levels of chlorinated compounds such as dichloromethane or phenolic compounds. Cleaning waters from the food industry may contain these substances as well
- aqueous wastes containing solvents
- high nitrogen wastes (potential for ammonia emissions)
- wastes containing phosphorus
- occasional inorganic wastes: for example wastes containing arsenic
- cyanide wastes - typically this waste will consist of solid or liquid cyanide salts, for example, sodium cyanide from surface metal treatments. They may also be present in printing wastes, usually as silver cyanide. Examples of cyanide based plating solutions include copper, zinc and cadmium cyanides
- developer waste (photographic wastes) typically includes a solution with a high percentage of ammonia salts, predominantly thiosulphate
- waste waters from shaping; oil wastes; organic chemical processes; and water and steam degreasing processes.

Without going into detail and/or individual and special cases, the essential sources of Ph-c plant treatable wastes are indicated in Table 3.36.

EWL chapter	Title	EWL list
06	Wastes from inorganic chemical processes	0601 waste acidic solutions 0602 waste alkaline solutions 0603 waste salts and their solutions 0604 waste containing metals 0605 sludges from on-site effluent treatment
07	Wastes from organic chemical processes	0701 wastes from the manufacture, formulation, supply and use (MFSU) of basic organic chemicals 0702 wastes from the MFSU of plastics, synthetic rubber and man-made fibres 0706 wastes from the MFSU of fats, grease, soaps, detergents, disinfectants and cosmetics
11	Inorganic wastes containing metal from metal treatment and the coating of metal; non-ferrous hydro-metallurgy	1101 liquid wastes and sludges from metal treatment and coating of metals (eg. galvanic processes, zinc coating processes, pickling processes, etching, phosphating, alkaline degreasing)
12	Wastes from shaping and surface treatment of metals and plastics	1201 wastes from shaping (including forging, welding, pressing, drawing, turning, cutting and filing) 1202 wastes from mechanical surface treatment processes (blasting, grinding, honing, lapping, polishing) 1203 wastes from water and steam degreasing processes
13	Oil wastes	1304 bilge oils 1305 oil/water separator contents
19	Wastes from waste treatment facilities, off-site waste water treatment plants and the water industry	1908 wastes from waste water treatment plants not otherwide specified

Table 3.36: Types of waste that may be treated in a physico-chemical treatment plant [121, Schmidt and Institute for environmental and waste management, 2002]

The essential mass flow from Ph-c plants is the waste water, corresponding to about 85 to 95 % mass of the waste accepted for treatment.

Aqueous marine waste

Most of the waste water from aqueous marine waste is contaminated with oil, organic substances and solid material (e.g. sediment). The contents of heavy metals, salts and other inorganic substances in the water and oil fractions are relatively low. Table 3.37 shows the acceptance and processing criteria for flocculation/flotation and biological treatment.

Component	Limit value acceptance (mg/l)	Limit value processing (mg/l)	List mixing policy*
PCBs	Detection limit	Detection limit	X
Dioxins	Detection limit	Detection limit	X
Pesticides	Detection limit	Detection limit	X
Organotin compounds	Detection limit	Detection limit	X
Brominated diphenyl ethers	Detection limit	Detection limit	X
Inhibition respiration	10 %	10 %	
N-total (Kjeldahl)	to discuss	500	
CN	to discuss	5	
Phenol	to discuss	1500	
VOX	100	20	
EOX	10	5	X
Cd	0.1	0.1	X
Hg	0.01	0.01	X
Total heavy metals	25	25	X
*the limit value of acceptance is in accordance with the policy on mixing.			

Table 3.37: Acceptance and processing criteria for flocculation/flotation and biological treatment for aqueous marine waste
[156, VROM, 2004]

Waste solids and sludges
Some waste solids and sludges treated by physico-chemical treatments are:

- asbestos
- slag or bottom ash from combustion processes
- FGT waste (e.g. incineration ashes from MSW, hospital waste or industrial waste incinerators)
- sludge to be stabilised. Sludges from chemical industry may contain sulphates and organic salts
- stable waste
- sludge from waste water processing (municipal or industrial)
- residues from the metallurgical industry (dusts, sludge, slags). These may have high contents of Cr(VI)
- spent catalysts
- paint residues
- mineral residues from chemical processing
- wastes containing acid and soluble compounds
- high arsenic content residues from the chemical, metallurgical or ore industries
- contaminated soil. According to meeting devoted to assessing indicators for soil contamination [99, Fons-Esteve, et al., 2002], there are three main indicators used to establish whether soil is contaminated or not. These are typically acidification, eutrophication (the typical indicator is nitrogen content) and the content of heavy metals (e.g mercury). Contaminated soil can contain rocks, bricks, and reinforcing rods that could damage the equipment used for material handling if not removed.

The following text gives some information about some of these types of waste.

Bottom ash and FGT wastes from combustion processes
Some wastes from combustion processes are bottom ashes, FGT waste and filter cakes. Table 3.38 shows the physico-chemical characteristics of such waste from MSW incinerators:

Properties	Compounds	Values
pH		11 – 12.5 – 13
Soluble salts content	Cl, sulphates	Up to 70 % (Conductivity 15000 – 27000 – 37000 µS/cm)
Heavy metals	Pb, Zn, Cd, Cr	Up to several %
Inert compounds	Silica, alumina, lime	
Fine particulates		<100 µm
Density		Low (0.4 – 0.6)
Hygroscopic material	Salts, excess lime content	
Leaching test before treatment	Solubles Cr Cd Pb Zn As	10 – 80 % 1.5 – 8 ppm 1 – 500 ppm 1 – 1400 ppm 1 – 10000 ppm 1 – 50000 ppm
Middle number in ranges corresponds to averages.		

Table 3.38: Characterisation of residues from MSW incinerators
[51, Inertec, et al., 2002]

The general components of slag/bottom ash from household incineration are silicates, alkaline earth, chloride, sulphates, non-ferrous metals (e.g. As, Cd, Cu, Pb), ferrous metals and heavy metals. The main components are the mineral fraction, the non-incinerated fraction and the scrap metal.

Categories	Percentage by weight (%)
Mineral fraction	85 – 90
Non-incinerated fraction	1 – 5
Metal scrap	7 – 10

Table 3.39: Main components of slag/bottom ash
[89, Germany, 2003]

Values in %-wt	Slag/bottom ash (fresh)			Slag/bottom ash after storage (ageing time of 3 months)		
Parameter	**Min.**	**Average**	**Max.**	**Min.**	**Average**	**Max.**
SiO_2	42.91	49.2	64.84	39.66	49.2	60.39
Fe_2O_3	9.74	12	13.71	8.41	12.7	17.81
CaO	10.45	15.3	21.77	10.42	15.1	23.27
K_2O	0.83	1.05	1.36	0.84	0.91	1.42
TiO_2	0.65	1.03	1.33	0.65	0.88	1.12
MnO	0.06	0.14	0.22	0.1	0.17	0.26
Al_2O_3	6.58	8.5	10.79	7.43	8.83	10.45
P_2O_5	0.55	0.91	1.49	0.5	1.04	2.61
MgO	1.79	2.69	3.4	1.84	2.59	3.51
Na_2O	1.86	4.3	5.81	2.05	4.15	7.49
Carbonates	2.56	5.91	10.96	5.59	5.83	7.62
Sulphates	2.5	15.3	28.3	5.8	12.5	22.5
Cl	1.3	3.01	7	1.5	2.71	4.6
Cr (ppm)	174	648	1035	295	655	1.617
Ni (ppm)	55	215	316	90	165	260.2
Cu (ppm)	935	2151	6240	1245	2510	5823
Zn (ppm)	1200	2383	4001	1795	3132	5255
Pb (ppm)	497	1655	3245	1108	2245	3900

Table 3.40: Chemical composition of bottom ash after the household incineration plant
[150, TWG, 2004]

The following Table 3.41 and Table 3.42 describe some general values of bottom ash parameters after the incineration process, with data from two different treatment plants.

Values	Pb	Cr	Cu	Cd	As	Zn	Hg	Ni
Minimum	0.6	0.1	0.2	0.0001	0.003	0.5	0.07	
Average	1.6	0.5	2.2	0.021	0.012	4.8	0.7	
Maximum	5.2 – 6	2 – 9.6	7	0.02 – 0.08	0.022	10 – 21	2	0.5
Values in g/kg of bottom ash								

Table 3.41: General bottom ash values after the household waste incineration process [89, Germany, 2003]

Metal	Bottom ashes (slag) (ppm)	Bottom ashes[1] (slag) (ppm)	Fly ash and residues from dry and semi-dry processes (ppm) [1]	Mixture of fly ash and sludge from wet scrubbing process (ppm) [1]
Cd	0.3 – 70.5	0.01 – 0.1	1 – 10	<0.001
Cr	23 – 3170	0.001 – 0.01	1 – 10	0.01 – 0.1
Hg	0.02 – 7.75	0.001 – 0.01	<0.001	<0.001
Pb	98 – 13700	1 – 10	10000 – 100000	0.001 – 0.01
[1] Values correspond to concentration ranges in initial leachates Some more information on incinerators can be found in the waste incineration BREF				

Table 3.42: Metals in bottom and fly ashes of municipal solid waste incinerators [113, COWI A/S, 2002], [150, TWG, 2004]

During the combustion of coal, two types of coal ashes are generated. Classic fly ashes are mainly composed of non-combustible elements and non-burned particulates, and contain, on average, 50 % silica, 25 – 30 % alumina, 8 % iron oxides (containing Ca, K, Mg, Na, Ti and traces of As, Cd, Cr, Cu, Ni, Pb, Se, Zn). The other type of fly ash is composed of silico-calcareous ashes that are generated from the particulate abatement techniques and sulphur oxide abatement techniques. These ashes are rich in calcium sulphate. More information can be found in the Large Combustion Plant BREF.

The ashes from heavy fuel oil typically contain sulphur, vanadium and nickel. They are also characterised by high percentages of non-burned carbon, typically 60 % but can reach up to 80 %. More information can be found in the Large Combustion Plant BREF.

Asbestos

Table 3.43 below shows ranges found in the composition of different asbestos types.

Value in %	Friable asbestos	Transite asbestos
Al_2O_3	0.16 – 1.57	1.08 – 2.60
CaO	2.86 – 3.89	7.53 – 36.20
Fe_2O_3	5.43 – 8.17	0.55 – 11.85
FeO	0.00	0.00
K_2O	0.02 – 0.26	0.39 – 0.43
MgO	69.00 - 78.49	1.22 – 56.13
MnO	0.04 – 0.18	0.01 – 0.2
Na_2O	0.41 – 0.73	0.01 – 0.14
P_2O_5	0.16 – 0.22	0.02 – 0.20
SiO_2	12.04 – 16.10	20.87 - 60.01
TiO_2	0.02 – 0.06	0.09 – 0.23
Loss on ignition [1]	48.47 – 51.53	17.96 – 44.35
[1] Indicator of the organic content of the sample.		

Table 3.43: Asbestos composition [94, USA DoE, 2002]

High temperature drying

The drying facility performs the pretreatment of aqueous paste-like wastes such as metal hydroxide sludges or coagulated lacquer and paint sludges.

Thermal distillative drying

Solid/paste like hazardous wastes which contain considerable amounts of free or bound fluids are treated. They are processed in order to recover solvents, to produce defined solid products or for drying in the facility.

In addition, heat cost allocator tubes or aerosol cans may also be treated. Heat cost allocator tubes are used for measuring heat energy consumption. They consist mainly of a glass tube and methyl benzoate as the evaporative medium. The drying residue (cullet) of the heat cost allocator tubes can be smelted in the corresponding steel mills or used in road construction. The condensate from the drying process can be recycled, i.e. it is re-used for the production of heat cost allocator tubes.

Waste IN in the treatment of specific wastes

Hydrogenation of POPs

According to the US DOE, this system can handle most types of waste, including landfill leachates, lagoon bottoms, soils, sludges, liquids, and gases. However, US DOE has cautioned that reaction by-products and intermediate reduction products need to be monitored in the off-gas from both the reduction process and the boiler. US DOE also noted the need to determine the fate of mercury and other volatile inorganics.

The process is non-discriminatory; that is organic molecules such as PCBs, PAHs, chlorophenols, dioxins, chlorobenzenes, pesticides, herbicides and insecticides are quantitatively converted to methane.

Supercritical water oxidation

Environment Australia reports that technology is limited to the treatment of waste that is either liquid or that has a particle size of less than 200 µm, and it is most applicable to wastes with an organic content of less than 20 %.

Supercritical water oxidation has been applied to a broad range of materials, e.g. aqueous waste streams, sludges, contaminated soils, industrial organic chemicals, plastics, synthetics, paints and allied products, industrial organics, agricultural chemicals, explosives, petroleum and coal products, and rubber and plastic products. It is applicable to the treatment of a range of contaminants including acrylonitrile waste water, cyanide waste water, pesticide waste water, PCBs, halogenated aliphatics and aromatics, aromatic hydrocarbons, MEK and organic nitrogen compounds.

The solvated electron technique

Table 3.44 below shows the waste IN and waste OUT for the treatment of chlorinated waste by the solvated electron technique.

Material treated	Products	Disposal options
Concentrated PCBs	Biphenyl, $Ca(OH)_2$, $CaCl_2$	Landfill as salts
PCBs in soils	Biphenyl, $Ca(OH)_2$, $CaCl_2$, clean soil	Return soil to ground
PCBs on surfaces	Biphenyl, $Ca(OH)_2$, $CaCl_2$	Collect salts and landfill
PCB/oil mixtures	Biphenyl, $Ca(OH)_2$, $CaCl_2$, oil	Re-use oil. Landfill salts
Concentrated HCB	Benzene, NaCl, NaOH.	Separate benzene and landfill salts
HCB in soils	Benzene, NaCl, NaOH, clean soil	Separate benzene and return soil with salt to ground

Table 3.44: Products and disposal options for the use of solvated electron technique
[100, UNEP, 2000]

3.3.2 Consumptions of physico-chemical treatments

Waste waters

In some physico-chemical treatments, bases are necessary. In some cases, waste bases are re-used in waste applications for neutralisation purposes. The neutralising agent used could be a solid or liquid waste stream or a bought-in alkali, as most plants need to buy in some supplementary alkalis. Aqueous acid containing metals, alkali and neutral wastes are common additions and the Ph-c plants are typically designed to produce a sludge containing slightly alkaline metal. Table 3.45 shows the consumptions of some physico-chemical treatments of contaminated water.

Parameter	Yearly consumption (t/yr) *	Specific consumption (kg/tonne of waste treated) *	Yearly consumption in inorganic pathway (t/yr)	Yearly consumption in organic pathway (t/yr)	Yearly consumption of WWT (t/yr)	Yearly consumption of lacquer treatment facility (t/yr)	Yearly consumption of laboratory chemical treatment (t/yr)
Average throughput	45000		20000	66000	30000	Lacquer: 15000 Solvent: 15000 Lacquer powder: 1000	1000
Average consumption of acids	230[1]	5.1	HCl: 69 Sulphuric: 48	HCl: 8 Phosphoric: 8	HCl: 39.4		0.5
Lime	590[1]	13.1	1023		50		10
Flocculation agents	290	6.4		8	16		
Other chemicals[2]		0.4 – 3.0					
Sodium sulphite			10.2		2		
Water consumption			759	9900	1788	2700	
Energy consumption				275 kW	369 MWh	Fuel oil: 1139 m^3 Electricity: 189 MWh	
Waste water			11573	48348	12687		250
Hydrogen peroxide			6.2				0.1
Sodium hypochlorite			4.9				
Iron chloride solution				118			
Iron oxide					65.8		
Sodium hydroxide				110			1
Activated carbon				6			
Potasium permanganate					0.4		
Splitting additives					25		
Amidosulphone acid					n.a.		

* Notes: Data based on the data from Ph-c plant operators with a capacity of 850 kt/yr combined. The data correspond to year 2001. The average age of the plants is about 17 years (ranging from 4 to 39 years). Approximately 84 % (from 73 to 91 %) of all the Ph-c plants for treatment of accepted waste observed here, can be attributed to EWL groups 11,12,13,16 and 19

[1] Values do not include waste acids or waste alkalis accepted and used

[2] Detoxification chemicals, organic breaking up of emulsions, sorption, sulphuric precipitation

Table 3.45: Consumptions of physico-chemical treatment of waste waters
[121, Schmidt and Institute for environmental and waste management, 2002], [135, UBA, 2003]

A total amount of approximately 0.4 m^3 prepared chemicals are used per m^3 waste water. Table 3.46 shows the chemicals consumed and some of their consumption levels for detoxification, neutralisation and dewatering for the removal of metals.

Chemical	Consumption
Lime or sodium hydroxide for neutralisation/precipitation	(NaOH 50 %) 120 l/m^3 waste water
Sulphuric or hydrochloric acid for acidification	(HCl 30 %) 10 l/m^3 waste water
Hypochlorite (oxidation cyanide)	
Iron (II) sulphate or sodium bisulphite (reduction Cr^{6+} to Cr^{3+})	
Aluminium sulphate or chloride (flocculation)	
Iron (III)chloride (flocculation)	
Sodium sulphide (precipitation)	0.3 kg/m^3 waste water
Materials for the improvement of precipitation, flocculation, coagulation and complex destruction	

Table 3.46: Chemicals consumed and some of its consumption levels for detoxification, neutralisation and dewatering for the removal of metals from waste waters
[156, VROM, 2004]

Precipitation/flocculation

The following inorganic materials are predominantly used in precipitation/flocculation:

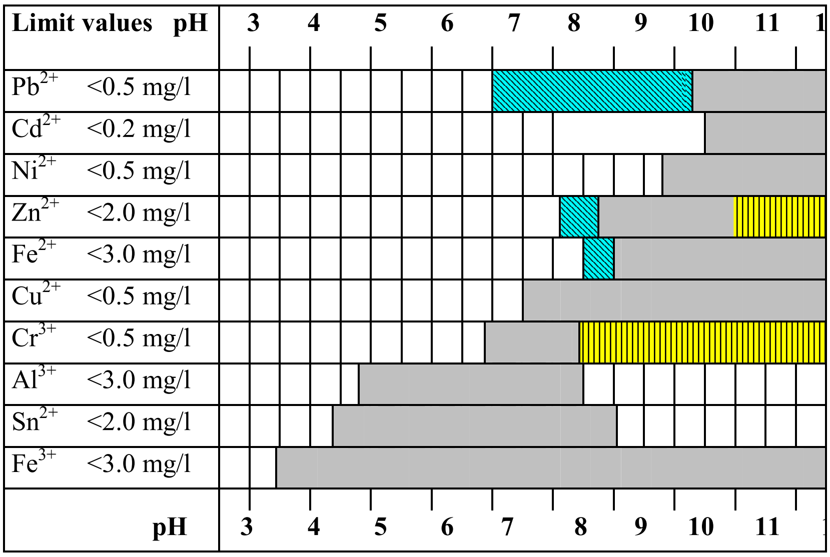
- caustic soda
- soda ash (sodium carbonate)
- lime
- iron (III) chloride
- iron (II) chloride
- aluminium sulphate
- sulphides.

Synthetic flocculation materials are also used for the improvement of floc formation and sedimentation characteristics. They consist principally of non-ionic polymers, anionic polymers, cationic polymers and co-polymers of ionic and non-ionic compounds.

Table 3.47 shows the chemicals used for the precipitation of solute heavy metals; this information refers to chemically pure chemicals. In practice, it may be seen that the quantities actually required may be 10 to 20 % larger. Precipitation values for different metals are shown in Table 3.48.

Used alkali (g)	Metal to be precipitated					
	Fe (II)	Fe (III)	Cu	Ni	Cr	Zn
CaO	100	150	88	96	162	86
$Ca(OH)_2$	134	201	116	126	213	114
NaOH	144	216	126	136	231	122
Na_2CO_3	190	285	168	181	307	162
MgO	73	110	63	69	117	62
$Mg(OH)_2$	105	158	92	100	169	90

Table 3.47: Theoretical consumption of alkalis in precipitation per 100g metal
[121, Schmidt and Institute for environmental and waste management, 2002]



▒	pH ranges, with which the solubility of the metal hydroxide precipitation with caustic soda solution lies below the values mentioned in the first column
▥	Expansion of these ranges through the use of lime milk
▧	Expansion of these ranges through the use of soda

Table 3.48: Range of precipitation values for various metals
[121, Schmidt and Institute for environmental and waste management, 2002]

Precipitation sludge must be disposed of if recycling is not possible. Dewatering is generally necessary. Precipitation/flocculation materials must be selected to suit the dewatering procedure used. Sludge formed from materials containing aluminium generally display poor dewatering characteristics.

Precipitation/flocculation is a reaction and/or a reaction combination which is essentially dependent on the pH value. To this extent, the most significant reference parameter is the pH value. Since the waste water produced through precipitation/flocculation is discharged into sewerage systems, certain criteria must be met. In order to maintain these values, additional treatment steps and procedures for the treatment of waste water follow flocculation and precipitation.

Oxidation/reduction

Redox reaction	Oxidant or reductor	pH	Observations
Oxidation of cyanide and nitrite	Sodium hypochlorite (NaOCl) or chlor gas (Cl_2)	for CN: ~ 10 for NO_2: ~ 3	• reaction relatively quick • relatively high degree of salting up of the resultant waste water • formation of organic materials, which are shown as AOX (Note: the limit value is AOX = 1 mg/l in the waste water to be introduced into the sewerage system)
Oxidation of cyanide and nitrite	Hydrogen peroxide (H_2O_2)	for CN: ~ 10, catalyst: Fe (II)-salts for NO_2: ~ 4	• reaction relatively slow • negligible salting up of the waste water, • no new formation of materials as AOX • formation of mud, due to catalyst (Fe II-salts) • formation of foam (in particular in the presence of organic materials)
Oxidation of nitrite	Aminosulphonic acid (NH_2SO_3H)	~ 4	• reaction slowed • formation of sulphates • formation of elementary nitrogen
Reduction of chromate	Sodium hydrogen sulphite ($NaHSO_3$)	~ 2	• fast reaction • causes salting up of the waste water • formation of mud
Reduction of chromate	sulphur dioxide (SO_2)	~ 2	• fast reaction • slight salting of the waste water • slight mud formation
Reduction of chromate	Sodium dithionite ($Na_2S_2O_4$)	pH independent	• fast reaction • leads to salting of the waste water • formation of mud
Reduction of chromate	Iron (II) sulphate or chloride ($FeSO_4$/$FeCl_2$)	~ 3	• slow reaction • leads to the salting up of the waste water • formation of mud

Table 3.49: Consumption of chemicals for redox reactions
[121, Schmidt and Institute for environmental and waste management, 2002]

Sorption (adsorption/absorption)
Table 3.50 contains information on various adsorbencies. The large area of activated carbon, which according to this is particularly well suited for the adsorption of materials is notable. However it must then be ensured that the material to be adsorbed (i.e. to be separated) also reaches the inner surface of the activated carbon. It is therefore the essential task of the reactor and plant technology to achieve an intensive contact between the material and the adsorbent to be separated. In the treatment of material mixtures, the effect and/or efficiency of adsorbents is determined in general by experiment.

TYPE	Characteristics			
	Specific surface (m^2/g)	Micropore volumes (ml/g)	Macropore volume (ml/g)	Apparent weight (g/l)
Grain carbon for water purification	500 – 800	0.3 – 0.6	0.3 – 0.4	300 – 500
Powder carbon for decolourisation	700 – 1400	0.45 – 1.2	0.5 – 1.9	250 – 500
Fine-pore silica gel	600 – 850	0.35 – 0.45	<0.1	700 – 800
Large-pore silica gel	250 – 350	0.3 – 0.45	0.05 – 0.1	400 – 800
Activated alumina	300 – 350	0.4	approx. 0.1	700 – 800
Adsorbent resin	400 – 500			650 – 700

Table 3.50: Physical data of adsorbents
[121, Schmidt and Institute for environmental and waste management, 2002]

Ion exchangers

Ion exchangers	Stability		Regeneration substance
	pH	°C	g/l resin
Weak-acid, cation exchanger ionic form: H^+, PF^+	1 - 14	75 - 120	HCl: 70 – 140 or H_2SO_4
Strong acid, cation exchanger ionic form: H^+	1 - 14	~120	HCl: ~80
Weak base, anion exchangers ionic form: OH^-, Cl^-	1 - 14	70 - 100	NaOH: ~60
Strong base, anion exchangers ionic form: OH^-, Cl^-	1 - 12	35 - 70	NaOH: ~80

Table 3.51: Overview of types of exchangers and their properties
[121, Schmidt and Institute for environmental and waste management, 2002]

Aqueous marine waste

Heat is required for the heating of tanks and pipelines in order to keep them frost-free, for the preparation of chemicals, for the improvement of separation processes and for other processes. The amount of energy consumed depends on climatic conditions. Electricity is required for pumps, compressors and other facilities. Further differences in energy consumption may be caused by a difference in storage capacity or the application of evaporation.

The overall consumption of energy for heat production varies from 140 to 490 MJ/m^3 waste water. The overall consumption of electricity varies from 65 to 170 MJ/m^3 waste water. The energy data include other activities such as the cleaning of vessels, which means that they are an overestimate of the energy consumption needed for physico-chemical and biological treatment.

For several steps in the treatment, chemicals are used, e.g. alkalis, acids, flocculating and coagulating agents, activated carbon and oxygen. The use of waste acids and alkalis reduces the consumption of primary chemicals. In Table 3.52, some data on the consumption of chemicals are presented.

Chemical	Consumption (kg/m^3 waste water)	Comments
Alkalis	2 – 3	
Acids	0 – 1	Depends on the use of waste acids
Flocculating/coagulating agents	1 – 7	
Oxygen	5	Depends on the use of air or oxygen
Activated carbon	0.04	

Table 3.52: Data on consumption of chemicals in the treatment of aqueous marine waste and similar waste
[156, VROM, 2004]

Water is required in centrifuges and for the preparation of chemicals. The use of the effluent from the biological treatment reduces the consumption of water.

Waste solids and sludges

Table 3.53 and Table 3.54 show consumption values from soil washing treatment plants.

Consumption	Used for	Value
Electrical	Pumps and attrition units	15 – 25 kWh per processed tonne of soil
Chemical	Function of the treated pollution. Some chemicals (such as the floculating agents) are usually used in all plants	3 to 5 kg per tonne of dry sludge
Water	Mainly due to loss of water with the residual filter cake	0.1 to 0.3 tonnes per tonne of processed soil

Table 3.53: Consumptions of soil washing processes plants
[123, Perseo, 2003]

Capacity	t/yr	68000
Fuel consumption	MJ/yr	0
Electricity consumption	MWh/yr	900
Electricity/plant capacity	kWh/t	13.235
Heat consumption	MWh/yr	0
Cooling	MJ/yr	0
Chemicals	sodium hydroxide anti-foaming products polyelectrolyte	

Table 3.54: Consumptions of a installation treating contaminated soil by washing
[66, TWG, 2003]

3.3.3 Emissions from physico-chemical treatments

3.3.3.1 Emissions from the physico-chemical treatments of waste waters

The physico-chemical treatment of waste waters generates a flow of decontaminated water which corresponds to the so-called waste OUT stream of the treatment. An analysis of this stream is given in Section 3.3.4. The following two figures (Figure 3.3 and Figure 3.4) extrapolate flow diagrams leading to the emissions from the physico-chemical treatment of waste waters.

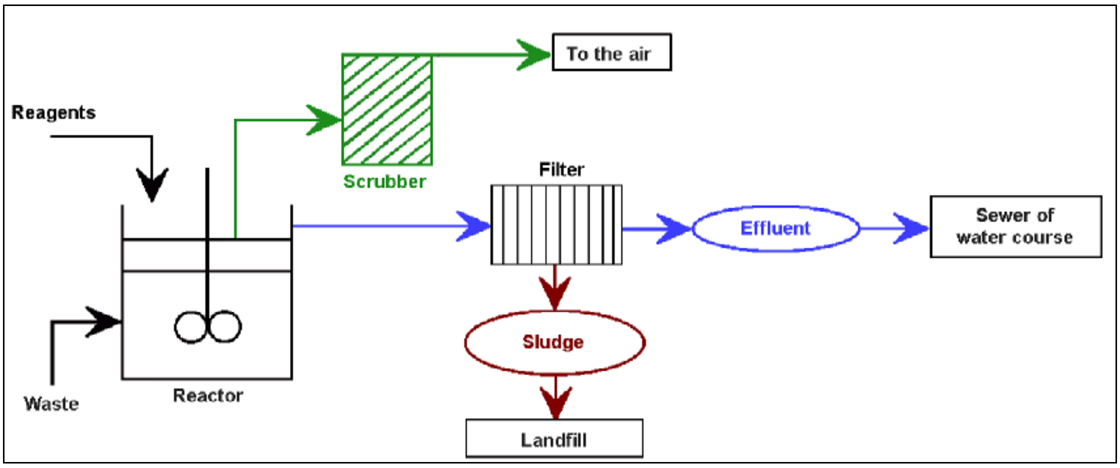


Figure 3.3: Main emission flows from the physico-chemical treatments of waste water
[80, Petts and Eduljee, 1994]

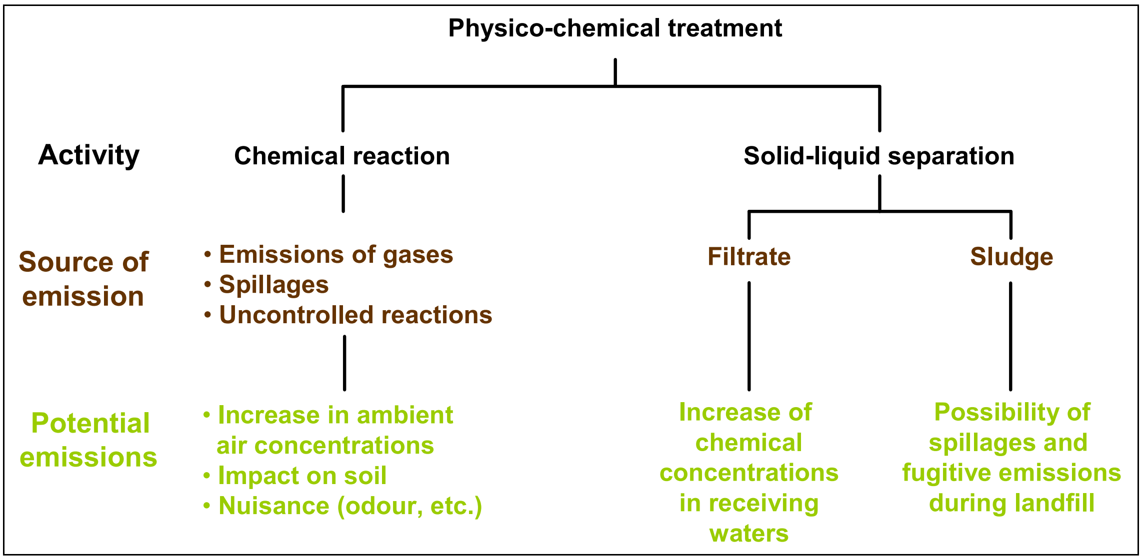


Figure 3.4: Potential emission streams from physico-chemical treatments
Note: Some of these emissions only appear in badly operated physico-chemical treatments
[80, Petts and Eduljee, 1994], [150, TWG, 2004]

Air emissions
Some organic compounds can travel through the plant without being removed and then end up in the final sludge or effluent, whereas others may be evaporated during the exothermic reactions of neutralisation or during sludge pressing. Certain organic wastes contain ‘hidden’ species. For example, lubricating oils contain naphthalene, BTEX, phenols, copper and nitrogen and can lead to ammonia and xylene emissions to the air during the oil separation from water, or to increased levels in the final site effluent. Aqueous wastes containing solvents may be emitted due to the heat of the process. High nitrogen wastes have a potential for ammonia emissions to the air.

Some materials passing through the plant (typically not captured by physico-chemical processes) are TOC/COD, dichloromethane, phenol, BTEX and naphthalene associated with the waste water from oil pretreatment and TOC, dichloromethane, phenol, BTEX and naphthalene associated with the waste from oil pretreatment.

The air emissions from individual plants depends on the abatement system used. Very few plants have monitoring programmes in place that can quantify their air emissions. Air emissions from these treatments are typically VOCs, acid gases and ammonia. Although difficult to quantify given the lack of monitoring programmes, it can be seen that if closed treatment vessels and air collection/treatment systems are in use, these emissions are reduced. Issues such as the presence of low concentrations of organic solvents in the waste might not always be picked up by WT operators, but these may be important environmentally as they could lead to relevant emissions to the air during the process.

Air emissions may be associated with rapid pH changes, rapid temperature rises and with vigorous agitation. Gaseous reaction products also still occur. Most installations will liberate VOCs from the waste through a mixture of heating, agitation or sludge pressing or drying. There is also always a possibility that reaction intermediates may be released as well. Emissions of metals to the air can be assessed on analytical results. Evaporation also occurs in an uncontrolled manner, such as the evaporation of solvents when mixing solids and liquids or from the stirring of sludges in open tanks.

Emissions of organic compounds may appear when treating mixed waste streams (for example, from the neutralisation of acid, solvents are displaced into the vapour phase which cannot be abated by a wet scrubber used to abate acidic emissions) or are present because its recovery is neither technically nor economically viable (that is, as contaminants associated with wastes that are difficult to handle are treated by other methods).

Air emission parameters	**Measured annual average emission values (mg/Nm^3)**	**Mass flow (g/h)**
Flow of exhaust air	325 Nm^3/t	
TOC[1]	2.84 – 36	500 (534 kg/yr)
Dust	0.21	40.3 kg/yr
BTX	4.9	
Benzene		2.5
HCN	<0.05 – 0.12	0.043 - 15
H_2S	0.31	15
Cl_2	<0.03	15
SO_2	1.17	0.5
HCl	0.3	0.2
Hg	0.01	0.0034
Notes: Data based on the data from Ph-c plant operators with a total capacity of 850 kt/yr. The data correspond to year 2001. The average age of the plants is about 17 years (ranging from 4 to 39 years). Approximately 84 % (from 73 to 91 %) of all the Ph-c plants for the treatment of accepted waste covered here can be attributed to EWL groups 11,12,13,16 and 19. Exhaust air emissions are in general measured intermittently. The measurements are essentially made to monitor the processes, where contamination of the exhaust air can be expected in the intended operation, such as evaporation or cyanide oxidation. [1] Values correspond to mg of carbon		

Table 3.55: Air emissions from physico-chemical treatment of waste water
[121, Schmidt and Institute for environmental and waste management, 2002], [135, UBA, 2003], [157, UBA, 2004]

The emissions of VOC from aqueous marine waste treatments range from 0.4 to 0.6 kg/m^3 waste water if no exhaust gas treatment is applied. Biological treatment generates emissions of odour. One of the example plants reports an average emission level of 540 million ouE/h.

Water emissions (for more information see Section 3.3.4)
Aqueous residues (if any) are generally sent to sewer. Wastes from the chemical industry, high nitrogen wastes (maybe landfill leachates) and oil recovery/re-processing may introduce additional species and thus need to be considered more carefully. High nitrogen wastes increase the likelihood of a discharge of nitrous oxide. Metals, ammonia and organic chemicals are typically present in water streams.

In all cases, the effluent consents will require protection of the sewerage treatment works from the plant discharge, this protection is focused on COD, pH, oil content, ammoniacal nitrogen, metal content, sulphates and sulphides, as well as dichloromethane (the most common halogenated cleaning compound and liable to be a contaminant of wash-waters and interceptors). The total discharge volume will usually be known.

Although precipitation techniques for metals are reasonably effective, a typical physico-chemical process (under a trade effluent consent) may discharge between 1 – 3 tonnes of metals to sewer annually (the actual value depends on the size of the plant and the amount and type of waste. For example, considering the emission values that appear in Table 3.69, and without considering Fe as a metal, a volume of waste water of 500000 m^3 is necessary to reach some of the upper levels of the range). This is associated with particulates carried over in the effluent from the process and arising from inefficiencies in either the precipitation stage or during settling out of the precipitated metals.

Most sites do not have data for the chloride, total nitrogen and total phosphorus in the sewer discharge. Rough calculations show that for sites where data are available, the emissions are low, unless the site specialises in phosphoric acid treatment or handles high nitrogen flows. Most sites are required to analyse for ammoniacal nitrogen so they can provide a minimum emission value.

The process of waste waters mixed with organic material (e.g. mix of mineral oil, synthetic oil, kerosene, interceptor waste, aliphatic hydrocarbon, aromatic hydrocarbon, alcohol, chlorinated solvents, esters, ethers, aldehydes, ketones, fats, waxes, greases) generates around 836 kg of waste water per tonne of waste IN and 5.5 kg of sludge per tonne of waste IN.

Emissions to water of salts, e.g. sulphates and chlorides, occur. These salts are added as reagents and are not removed in the process of precipitation, neutralisation and filtration. This causes the effluent to have high concentrations of these compounds.

Solid wastes and emissions to land

The sludge generated from physico-chemical treatment plants can be pressed and sent to further treatment, pressed and mixed with other sludges (generally organic) on site or mixed with residues from flue-gas cleaning to give a solid product (with exothermic reaction). Almost all of the sites produce a sludge/cake, which is then commonly incinerated or co-incinerated, or in a few cases directly landfilled.

Metal levels in the waste are well characterised, but organic contamination is not. N and P are not typically quantified in waste and will be present in the aqueous solution.

Process generated waste	Specific amount (kg/tonne of total waste processed in the Ph-c treatment plant)
Oil	30 – 90
Concentrates[1]	14 – 40
Hydroxide sludge[2]	60 – 90
Mud from purification and emptying processes	10 – 50
Notes: Data based on the data from Ph-c plant operators with a total capacity of 850 kt/yr. The data correspond to year 2001. The average age of the plants is about 17 years (ranging from 4 to 39 years). Approximately 84 % (from 73 to 91 %) of all the Ph-c plants for the treatment of accepted waste observed here, can be attributed to EWL groups 11,12,13,16 and 19. The oil is generally recycled and the remaining substances recycled or disposed of, depending on their characteristics and the market conditions. [1] Concentrates from evaporation/stripping and membrane filtration as well as from ultrafiltration and ion exchangers. [2] The weight relates to damp mud, drained TS: ~35 – 45 %.	

Table 3.56: Process generated waste from physico-chemical treatment plants [121, Schmidt and Institute for environmental and waste management, 2002]

Waste from the Ph-c treatments arise principally from precipitation/flocculation, concentrates from membrane filtration, evaporation or ion exchange; waste is also produced in cleaning and draining processes, constructions and containers. The extent to which waste can be used depends on the individual case. For example, separated oil is generally recyclable, concentrates from membrane filtration, evaporation or ion exchange can be recycled in some cases, sludge from precipitation/flocculation are generally disposed of, waste from cleaning and draining are generally disposed of and disposal is usually by immobilisation or incineration.

Table 3.57 below shows the composition of sludge generated in the physico-chemical treatment of waste waters.

Compound	Value	Unit
pH	7 – 9	
TOC	54.7	wt-%
Loss of ignition	54.7	wt-%
Hydrocarbons	30000	mg/kg
PCDD/F	<0.1	ng-TE/kg
PCB ($\sum$ 6)	<0.12	mg/kg
EOX	10	mg/kg
CN total	<0.1	mg/kg
As	0.2	mg/kg
Cd	2.7	mg/kg
Cr total	887	mg/kg
Cu	349	mg/kg
Hg	0.2	mg/kg
Ni	210	mg/kg
Pb	211	mg/kg
Tl	14	mg/kg
Zn	1970	mg/kg

Table 3.57: Sludge generated in the physico-chemical treatment of waste waters [157, UBA, 2004]

The amount of sludge containing metal (filter cake) that is produced depends on the specific contaminants in the waste water, their concentrations and on the reagents and other chemicals that are used. The sludge quantity varies from 2.5 to 10 % of the waste water input. By replacing lime by sodium hydroxide the amount of filter cake is reduced. However, lime is necessary for the precipitation of fluorides.

The filter cake with high concentrations of metals, e.g. nickel and copper, can be used as a raw material in the metallurgical industry. In other cases, the filter cake is disposed of as solid waste.

Solid residues from aqueous marine waste

The generated solid residues are:

- solid residues from the decanter/centrifuge and filters (50 kg/t waste water)
- separated oil and chemical fractions (possibly suitable for re-use as fuel).

Emissions from particular physico-chemical activities

The emissions listed in Table 3.58 below can be expected to occur from most treatment plants. The scale of the emission depends on the plant throughput and on the abatement systems applied.

Physico-chemical activity	Air	Water	Residues/Soil
Addition of solid sodium carbonate or addition of sulphuric acid to form nickel or chromium sulphate	Emissions of CO_2, plus other acid gases (e.g. SO_x) depending upon the initial solutions	Liquid fraction is returned into the treatment and blending part of the plant. This is a tiny fraction of the main waste IN	The product precipitates out and is left to cool and crystallise before being bagged and sent off for recycling
Cyanide oxidation		HOCl	
Fluorescent tubes/lamp processing	Hg and SO_x	The discharge is a weak sodium hydroxide solution	
Precipitation of metals		Zn, Cu, Cd	
Silver recovery systems	There is an unquantified issue of ammonia, and possibly SO_x, from photographic chemicals due to the high nitrogen and sulphur levels in the solutions. Additionally there may be There are additional VOC emissions due to bulking and transfer processes		Possibly high nitrogen levels in the waste
Treatment of printing and photographic waste	Ammonia, VOC and potentially SO_x	Suspended solids, nitrogen (mainly nitrate) and COD	Waste typically has a high nitrogen content
Use of raw caustic		Hg	
Unit operations			
Air stripping	Ammonia and VOCs, including organic solvents (e.g. DCM)		
Dissolved air flotation (DAF)			Sludges that are taken from the bottom of settlement tanks will generally be up to 4 % dry solids
Evaporation	Normally takes place in fully enclosed systems but various vent valves can result in fugitive emissions		
Filtration/pressing This is a common area for emissions from chemical plants	Ammonia and, if there is a high organic content in the wastestreams, VOCs		
Ion exchanger		The eluate of an ion exchanger must be further treated in the plant according to its composition/concentration	

Physico-chemical activity	Air	Water	Residues/Soil
Mixing tanks	May produce a range of emissions, partly as the result of chemical reactions, and partly from heat effects reducing the solubility of gases in water. Ammonia is the most common gas mentioned as a problem at this stage of the process.		
Neutralisation	This can be a violent exothermic reaction with a rapid change in pH. Acidic acids such as CO_2, HCl, Cl_2, NO_x, and SO_x, as well as ammonia are emitted from the reactor tank, together with any contaminant volatile materials, such as cleaning solvents in wash-waters. The gases can carry liquors and particulate matter with them	Typical components are chloride, phosphorus, nitrogen and metals	Typical components are chloride, phosphorus, nitrogen and metals
Organic splitting of emulsions			Generally smaller quantities of mud (filter cakes) develop in organic splitting than with acid splitting
Oxidation/reduction		The salination of the waste water is process-dependent	
Settlement	Emissions to the air are possible but unlikely		Sludges that are taken from the bottom of settlement tanks will generally be around 0.5 – 1.0 % dry solids content
Sludge management (e.g. pressing or sludge storage)	VOCs as fugitive emissions. Gases from solution		
Solvent extraction	Solvents as fugitive emissions. Significant potential for emissions on transfer and emergency releases	Solvents	
Stripping	Emissions are trapped in the areas provided in the Ph-c plant		

Table 3.58: Emissions from physico-chemical treatment processes applied to waste water
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [121, Schmidt and Institute for environmental and waste management, 2002]

3.3.3.2 Emissions from the physico-chemical treatment of waste solids and sludges

The emissions listed in Table 3.59 below can be expected to occur from most treatment plants. The scale of the emission depends on the plant throughput and on the abatement systems applied.

Physico-chemical activity	Air	Water	Residues/Soil
Filtration/pressing	Ammonia and, if there is a high organic content in the wastestreams, VOCs		
Buildings for immobilisation mixing	Emissions via roof vents. Emissions occur during transfer from the mixing pit to removal off-site; and via access doors from spillages/leaks during charging of the reaction vessels		
Sludge blending	Particulate matter and VOCs, particularly if an exothermic reaction occurs		
Sludge management (e.g. pressing or sludge storage)	VOCs as fugitive emissions. Gases from solutions		
Solidification	There is a potential for particulate emissions from this operation		
Automated charging of waste	VOC, dust odour during the transfer of wastes and reagent		
Reaction vessel	Emission occur due to the reaction of incompatible substances. Uncontrollable reactions due to incorrect dosing of reactants or the formation of hot spots through poor mixing	Leakage through badly maintained or damaged equipment	Leakage through badly maintained or damaged equipment
Reagent silo	Dust arises from the overfilling of reagent silos. Also fugitive dust emissions from silo connections and dust from reagent stockpiles stored loose		

Table 3.59: Emissions from physico-chemical treatment processes applied to solids and sludges [55, UK EA, 2001], [56, Babtie Group Ltd, 2002]

The fugitive emissions from material handling operations for *ex situ* processes are often overlooked or ignored, but they may represent a significant fraction of the total emissions from the soil treatment.

Emissions from soil excavation and removal activities

VOC emissions from handling operations in soil excavation and removal result from the exchange of contaminant-laden soil-pore gas with the atmosphere when soil is disturbed, and from some diffusion of the contaminants through the soil. There are several potential emission points involved in excavation; all are considered to be fugitive area sources. For excavation, the main emission points of concern are emissions from:

- exposed waste in the excavation pit
- material as it is dumped from the excavation bucket, and
- waste/soil in short-term storage piles.

In addition, the earth-moving equipment will involve additional sources of emissions of VOC, particulate matter, nitrogen oxides, etc. It is known that large amounts of VOCs may be released from soil during handling, so VOCs are typically the emissions of most concern. Emissions of particulate matter and associated metals and semi-volatile compounds may be of concern at particular sites.

Given the frequency with which the excavation of contaminated soils is carried out, surprisingly little air emission or emission rate data for excavation have been published.

However, some measured emission rates for two sites for combined excavation and dumping operations are available and quote figures as high as 4 g/min for specific compounds. Here, most of the VOCs present in the soil was stripped from the soil during excavation, based on a comparison of measured total emissions versus the mass of these same contaminants in the soil (calculated from soil concentration data). This was true for both sites, despite differences in soil concentrations and soil type.

Activity	Sludge volume (m^3)	Exposed surface area (m^2)	C_{8+} hydrocarbon emission rate (g/s)	C_{8+} emission flux ($g/m^2/s$)
Sludge disturbance	25 – 27	45 – 125	1.33	0.01 – 0.03
Sludge excavation	26 – 48	125 – 261	7.76	0.03 – 0.06
Sludge dewatering	1.7	3.3	1.24	0.38
Post-disturbance	26	91	1.11	0.01

Table 3.60: Results of emission measurements
Based on [30, Eklund, et al., 1997]

The magnitude of volatile organic compound (VOC) emissions depends on a number of factors, including the type of compounds present in the waste, the concentration and distribution of the compounds, and the porosity and moisture content of the soil. The key operational parameters are the duration and liveliness of the handling, and the size of equipment used. The longer or more energetic the moving and handling, the greater likelihood that organic compounds will be volatilised. The larger the volumes of material being handled per unit operation, the lower the percentage of VOCs that are stripped from the soil, because the surface area to volume ratio is minimised.

Soil containing benzene or other volatile carcinogens would likely pose a large risk to on-site workers and the surrounding populace if it were to be excavated.

The magnitude of emissions from soil handling operations will vary with the operating conditions. The rate of excavation and dumping, the drop height, the amount of exposed surface area, the length of time that the soil is exposed, the shape of the storage piles, and the dryness of the surface soil layers will all influence the levels of VOC emissions. Add-on control technologies are available for minimising emissions, but these are relatively ineffective and costly to implement compared with the controls for point sources.

Emissions from thermal desorption

Air emissions from thermal desorption systems are influenced by the waste characteristics, the desorption process applied, and the emissions control equipment used. The air emissions associated with thermal desorption come from several sources. The point sources of air emissions vary widely with each process. The stack of an afterburner vents combustion products, as does a fuel-fired heating system if the combustion gases are not fed into the desorber. A fuel-fired heating system typically operates with propane, natural gas, or fuel oil. If the VOC emission controls consist of a baghouse, scrubber, and vapour phase carbon adsorber, the off-gas will contain small concentrations of the original contaminants, as well as the products of any chemical reactions that might occur. The volume of off-gas from a thermal desorption unit depends on the type of processor. Table 3.61 below gives some values for emissions from thermal desorption.

	Flow of gases (Nm^3/h)	Pollutants that may be contained
Direct heating	17000 – 85000	VOC
Indirect heating	1700 – 8500	VOC

Table 3.61: Emissions from direct and indirect heating thermal desoption
[30, Eklund, et al., 1997]

Various types of thermal desorption systems can produce up to nine residual process streams: treated soil, oversized media rejects, condensed contaminants, water, particulate control dust, clean off-gas, phase separator sludge, aqueous-phase spent carbon, and vapour- phase spent carbon. Off-gases from indirectly heated units, i.e. thermal screws, can be treated with smaller chemical/physical systems, such as a baghouse or a condenser, followed by an afterburner.

Pollutant	From
Fugitive emissions	• excavation of contaminated soil • classifier, feed conveyor, and the feed hopper • components of the thermal desorption system and controls • exhaust gases from the heating system, treated soil, particulate control dust, untreated oil from the oil/water separator, spent carbon from liquid or vapour phase carbon adsorber, treated water, and scrubber sludge
Particulate matter, nitrogen oxides (NO_x), carbon monoxide (CO) and acid gases	Combustion and pyrolysis
Dioxins, furans and phenol	

Table 3.62: Generic emissions from thermal desorption
[30, Eklund, et al., 1997]

Parameter	Initial concentration [1] (ppm)	Final concentration [1] (ppm)	Removal efficiency (%)	Typical off-gas characteristics[2] stack concentration
PM		700 – 1000 mg/Nm^3		
Benzene	0.11 - 39.5	<0.01 – 0.06	84.5 – 99.9	4.3 – 8.6 ppm
Toluene	0.27 – 2	<0.01 – 0.1	n/a	0.6 – 0.8 ppm
m,p-Xylenes	<0.8 – 3	0.2 – 1.2	<75	0.42 – 3.5 ppm
o-Xylenes	3.1 – 15.6	<0.01	99.7 – 99.9	
Total Xylenes	13.1	0.1	99.2	
Ethylbenzene	0.11	<0.01	>90	
THC	39 – 393	5.7 – 9.5	85 – 97.5	129 – 2800 ppm
VOC		0.045 – 2.27 kg/h		
Diesel	1875	<1	>99.9	
Naphthalene				5136 – 6757 µg/Nm^3
Acenaphtylene				634 – 901 µg/Nm^3
Acenaphthene				317 – 638 µg/Nm^3
Fluoranthene				405 – 763 µg/Nm^3
Phenanthrene				385 – 645 µg/Nm^3
Anthracene				<1.4 – 427 µg/Nm^3
Fluoranthene				24 – 135 µg/Nm^3
Pyrene				32 – 111 µg/Nm^3

[1] Based on two or three installations depending on the parameter.

[2] Based on two installations. Emission control equipment consists of a wet scrubber and cyclonic demister. ppm values refered to dry conditions

The VOC emissions from asphalt aggregate dryers will vary by several orders of magnitude depending on whether afterburners are used as a control device. These treatment systems typically do not employ VOC controls, unless they have been modified for soil remediation.

A company has estimated the typical emissions for soil treatment in a modified asphalt aggregate dryer. This system consists of a direct-fired rotary drum operating at 290 – 540 °C. A primary cyclonic tube collector and pulse-jet baghouse are used to control particulate emissions. A thermal oxidiser (i.e. an afterburner) destroys organic compounds in the off-gas stream (99 – 99.99 % efficiency). Based on a processing rate of 32 – 54 t/h.

Table 3.63: Characteristics of inputs and outputs of asphalt aggregate dryers
[30, Eklund, et al., 1997]

Contaminant	Units	Residence time (minutes)	Temperature (°C)	Initial concentration	Final concentration	Rate of uncontrolled emissions (g/h)	Estimated emissions rate (g/h)
PCBs	ppm	19	550	37.5	2	1.14	5.68e-02
2,3,7,8-TCDD	ppb	40	560	260	0.018	0.00832	4.16e-04
	ppb	19	560	236	0.018	0.00755	3.78e-04
	ppb	10.5	560	266	0.018	0.00851	4.26e-04
	ppb	24	460	233	0.5	0.00744	3.72e-04
	ppb	5.6	550	48	0.084	0.00153	7.67e-05
	ppb	20	555	56	0.23	0.00178	8.92e-05

Overall estimated efficiency is 95 %

Table 3.64: Estimated emissions of selected compounds for the clean-up of PCB contaminated soil using a thermal desorption process
[30, Eklund, et al., 1997]

Emissions from vapour extraction of solid waste

The air emissions associated with vapour extraction systems come primarily from the stack. Additional releases of volatile organics may occur from the treatment of any contaminated water that is extracted. Fugitive emissions are considered negligible due to the negative pressure throughout most of the system.

Emissions include untreated volatile organics from the extraction process. A removal and subsequent emission of semi-volatile organic compounds will also occur, though less efficiently than for VOCs. There may also be smaller amounts of air emissions associated with the control system. Due to the variety of technologies used for vapour treatment, stack emissions may also include some products of incomplete combustion, NO_x, particulate matter, CO, and acid gases. Of primary concern, however, are the volatile organics emitted from the point sources. Air emission data for several vapour extraction systems are summarised in Table 3.65.

No. of systems surveyed	Parameter	Units	Range or value	Approximate average
13	Flowrate per well	m^3/min	0.2 – 8	2
	Removal	kg/day	0.9 – 113	27
	Exhaust gas concentration	ppmv	20 – 350	100
17	Total flowrate	m^3/min	0.1 – 161	23
	Treatment:	n° systems		
	• none		9	
	• carbon		6	
	• catalytic incineration		1	
	• combustion		1	
	Removal rate	kg/day	2 – 195	45
17	Total flowrate	m^3/min	0.7 – 318	62
	Pollutant concentration	ppmv	150 – 3000	400
	Control efficiency	%	90 – 99	95

Table 3.65: Emissions from vapour extraction systems
[30, Eklund, et al., 1997]

The emission rate of VOC compounds over time from continuously operated vapour extraction systems tends to show an exponential-type decay curve.

Pollutant	Peak uncontrolled stack emissions [1] (g/h)	Peak controlled stack emissions [2] (g/h)
Trichloroethylene (TCE)	1712	17.1
trans-1,2-Dichloroethylene (DCE)	99.4	0.99
1,1,1-Trichloroethane (TCA)	13.6	0.14
Tetrachloroethylene (PCE)	3.18	0.03
TOTALS	**1830**	**18.3**

[1] Uncontrolled emissions based on the removal rate of each contaminant
[2] Based on estimated 99 % overall control efficiency for two carbon adsorption canisters in series

Table 3.66: Estimated emissions for an in-situ vacuum extraction system
[30, Eklund, et al., 1997]

Emissions from soil washing
In the soil washing process, the greatest potential for emissions of volatile contaminants occurs in the excavation, materials handling, feed preparation, and extraction processes. The waste streams also have the potential to be sources of VOC emissions. The solvent recovery process involves vaporisation of the solvent, so fugitive emissions are possible from this as well as from other stages of the solvent process. Waste streams also have the potential to be sources of VOC emissions if any VOCs are already present in the waste stream. For solvent extraction processes, emissions of the solvent itself also may be a cause for concern.

Storage areas need to be kept under specific control to avoid pollution dispersion, especially of dust. For liquid effluents, the plants are always equipped with a water-slurry treatment unit, where the water is sent before being discharged.

Soil washing generates four waste streams: contaminated solids separated from the wash-water; waste water; waste water treatment sludge and residual solids; and air emissions.

Water parameter	Concentration (mg/l)
Suspended solids	60
BOD_5	25
COD	350
Nitrit N (NO_2-N)	10
P, total	2
Cr, total	0.3
Cu	0.5
Hg	0.005
Ni	0.3
Pb	0.3
Zn	2
Residues generated by the process[1]	
Sludges	Mineral sludges
Other residual fractions	Particle PAHs and metal oxides
[1] The subsequent fate of these residues are reported to be landfill	

Table 3.67: Emissions from an installation treating contaminated soil by washing
[66, TWG, 2003]
Note: Capacity of the installation is 68 kt/yr

Emissions from solvent extraction

Up to five waste streams may result from the solvent extraction process: concentrated contaminants; solids; waste water; oversized rejects; and treated air emissions.

Solvent extraction units will be of a closed-loop design in which the solvent is recycled and re-used. Typically, solvent extraction units are designed to produce negligible air emissions, but some solvents have been detected in the off-gas vent system. In addition, significant levels of emissions (both vapour-phase and particulate matter) may occur during waste preparation activities such as excavation and materials handling.

Emission from treatments of FGT waste

The main environmental concern related to handling, utilisation and disposal of combustion wastes is the potential emission of heavy metals, organic pollutants and salts. The main pathways for this are by leaching and by airborne dust emission. As airborne emissions can be controlled relatively easy, leaching is an environmentally more important issue. It should also be noted that hydrogen gas generation from FGT waste by contact with water has been documented and can potentially cause considerable problems. Its generation is dependent on intermediate FGT waste storage and the type, design and operation of the landfill that it may be developed.

Emissions from stabilisation methods

Several of the stabilisation methods have an initial washing step, where a major part of soluble salts and, to some extent, metals are extracted before chemical binding of the remaining metals. These methods are finalised by dewatering the stabilised product, which will then be ready for landfilling. Then, washing solid waste generates a waste water that needs some sort of treatment because of the content of some components. However, depending on the local authorities, such generated waste water may be discharged into the environment or treated in the chemical industry to recover some salts (e.g. sodium salts).

Emission from asbestos treatments

The fibrous nature and the size of the fibres are the main parameters that makes asbestos dangerous. During treatment some emissions may be generated.

3.3.3.3 Emissions from the treatment of specific wastes

Hydrogenation of POPs

At a Canadian facility, product gas was found to contain no detectable PCBs, while concentrations of total chlorobenzenes and dioxins were similar to those of the blanks. This suggests that the product gas did not contain quantifiable levels of these substances. When the product gas was burned in the steam reformer, dioxins were emitted from the reformer stack at a concentration of 15 pg TEQ/Nm^3. This dioxin formation was attributed to the use of PCB contaminated air from the site of the reformer's combustion air.

All outputs from the destruction of PCB contaminated waste using this process can be contained and tested. There are no uncontrolled emissions from the process which could result in releases of PCB contaminated air, solids, or liquids to the surrounding environment. Releases of PCBs to the environment could only occur during waste handling prior to treatment, where the possibility of spillage exists.

Because the reaction takes place in a reducing atmosphere in the absence of oxygen, the possibility of dioxin and furan formation is said to be eliminated. If the hydrogen (dry basis) content is maintained at percentages greater than 50 %, the formation of PAHs is prevented.

Type of waste	Destruction efficiency (%)	DRE (%)
PCB oils	99.999808 – 99.9999996	99.9999985 – 99.9999997
chlorobenzenes	99.9999836 – 99.9999972	99.9999842 – 99.9999985
Dioxins present in PCB oils	99.999 – 99.9999	

Table 3.68: Reported destruction efficiency of hydrogenation processes
[100, UNEP, 2000]

If either the product gas or the ambient air used as combustion air for the boiler or similar units contains hydrogen chloride or other chlorinated species, dioxins may be generated during their combustion. In order to meet the fundamental technical criteria for POPs destruction, both the product gas and combustion air must be treated to remove such chlorine donors and so prevent dioxin formation.

Care is required to avoid high rates of gas generation, which could over-pressurise systems. The process has a limited surge capacity: over-pressurisation could therefore result in the release of waste material.

During typical operations, 30 to 50 % of the product gas is burned as fuel for the boiler or other auxiliary units.

Residues generated by the process include product gas from the reactor, scrubber water and sludge from product gas treatment, and small quantities of grit from the reactor. The product gas is either catalytically reformed to recover hydrogen or burned as fuel in one or more of the auxiliary systems – the boiler, catalytic reformer and/or sequencing batch vaporiser.

Hydrogenation of PCBs and POPs

All emissions and residues are captured for assay and reprocessing, if needed. Destruction rates ranging from 99.9 to 99.99999 % have been reported at sites operating on a commercial scale in Australia.

Supercritical water oxidation

Process residues are usually contained and consist of water, gas (less than 10 ppm of CO and very low amounts of oxides of nitrogen, acid gases such as hydrogen chloride or sulphur oxides and particulates) and solids if the waste contains inorganic salts or organics with halogens, sulphur or phosphorus. Residues generated during the process such as ash and brine require disposal.

3.3.4 Waste OUT from physico-chemical treatments

Much of the waste OUT from these processes goes to landfilling.

Waste waters

The essential mass flow from Ph-c plants is the waste water, corresponding to about 85 to 95 % of the mass of the waste accepted for treatment. The waste water quality of Ph-c plants is regularly monitored by the supervisory authorities and within a framework of self-monitoring. Due to this monitoring activity, extensive data are available on the composition of waste water from Ph-c plants.

Water emission parameters	Ranges values of the annual average values (ppm)	Ranges of annual charge (kg/yr)
pH	6.9 – 10.4	
Electric conductivity	1150 – 13500 µS/cm	
Transparency (view depth)	10 – 47 cm	
Suspended solids	<0.5 – 32 <0.1 – 2.1 ml/l	<0.6
TOC	2200 – 3800	38061
BOD	5 – 2490	
COD [1]	200 – 17870	
Hydrocarbons	<0.1 – 19.8	89
Detergents (anionics)	0.6 – 14.8	
Mineral oil	5 – 10	
Phenol index	0.8 – 25	317
AOX	<0.01 – 0.7	9
EOX	<0.1 – 0.5	
BTX	<0.1 – 1.2	10
Cl	3975 – 35420	
Cl free	<0.1 – 0.3	
CN	<0.1 – 0.6	<1
CN free	<0.01 – 0.1	
F	0.5 – 8.6	
N - organic	109 – 440	
N - total	8.4 – 590	
NH_3-N	22 – 1330	
Nitrate-N	0.9 – 472	
Nitrite-N	0.90 – 10.2	38
P - total	<0.1 – 14.75	
Sulphate	65 – 3630	
Sulphide	1012	
Sulphide free	<0.1 – 0.77	<1
Al	<0.1 – 5	63
As	<0.01 – 0.1	<0.1
Cd	0.0004 – 0.1	
Co	≤ 0.1	
Cr total	0.05 – 0.3	3.8
Cr (VI)	<0.01 – 0.1	<1
Cu	<0.1 – 0.4	2.5
Fe	0.2 – 20	253
Hg	0.0001 – 0.02	<0.02
Mn	<0.1 – 2.7	
Ni	0.05 – 1.4	3.8
Pb	<0.02 – 0.7	<1
Se	<0.1 – 0.5	
Sn	<0.1 – 0.4	
Zn	<0.1 – 3.9	12

Notes: Ranges have been constructed from several sets of emission data provided. A data set is based on the data from Ph-c plant operators with a total capacity of 850 kt/yr. The data correspond to year 2001. The average age of the plants is about 17 years (ranging from 4 to 39 years). Approximately 84 % (from 73 to 91 %) of all the Ph-c plants for the treatment of accepted waste covered here, can be attributed to EWL groups 11,12,13,16 and 19. Another set corresponds to 20/80 percentile of the annual average values for some Ph-c plants, and another to measured minimum/maximum values found in demulsification plant treatment (data from 1994 – 1999)

[1] Some data relate to THE dissolved COD fraction and other correspond to the total COD

Table 3.69: Waste OUT from the physico-chemical treatment of contaminated waters [121, Schmidt and Institute for environmental and waste management, 2002], [134, UBA, 2003], [150, TWG, 2004], [156, VROM, 2004], [157, UBA, 2004]

Outputs of lacquer treatment facility are shown in Table 3.70 below:

Material	Amount (t/yr)	Composition (mg/kg)	
Dried material	10000	PCB	<0.05
		BTEX	104.8
		As	<1
		Cd	6.7
		Cr total	77
		Cu	905
		Hg	0.25
		Ni	43
		Pb	339
		Tl	<0.5
		Cyanide total	6200
Organic process water	2000	Cd	<0.5
		Hg	<0.5
		Zn	1.7
Solvent reclaim	13000		

Table 3.70: Waste OUT of physico-chemical treatment of contaminated water treating mainly lacquer coagulum and solvents
[135, UBA, 2003]

Table 3.71 shows the emission levels achieved after a polishing step of the effluent, e.g. by sand filtration or ion exchange filters.

Compound	Concentration (mg/l waste water) (24 hour samples)
Free cyanide	1.0/0.2
Halogenated VOCs	0.1
Mineral oil	200 (random sample)
Ag	1.0/0.1
Cd	0.2
Cr (total)	1.0/0.5[1]
Cr(VI)	0.1
Cu	2.0/0.5
Ni	2.0/0.5
Pb	2.0/0.5
Sn	3.0/2.0
Zn	2.0/0.5
[1] standards for discharged load of metals (Cr, Cu, Ni, Pb and Zn) <200 g/day and >200 g/day	

Table 3.71: Emission levels achieved after a polishing step of the effluent, e.g. by sand filtration or ion exchange filters
[156, VROM, 2004]

Waste solids and sludges

The final material after stabilisation/solidification will have a similar composition of metals and organic content as the original waste. However, the final material has a reduced toxicity and solubility of metals and organic compounds compared to the original waste.

The annex of the Landfill Directive (EC 33/2003) contains the criteria and procedures for the acceptance of waste at landfills. The criteria contain some limit values for hazardous waste acceptable at different types of landfills. These are based on leaching limit values and restrict some metals, some anions and organic compound parameters.

Water permeability of stabilised waste depends on many parameters (e.g. nature of the waste, nature and amount of added reagent, aimed objectives) so permeability values may vary from 10^{-9} to 10^{-12} m/s.

Immobilised bottom ash/slag

In general, there are several possibilities employed for the re-use of bottom ash, after treatment. When the slag values do not meet defined parameters, a slag re-use with defined technical safety measures is possible. Some examples of re-use options are described below and are shown in Table 3.72:

- used in road and street construction. The bottom ash is used as a solid base for at the construction of, e.g. parking places, airports and harbour areas. However, there is a need for an impermeable layer which coaches over the bottom ash layer to avoid leaching, this can be asphalt or perhaps concrete
- used in soil constructions, e.g. road embankments or noise protection walls. It is important that the area where bottom ash will be used has to be a hydrogeologically favourable land. This means that there has to be a layer of 2 meters of clay or loam which protects the groundwater from adverse effects. Furthermore, there has to be a mineral surface which is impermeable (d >0.5 m and $k_f < 10^{-8}$ m/s)
- used in important water management zones and in hydrogeologically sensitive areas and is subject to exception for individual case inspections.

Recycling paths of treated bottom ash/slag	%
Anti-freeze course	27
Filling material	22
Ballast substructure	11
Improvement of land	9
Base frame/dam construction	5
Land consolidation	5
Noise protection wal	3
Landscaping	1
Unbound street and road construction	1
Others	16

Table 3.72: Recycling paths of the mineral fraction of treated bottom ash in Germany [150, TWG, 2004]

The following Table 3.73 and Table 3.74 below characterise the important bottom ash parameters after a physico-chemical treatment process.

Metals	Minimum	Average	Maximum
As	0	0.074 – 0.15	0.187
Cd	0.0008	0.0037 – 0.01	0.0167
Cr	0.067	0.172 – 0.6	0.726
Cu	0.150	0.6 – 6.826	29.781
Hg	0	0.01 – 0.07	0.37
Ni	0.023	0.165 – 0.6	0.661
Pb	0.19	1 – 1.222	4.063
Tl	0		
Zn	0.470	1.5 – 2.970	14.356
Units: in g/kg, except Hg that is in mg/kg Zero in this table means below analysis detection limit			

Table 3.73: Metal composition of treated bottom ash after treatment (solid analyses) [89, Germany, 2003], [150, TWG, 2004]

Chemicals	Minimum	Average	Maximum
Cl	29		
Sulphates	43		
CN total	0		
Phenol index	0		
As	1.3	5.3	16.1
Cd	0	0.8	5
Cr	0	15.2	200
Cu	0	60.7	300
Hg	0	<0.2	1
Ni	0	2.9	40
Pb	0	11.4	59.0
Tl	2		
Zn	0	19.4	300
Units in µg/l Zero in this table means below analysis detection limit			

Table 3.74: Eluate analysis of bottom ash quality after treatment
[89, Germany, 2003], [150, TWG, 2004]

Waste OUT from a classical soil washing unit

Generally, soil washing units produce recycled materials suitable for the construction industry (concrete producers, asphalt plants) or as refilling materials after internal quality control and external control have been carried out on the specific properties of the materials (to ensure compliance with local regulations)

Different fractions can be distinguished:

- coarse fraction: gravels which can be calibrated in several ways. These are basically formed by fine gravels measuring 2 – 20 mm and coarse gravels measuring 20 – 80 mm
- sand fraction: consist of sand generally sized from 60 µm to 2 mm
- residual organic fraction (>60 µm): these fractions are incinerated or sent to an appropriate landfill
- fine residual fraction (filter cake <60 µm): usually this is sent to a special landfill with or without additional treatment (e.g. inertisation, stabilisation) or may be sent for a further treatment if required (e.g. thermal desorption, classical incineration).

	Capacity (t/yr)
Waste IN	68000
Waste OUT	50500
• sand	36000
• gravel	13000
• fines	1500

Table 3.75: Waste OUT of a installation treating contaminated soil by washing
[66, TWG, 2003]

Waste OUT from excavation

Excavation has been found to decrease the soil moisture content and the dry bulk density of the soil. Data show that the water content fraction decreases by 35 % to 56 % and the dry bulk density of the soil decrease by 13 %.

Waste OUT from thermal distillative drying

The dry residue of the treatment of aerosol cans is separated into steel and waste aluminium before smelting. These metal fractions fulfil all acceptance criteria of the steel mill operations. The condensates from the drying process consist of complex solvent mixtures that may only be used thermally or have to be incinerated. When unused faulty aerosol cans are treated, it may be discussed in advance with the producer if recycling of the contained solvents is also possible.

Waste OUT from a CFC treatment plant

Table 3.76 below shows the specification of the products achieved by the cracking of the CFC solvents.

Parameters	**Unit**	**Target**	**Actual value**
Water content	ppm	<50	34
Oil content	ppm	<100	60
Amine content	ppm	<100	10
Acid	ppm	<1	0.03
Halogens	vol-%	<0.1	0.004
PCB and PCT	vol-%	0	0
Information from a CFC distillation plant of Figure 2.11 shown in Section 2.3.5 This interconnection treatment facility converts CFCs into hydrochloric acid and hydrofluoric acid.			

Table 3.76: Specification of CFC cracked products
[147, UBA, 2003], [150, TWG, 2004]

3.4 Emissions and consumptions from waste treatments applied mainly to recover the materials from waste

[6, Silver Springs Oil Recovery Inc., 2000], [13, Marshall, et al., 1999], [14, Ministry for the Environment, 2000], [29, UK Environment Agency, 1996], [41, UK, 1991], [42, UK, 1995], [56, Babtie Group Ltd, 2002], [66, TWG, 2003], [86, TWG, 2003], [96, Straetmans, 2003], [125, Ruiz, 2002], [129, Cruz-Gomez, 2002], [147, UBA, 2003], [150, TWG, 2004], [156, VROM, 2004], [157, UBA, 2004]

This section contains the emissions and consumptions of treatments mentioned in Section 2.4. The following sections (Sections 3.4.X) details information available to site WT operators from their current recording systems and highlights areas where emissions are likely to occur. The structure of each of the following sections in this section is the same as the one followed in Section 2.4. Emissions associated with ancillary treatments, e.g. transfer station operations, are covered in Section 3.1.

3.4.1 Waste IN treated to obtain a recycled material

When the aim is to obtain useable materials and not just material to be disposed of, the treatment given to each type of waste will typically be very specific, and will target the conversion of the waste into the useable end-product required.

Waste oils

Oils have many uses, e.g. they are used as a fuel, as lubricants, as a heat transfer medium, as cutting fluids, and as hydraulic fluids. Each has its own specification, usually based upon the hydrocarbons occurring within a specific boiling point range from the distillation of crude oil. Oils that need to be stable at high temperatures will not include large quantities of low boiling point hydrocarbons, whereas, oils used as fuel are more likely to include these lower boiling point hydrocarbon mixtures.

Before marketing, most base oils produced in mineral oil refineries are blended with a variety of additives to give them the required properties. Typical additive packages comprise between 5 and 25 % of the base oil. However, probably at least half of the additive package is base oil used as solvent. Lubricating oils contain large numbers of additives, but the actual formulae are in most cases trade secrets. Data on the components and additives in new oils are given in the Safety Data Sheet which accompanies fresh products as supplied, however precise details of the formulations are company proprietary. Hydraulic oils contain very few additives.

Some general classes of additives have been identified and are shown in Table 3.77 below. The information is not specific, but suggests that a number of metal additives, some chlorinated organic compounds, aromatic hydrocarbons, phenolic compounds and different kinds of polymers are used.

Additive	Compounds used
Anti-corrosion	Zinc dithiophosphates, metal phenolates, fatty acids and amines
Anti-foam	Silicone polymers, organic copolymers
Anti-oxidant	Zinc dithiophosphates, hindered phenols, aromatic amines, sulphurised phenols
Anti-wear	Zinc dithiophosphates, acid phosphates, organic sulphur and chlorine compounds, sulphurised fats, sulphides and disulphides
Detergent	Metallo-organic compounds of sodium, calcium and magnesium phenolates, phosphonates and sulphonates
Dispersant	Alkylsuccinimides, alkylsuccinic esters
Friction modifier	Organic fatty acids, lard oil, phosphorus
Metal deactivator	Organic complexes containing nitrogen and sulphur amines, sulphides and phosphites
Pour-point depressant	Alkylated naphthalene and phenolic polymers, polymethacrylates
Seal swell agent	Organic phosphates, aromatic hydrocarbons
Viscosity modifier	Polymers of olefins, methacrylates, di-enes or alkylated styrenes

Table 3.77: Types of additives used in lubricants
[67, DETR, 2001]

Additives need to be retained in the oil over its whole useful life. This means that even if the individual substance would be expected to be driven off at normal engine operating temperatures, there must be another additive incorporated that binds it within the oil formulation.

This requirement to keep additives in circulation, and to keep breakdown products in circulation to increase the longevity of the oil, creates one of the discussion points for emissions of waste oil. Although a number of components are solid at ambient temperatures and could be expected to settle out of the oil and into the sludge layer, dispersants in the oil will tend to keep them within the oil layer. Larger solids are taken out of the engines by the oil filters.

During use, the composition of the oil will charge markedly, due to the breakdown of the additives, the formation of additional products of combustion and unburned fuels, the addition of metals from wear and tear on the engine and from the breakdown of the base oil itself.

Large treatment sites recognise that there will be a range of species in waste oil and thus screen the incoming waste for flashpoint, metal and chlorine levels; whereas smaller sites will typically just accept the oil waste. There is a distinct shortage of analysis data for incoming wastes, although the screening activities of a few sites show that industry anticipates high metal levels and contamination by flammable solvents, giving a measurable flashpoint.

Used oils collected by high volume users can be more tightly controlled and may hence be more consistent in composition.

Type of waste containing waste oils	Comment
Oil filters	No specific analysis has been found but these are known to contain waste engine oils plus the residues of larger sized solids formed in the engine and that have been trapped in the filter. In addition, there is the plastic and metals of the filter. Metals tend to go for recycling
205 litre steel drums	Waste oil and steel
25 litre drums	Waste oil and plastics
Bulk used engine oil	Used engine oil is the main wastestream processed at waste management licensed sites. Most of the emissions will be due to this material

Table 3.78: Type of waste containing waste oils
[56, Babtie Group Ltd, 2002]

There are no comprehensive analyses available of the waste oils entering oil treatment plants. Instead the next couple of tables (Table 3.79 and Table 3.80) show the data gathered on the chemical components that typically exist in the different types of waste oils. It is not expected that in reality all waste oils will be covered by the lower or top ends of the ranges mentioned in these two tables.

Waste oil components	Concentration range (ppm)	Origin/comments
Al	4 – 1112	Bearing wear or engine
Alkyl benzenes	900	Petroleum base oils
Aromatic compounds	14 – 30 w/w-%	For used motor oil, these arise from the lubricant base oil
Aliphatic compounds	65.4 w/w-%	N-alkanes are about 0.4 % waste oil, but the distribution is slanted towards the longer molecules that are less likely to evaporate: • tetralin 0.0012 % • dodecane 0.014 % • tridecane 0.014 % • octadecane 0.07 % • nonadecane 0.2 %
Antifreeze		
As	<0.5 – 67	
Ash content	0.4 – 0.64 [1]	
Ba	50 – 690	Detergent additives, additive package
BTEX	300 – 700	A composite analysis shows a high level of short chain hydrocarbons (benzene (0.096 – 0.1 %), xylenes (0.3 - 0.34 %), toluene (0.22 – 0.25 %)), with boiling points below 150 °C.
Ca	900 – 3000	Detergent additives
Cd	0.4 – 22	
Cl	184 – 1500[2]	Chlorine in used oils arises from: • contamination (either accidental or deliberate) with chlorinated solvents and transformer oils, both of which are now more closely controlled • lubricating oil additives • the lead scavengers added to leaded gasoline • it is used as a cold-flow additive
Chlorinated hydrocarbons	37 6300 18 – 2800 18 – 2600 3 – 1300	dichlorodifluoromethane trichlorotrifluoroethane trichloroethanes trichloroethylene perchloroethylene used oils can have a significant, but variable, chlorine content, including organochlorines as PCB, dichlorodifluoromethane, trichlorotrifluoroethane, 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene. They may be formed chemically during the use of contaminated oil
Cr	2 – 89	Engine wear
Cu	<11 – 250	Bearing wear
Engine blowback	8 – 10 w/w-%	Absorbed gas, gasoline and diesel fuel. A variety of 'thermal breakdown products' are also included in the composition of waste oil
Fe	100 – 500	Engine wear
Halides	Up to 500	
Heavy hydrocarbons		Arise from polymerisation and from the incomplete combustion of the fuel
Hg	0.05 – <11	
Light hydrocarbons	5 – 10 w/w-%	A certain amount of unburned fuel (gasoline or diesel) dissolves in the oil and also arise from breakdown of the oil
Lubricant base oil	Up to 95 w/w-%	Major components are aliphatic and napthenic hydrocarbons and/or olefin polymers (e.g. polybutenes and poly-alpha-olefins in some lube base oils). Smaller amounts of aromatic and polyaromatic hydrocarbons are also present. The heavy metal content is less than 500 ppm. Phenols may be present at a few ppm

Waste oil components	Concentration range (ppm)	Origin/comments
Metals such as Al, As, Ba, B, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, P, Pb, Sb, Si, Sr, Ti, V, Zn	Up to 10000 combined	These originate from the lube oil additives, engine wear and foreign sources. They appear in waste oils as additives within lubricating oil, from wear and tear on engines and with machining oils. Additives (particularly the metals) typically remain in the oil after use
Mg	100 – 500	Detergent additives
Ni	10	Engine wear
Naphthalenes	9.7 – 470 – 2300 [4]	From base oils
Nitrogen compounds		From the addition of nitrogen compounds
Non – lubricant related compounds		Used oil often becomes contaminated by all kinds of materials, usually because of bad collection/segregation. Materials that may appear are brake fluid and antifreeze, vegetable oils, cigarette packets, solvents, etc.
P	6 – 1000	Anti-oxidant/anti-wear additives
PAH	30.3 – 204 – <1000 [4] Sum of 26 individual PAHs represented 0.17 % of the oil or 1.2 % of the aromatic fraction	The aromatics also include a huge range of PAHs in concentrations of up to 700ppm for an individual species. They appear from base oils and from incomplete combustion. Examples are benz(a)anthracene (0.87 – 30 ppm), benzo(a)pyrene (0.36 – 62 ppm), pyrene (1.67 - 33 ppm), naphthalene (47 ppm), biphenyl (6.4 ppm) and also chlorinated polyaromatics
PCB	<0.5 – 11 – <50	Under the Waste Oil Directive, the maximum content of PCB allowed in used oils to be treated for disposal is 50 ppm. It occurs due to contamination with transformer oils
Pb	8 – 1200 Up to 14000 when leaded gasoline is used	Leaded gasoline/bearing wear
S	0.1 – 2.8 w/w-%	From base oil and combustion products.
Sediments	0.5 – 2 w/w-%	Soot and sediment from the combustion chamber, free metals and dirt. Sediment formation is aggravated by the mixing of used oils from several manufacturers' additive packages, and collection sources
Si	50 – 100	Additives/water
Sn	Trace amounts	Bearing wear
Tl	0.1	
V	300	From base oil
Water	5 – 10 w/w-% [3]	Combustion
Zn	6 – 4080	Anti-oxidant/anti-wear additives

Note: Additions of figures cannot be made to fit perfectly because they correspond to different sets of data.

[1] Both parameter limits are average values

[2] Up to 8452 ppm in collected used oil due to contamination with chlorinated solvents and sea salt from ship slops

[3] Up to 30 %

[4] When three numbers appear in a range, the middle number corresponds to the average

Table 3.79: Indicative list of components present in used oils
[4, Langenkamp, 1997], [5, Concawe, 1996], [6, Silver Springs Oil Recovery Inc., 2000], [14, Ministry for the Environment, 2000], [37, Woodward-Clyde, 2000], [56, Babtie Group Ltd, 2002], [42, UK, 1995], [150, TWG, 2004]

Used industrial oils

A variety of oils are used in industry including soluble oils and some halogenated oils, although these are becoming less common. Oil is used as hydraulic oil, as lubrication, as a heat transfer medium, as an electrical medium and as a cutting fluid.

Soluble oils/machining oils are very common, but there is no information so far about their composition. Many of these industrial oils undergo intensive in-house recycling to extend their useful life, and the majority of any metal contaminants associated with grinding operations are removed by in-house systems and recovered. In the absence of other data, the following assumptions have been made:

- these oils are used in open systems. Their formulations do not include very low boiling point/volatile hydrocarbons because of the fire risk and health risks during use and the need to retain the product characteristics during use. They are agitated during use, and take away excess heat from machining surfaces, thus in operation they are heated above the ambient temperature. Therefore, VOC emissions during waste treatment are typically very small
- the metal content will vary considerably from source to source. The main metals worked with will be copper, zinc, nickel and chromium.

	Concentration	Reason
Cadmium	50 % of concentration in lubricating oil or 0.000155 %	Cadmium is currently being phased out from the manufacture
Chromium	100 % of concentration in lubricating oil or 0.0028 %	Common: typically used at the same level as in engine oil
Copper	100 % of concentration in lubricating oil or 0.025 %	Common: typically used at the same level as in engine oil
Lead	0	No particular reason to machine this
Naphthalene	0.0042 %	No data at all, naphthalene is in all oils, but would expect the formulation to have the lowest amount possible (taken from fuel oil n^{o}6 content) because it would be a solid at room temperature and does not seem to add anything chemically useful to the formulation
Nickel	0.0028 %	No data for lubricating oils
PCB		Found in transformer coolant oils
Xylenes	0.22 %	
Zinc	50 % of concentration in lubricating oil or 0.029 %	Common machining component, but zinc appears to be a major additive in lubricating oils

Table 3.80: Estimated metal concentrations in industrial waste oils
[56, Babtie Group Ltd, 2002], [86, TWG, 2003]

Electrical oils are specialist oils which undergo a laundering process, so very little waste arises from them. The main concern with these oils is the risk of PCB contamination. Typically waste treatment facilities do analyse for PCBs.

Oily water from interceptors

Most waste from interceptors comes from car parks and vehicle service areas. It is, therefore, reasonable to assume that it is similar in content to used engine oil but will contain additional silt, possibly vehicle tyre wear particles, fuel combustion products and road making tars. Spilt fuel will also be collected at the interceptor, but any materials that are capable of evaporating to the air at ambient temperatures will have done so before the interceptor waste is collected.

A proportion of oil interceptors arises from manufacturing sites and collected waste industrial oils. These will have far lower concentrations of combustion products, but might have higher metal concentrations, depending on the industrial application.

Waste solvents
Waste solvents may be generated in the following industrial sectors:

- paints, coatings and paint removers
- inks
- chemical and pharmaceutical industry
- film production
- production of synthetic fibres
- rubber, plastic and resin solutions
- solvents for degreasing
- solvents for dry cleaning
- for agriculture products
- aerosol cans and dispensers.

The wastes that are considered as solvents correspond mainly to EWL codes 07, 08, 09 and 14. The final code corresponds to a category especially devoted to organic solvents. There are four main classes of solvent mixtures which make the solvent unusable in its present state and this promotes its recovery. These are:

- mixture with air. This usually occurs when the solvent has been used to dissolve a resin or polymer which is laid down by evaporating the solvent. Recovery from air can pose problems because the solvent may react on a carbon bed adsorber or be hard to recover from the steam used to desorb it
- mixture with water. Whether this arises in the solvent-based process or in some part of the recapture of the solvent, it is very common to find that the solvent may be contaminated with water. Removal of water is a simple matter in many cases but in others it is so difficult that restoration to a usable purity may prove to be uneconomic. It should always be borne in mind that the water removed in the course of solvent recovery is likely to have to been discharged as an effluent and its quality is therefore important
- mixture with a solute. A desired product is often removed by filtration from a reaction mixture. The function of the solvent in this case is to selectively dissolve the impurities (unreacted raw materials and the products of unwanted side reactions) in a low viscosity liquid phase, with a very low solvent power for the product. The choice of solvent is often limited in such cases, but significant improvements in the solvent's chemical stability can sometimes be found by moving up or down a homologous series without sacrificing the selectivity of the solvent system. A less sophisticated source of contamination by a solute occurs in plant cleaning, where the solvent power for any contaminant is of primary importance but where water miscibility, to allow cleaning and drying to take place in a single operation, is also an important property
- mixtures with other solvents. A multi stage process such as that found typically in the fine chemical and pharmaceutical industries can involve the addition of reagent dissolved in solvents and solvents that are essential to the yields or even to the very existence of the desired reaction.

Vegetable waste oils
Cooking oils from restaurants and hotels.

Waste catalysts
The spent catalysts that may be regenerated ex-situ are:

Metal catalysts
For example, platinum-alumina reforming catalysts which can be regenerated by the removal of carbonaceous deposits from the catalyst surface using a carefully controlled combustion procedure, followed by platinum redispersion and rechloriding of the catalyst support).

Noble metal catalysts

These can be regenerated by removing the coke deposits to successfully restore the activity, selectivity, and stability performance of the original fresh catalyst. Coke deposits are removed by controlled combustion.

Base metal catalysts

Hydroprocessing catalysts can be regenerated using different methods such as regenerative oxidation treatment to remove coke (ex-situ regeneration) or redispersion of the metals in the case of poisoning by the sintering of metals.

Zeolites

These can be regenerated relatively easily by using methods such as heating to remove adsorbed materials, ion exchanging with sodium to remove cations, or a pressure swing to remove adsorbed gases. However, they are not regenerated ex-situ because the structure is, in most cases, damaged and depending on the application the pores can be contaminated with heavy metals or other catalyst poisons.

Waste activated carbon

Most industrial plants tend to send their spent carbon off-site for regeneration by a large centralised carbon manufacturer. Quantities of spent carbon from industrial sources (textiles, refinery products, carpet mills, plastic industry, phenolic resins, herbicides, explosives, detergents, solvents, dyes), whilst reasonably substantial, do not approach those obtained from potable water purification. From discussions with various carbon regenerators, it appears that water treatment provides the single largest source of spent carbon. Activated carbon adsorption systems can be used for a wide variety of applications, and can potentially contain a cocktail of adsorbed pollutants. The contaminants found in spent activated carbons are typically:

- chlorine
- COD/BOD
- pesticides
- bulk organics imparting colour, taste and/or odour (i.e. humic acids)
- general organics such as phenol
- metals such as iron, aluminium, cadmium and mercury
- inorganic elements such as calcium and phosphorus
- dyes (cause of colour)
- detergents
- phenols
- explosives (only in material that comes from the manufacture of explosives).

Activated carbon products are basically available in three forms: extruded activated carbon, granular activated carbon, and powder activated carbon. The last form is not regenerated.

Waste ionic resins

A large proportion of resins sold worldwide are used in water treatment (i.e. water softening). The remaining balance is divided between chemical processing, extractive metallurgy, and food and pharmaceutical processing.

Operating ion exchange resins may concentrate toxic ions such as chromate and cyanide, or heavy metals. Due to the predominance of water applications, they may also contain pesticides, chlorine, phenol and inorganic elements such as calcium, sodium, manganese and phosphorus.

Conventional ion exchange resins are bead-shaped, and behave as plastic ball bearings when handled. They contain ion-active sites throughout their structure, have uniform distribution of activity, and can usually resist breakages resulting from handling, or from osmotic shock (i.e. a rapid change in solution environment). Most beads are sold in the 40 µm to 1.2 mm size range.

Treatment of liquid photographic waste

Parameter	Concentration (mg/l)	
Hydrocarbons	6000	emission in evaporation step (colour photo processing waste)
EOX	10	
Respiration inhibition	5 %	
Metals (Zn, Ni, Pb, Cr, Mo)	50	
Ag	50/100	black and white/colour photo processing waste
Cd	1.0	
Cu	25	
Hg	1.0	

Table 3.81: Acceptance criteria for desilvered photographic liquid waste and similar waste waters (with the same processing path)
[156, VROM, 2004]

3.4.2 Consumptions of waste treatments to obtain a recycled material

Consumptions in the re-refining of waste oils

Other than transportation, the main operating overhead relates to the generation of steam for heating waste oil.

Process	Compounds used within the process	Consumptions (values in kg/tonne of waste oil if not otherwise specified)
Acid/clay process	Sulphuric acid as a precipitate agent of heavy metals. Clay as a filtration/neutralisation agent	 36
Pretreatment of waste oil	Demulsifiers to help in the settling process	
Distillation/clay process	Clay	40
Propane de-asphalting (PDA)	Consumption of energy is higher than in the regeneration by chemical treatment or by hydrogenation	
Thin film evaporator (TFE) + clay process	Clay	60
TFE + hydrofinishing	Hydrogen and catalysts	
TFE + solvent extraction	Solvent	
TFE + chemical treatment + solvent extraction	Energy Caustic Solvent	3.2 MJ/kg of used oil 10 0.3
TFE + solvent extraction + hydro-finishing	Hydrogen catalyst Mohawk chemical Hydrogen gas	0.25 12 2
TDA (thermal de-asphalting) + clay treatment	Clay	100
TDA + hydrofinishing (high pressure)	Catalyst	0.5
PDA (propane de-asphalting) + hydro finishing (medium pressure)	Propane	8.25
With thermal clay treatment	Fossil energy resources	4.26 MJ/kg of used oil
With hydro-finishing	Energy	9.93 MJ/kg of used oil
Vacuum distillation + chemical treatment	Fossil fuel consumption Primary energy Water consumption	47 kg eq crude oil 2681 MJ 3300
Regeneration process	Fossil energy resources	42.46 MJ/kg of oil
Caustic soda and bleaching earth treatment (ENTRA)	Caustic soda Bleaching earth	30 20
Direct contact hydrogenation (DCH)	Hydrogen Catalyst	70 Nm^3/t 0.5

Table 3.82: Consumptions of different waste oil re-refining techniques
[6, Silver Springs Oil Recovery Inc., 2000], [7, Monier and Labouze, 2001], [11, Jacobs and Dijkmans, 2001], [13, Marshall, et al., 1999], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [150, TWG, 2004]

Table 3.83 gives the consumptions for the re-refining of part of the waste oil to base oil which can then be re-used as lubricating oil, together with the regeneration of the remaining waste oil to fuel oil.

	Consumptions	Units
Economics		
Capital investment expenses for treatment plant	4.85 (36)	EUR (DKK) millions
Maintenance	0.094 (0.7)	EUR (DKK) millions per year
Operation period	20	years
Labour input	10	number of persons
Resources used		
Chemicals	291.5	tonnes
Water	8000	m^3
Electricity	1150	MWh
Fuel oil	1200	m^3
Base: 26000 tonnes yearly collected waste oil to base oil (8000 tonnes), fuel oil (12000 tonnes) and asphalt (4000 tonnes)		

Table 3.83: Consumptions of waste oil re-refining activities
[12, Birr-Pedersen, 2001]

Figure 3.5 depicts a block diagram showing a comparison between the inputs and outputs of different re-refining processes.

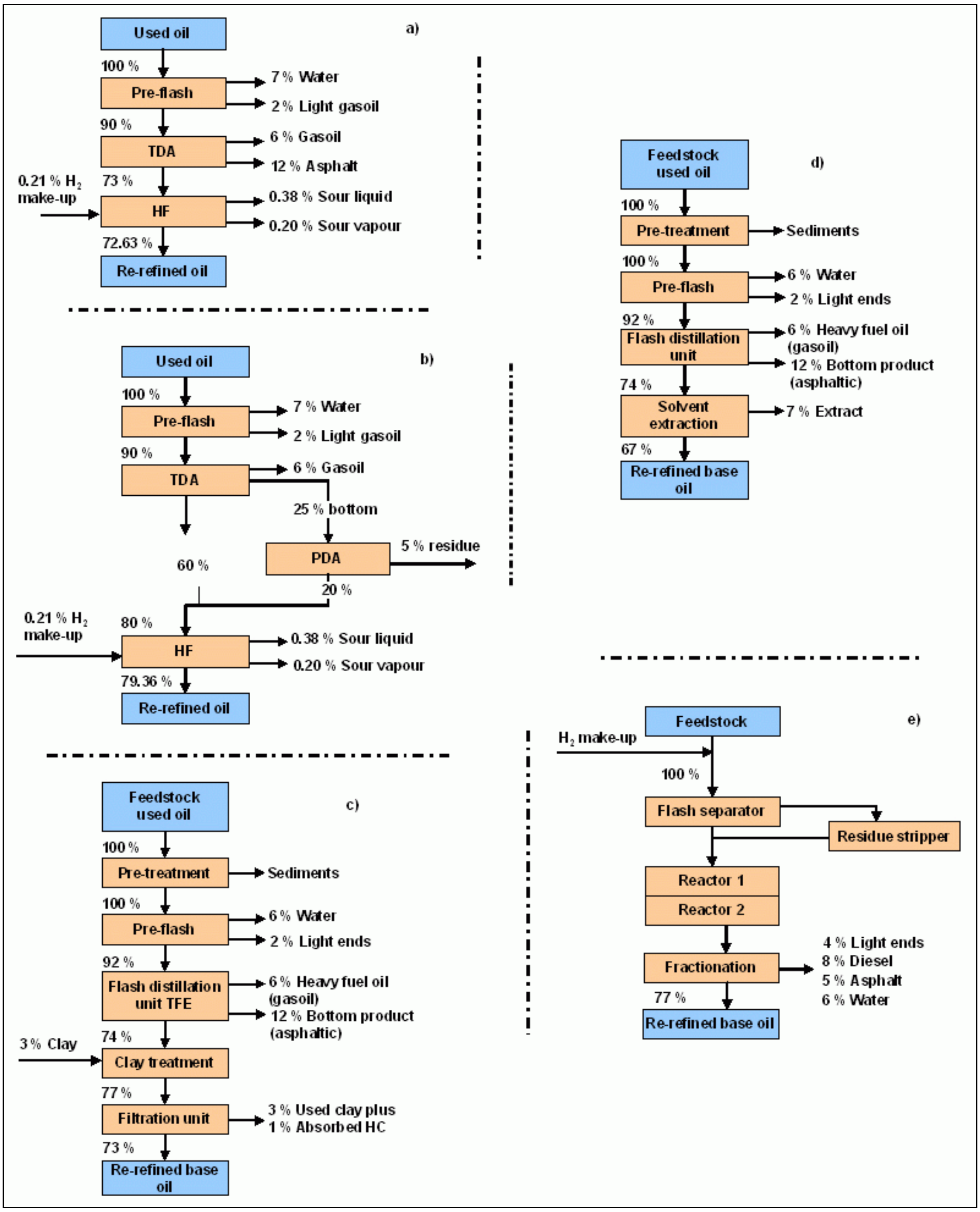


Figure 3.5: Inputs and outputs of the re-refining treatment
Note: a) TDA/HF, b)TDA/PDA/HF, c)TFE/clay treatment, d)TFE/solvent, e) DCH
HF = Hydrofinishing. % represents the amount that goes in that stream based on 100 % used oil entering the system
[36, Viscolube, 2002], [86, TWG, 2003], [150, TWG, 2004]

Table 3.84 shows the consumptions of the TDA system and the TDA combined with a PDA.

Traditional TDA/HF system						
Consumption and utilities	**PF**	**TDA**	**HF**		**Total**	**Unit**
Electrical consumption	1.5	12	20		33.5	kWh
MP steam	285	322	70		677	kg
Cooling water (make-up)(1)	1.1	5	0.3		6.4	tonne
Fuel (absorbed heat)	/	670	711		1380	MJ
Hydrogen	/		2.1		2.1	kg
Catalysts	/		0.2+0.05(2)		0.2+0.05(2)	tonne
Propane make-up						kg
High recovery system						
Consumption and utilities	**PF**	**TDA**	**HF**	**PDA**	**Total**	**Unit**
Electrical consumption	1.5	12	20	13	46.5	kWh
MP steam	285	322	70	135	812	kg
Cooling water (make-up)(1)	1.1	5	0.3	4	10.4	tonne
Fuel (absorbed heat)		670	711	920	2300	MJ
Hydrogen			2.1			kg
Catalysts			0.2 + 0.05(2)		0.2 + 0.05(2)	tonne
Propane make-up				0.8	0.8	kg

(1) Based on 10 % evaporation losses

(2) Demetalisation catalyst + Refining catalyst

Note: Consumption based upon 100 kt/yr waste oil capacity, considering 10 % water contents. All the parameters are expressed in unit/tonne of waste oil.

HF: hydrofinishing, PDA: Propane de-asphalting, TDA: Thermal de-asphalting, PF: Pre-flash, MP: medium pressure

Table 3.84: Consumption values of the TDA system and the TDA combined with a PDA processes [66, TWG, 2003], [150, TWG, 2004]

Capacity	t/yr	2001	4600	6824	15000	17171	19960	46208	90500
Fuel consumption	GJ/yr		19146	33486	40671	54751	16705	405883	
Electricity consumption	MWh/yr	345	225	1200	1380	2024	655	9215	
Heat consumption	MWh/yr	157			0	15208			
Water	m^3/yr	617		80000	9848	9929	1557	407000	2213000
Cooling	MJ/yr				44000				
Electricity/Plant capacity	kWh/t	172.4	48.9	175.8	92	117.9	32.8	199.4	
Heat/Plant capacity	kWh/t	78.5				885.7			

Table 3.85: Consumptions from different waste oil re-refining plants in the EU [66, TWG, 2003]

Consumptions of the regeneration of waste solvents

Table 3.86 shows consumption data for two facilities operating in the EU. Other data reported energy consumptions lower than 1 GJ/tonne.

Consumption parameter	Units		
Capacity	kt	12	27.5
Gas fuel	GJ/yr	19651	
Fuel consumption	GJ/yr		31628
Electricity	MWh/yr	1571	2984
Water	m^3/yr	19000	40776

Table 3.86: Consumptions of two regeneration treatment of waste solvents [66, TWG, 2003], [130, UBA, 2003]

Consumptions of regeneration of spent catalysts

Table 3.87 shows an overall material balance for an example regeneration. Almost 375 t of catalyst was recovered for re-use.

Overall material balance	Values in kg	
As received material		620982
Inert support	27099	
Unregenerated dust and fines	9569	
Total unregenerated feed to regenerator		584314
Shorts from length grading and regenerated dust and fines	37191	
Loss on ignition	172143	
Net regenerated catalyst		374980

Table 3.87: Mass balance in a commercial regeneration of CoMo catalyst
[125, Ruiz, 2002]

Consumptions in treatment of solid photographic waste

The electricity consumption for shredding, washing/rinsing and electrolysis amounts to 100 to 300 kWh/t film waste. Depending on the process of desilvering, auxiliary materials are used. These are shown in Table 3.88.

Desilvering with bleach-fix	Desilvering with iron chloride
Sodium hydroxide (20 %): 6 l/t film	Iron chloride (40 %): 11 l/t film
Sulphuric acid: 6 l/t film	Hydrochloric acid (36 %): 8 l/t film
Sodium bisulphite: 12 l/t film	Sodium sulphite: 12 l/t film
	Hydrogen peroxide (35 %): 4 l/t film

Table 3.88: Used amounts of auxiliary materials for desilvering film waste
[156, VROM, 2004]

Consumptions in the treatment of liquid photographic waste

Consumption of energy

The required electricity for electrolysis ranges from 12 to 46 kWh/t photographic liquid waste. The electricity consumption is dependent on the iron content. For bleach-fix, the consumption is higher due to the higher iron content. The ultrafiltration requires approximately 27 kWh_e and 13 MJ/t liquid waste for the heating of the rinse-water. The electricity consumption of chemical removal of silver is estimated on 3.5 kWh/t liquid photographic waste.

The energy consumption for evaporation is approximately 220 MJ/t waste water. If evaporation is also applied as a pretreatment, in the case of colour photo processing waste water, the energy consumption is approximately 350 MJ/t waste water. The required electricity for electroflocculation, in the case of extra desilvering, is approximately 80 kWh/t waste water. Further physico-chemical and biological treatment requires approximately 5 kWh_e/t waste water.

Consumption of chemicals

Table 3.89 shows the consumption of chemicals for sulphide precipitation/ultrafiltration of photographic liquid waste.

Chemical	Consumption (kg/t photo processing waste)	Function
Sodium sulphide (40 %)	0.1	Precipitation of silver (and other metals)
Citric acid	0.7	Cleaning of the membranes
Sodium hydroxide	0.01	Cleaning of the membranes
Detergents	0.01	Cleaning of the membranes
Water	75	Cleaning of the membranes

Table 3.89: Consumption of chemicals for sulphide precipitation/ultrafiltration
[156, VROM, 2004]

For chemical removal of silver, the consumption of chemicals is estimated at 1.5 sodium borohydride and 2.5 sulphuric litres per tonne of photographic liquid waste.

In the physico-chemical treatment of desilvered photographic liquid waste, several chemicals are used. The consumptions are shown in Table 3.90. If evaporation is applied as a pretreatment, practically no chemicals are consumed in the following treatment steps. Most contaminants have already been removed in the evaporation step.

Chemical	Consumption (kg/t waste water)	Comments
Sodium hydroxide (33 %)	0.007	
$FeCl_3$	0.003	
Powder carbon	0.5	
Flocculant	5	In the case of desilvering
Na_2S (40 %)	15	In the case of desilvering

Table 3.90: Consumption of chemicals in the treatment of desilvered photographic liquid waste [156, VROM, 2004]

3.4.3 Emissions from waste treatments to obtain a recycled material

3.4.3.1 Emissions from the re-refining of waste oils

In order to evaluate emissions from the re-refining of waste oils several issues need to be considered:

- waste lubricating oils contain shorter chain organics than new lubricating oils and therefore VOCs are likely to be relevant
- sulphur and chlorine are known ‘problem’ compounds found in waste oils
- aromatic compounds are more polar in general than aliphatic molecules and are therefore more likely to be present in the aqueous phase.

The oil processing sector has a narrow range of operations and is the most likely to respond to a generic method of calculating emissions if the oil constituents can be identified. The following detail the different pollutants and media where they can be found. Some tables have been constructed to focus on the pollutants (Table 3.91 and Table 3.92) whereas others focus on the activities that may lead to pollution (Table 3.93).

Species	Air	Water	Waste and soil
Organic compounds			
Benzene	yes - some data, but difficult to apportion between air/water/land	yes - some data, but difficult to apportion between air/water/land. Polar compound	yes - some data, but difficult to apportion between air/water/land
Ethyl benzene (VOC)	No data available	yes (as BTEX)	yes (as BTEX)
Toluene		yes - some data, but difficult to apportion between air/water/land	yes - some data, but difficult to apportion between air/water/land
Xylenes	yes - some data, but difficult to apportion between air/water/land	yes - some data, but difficult to apportion between air/water/land	yes - some data, but difficult to apportion between air/water/land
VOCs	yes - some incomplete data, but difficult to apportion between air/water/land. Lower chain alkanes likely to go to air. Since used oil usually contains light ends such as gasoline, VOCs may be emitted from storage (from the tank and their associated pipework) for every process considered. The behaviour of oils undergoing heating and agitation generates VOCs emissions	BTEX in particular are polar molecules, but also volatile, and are present in the aqueous phase and/or evaporated to the air	
Naphthalene		Some data available	Some data available
Biphenyl		Limited data, may not be relevant	Limited data
Phenol	Not air emissions expected because too soluble in oil and water	Relevant but no data	Relevant but no data
Sulphur and nitrogen compounds	The gradual increase in sulphur and nitrogen additives in lubricating oils may require sites to monitor for these		Found in used oil sludge
PCBs and chlorinated solvents: Identified as present in some analyses		Solvents and lighter compounds are removed in the dewatering. Naphtha and light distillate cuts are typically distilled off upstream of the main processing facilities. If the hydrocarbon streams are fed to a hydrotreater, the chlorides may be removed	Used oil sludge

Species	Air	Water	Waste and soil
PAHs. These used to be a problem in re-refined base oils. However, recent tests indicate that it is possible to remove PAHs in the regeneration process of modern plants, thus avoiding the accumulation of PAHs. PAHs are destroyed by severe hydrogenation which also removes nitrogen, sulphur, metals and chlorides	PAHs are unlikely to be discharged to the air during the oil treatment processes. They are not volatile compounds, and their position as an air carcinogen is due to them being released as a combustion product from fossil fuels. Potential for PAH emission may be during the processing of oil filters. Most filters are crushed at some point, producing a fine oil mist. There may be a hood and an exhaust vent, but this is a potential mechanism to deliver PAHs to the air and the oil in oil filters have a larger concentration of particulate matter and hence PAHs. This may not be of significant importance, as it is the smaller particles that are more likely to form an air discharge. The behaviour of oils undergoing heating and agitation may generate PAHs emissions.	Relevant but no data	The heavy PAHs in the regeneration plants end up in either the residue stream and/or the asphalt blends. The lighter ones remain in the lube oil cuts. Also possibly found in a used oil sludge. Relevant but no data
Other air pollutants			
CO_2 from many combustion processes			
Odour	Odour has been identified as an important problem in re-refining installations		
Typically water and waste parameters			
Total nitrogen		Nitrogen and phosphorus additives	Nitrogen and phosphorus additives
Total phosphorus		Nitrogen and phosphorus additives	Nitrogen and phosphorus additives
TOC		Calculated from COD as 1/3 of COD	Not available except as calculated from oil content, but this will be too low (or COD)
Chloride		Additives in oil and salt on roads	Additives in oil and salt on roads
Oil		The oil itself is a visual pollutant when it floats on water, and drinking water is rapidly tainted by the taste of oil	Used oil sludge

Species	Air	Water	Waste and soil
Metals			
Metals			The metals from regeneration processes are mostly in the residue cut. The volatile metals are removed by the hydrotreatment guard reactor if they are hydrotreated. Also possibly found in used oil sludge
Arsenic	Not expected	Some data available	Some data available
Cadmium	Not expected	Some data available, but being questioned	Some data available, but being questioned
Chromium	Not expected	Some data available	Some data available
Copper	Not expected	Limited data	Limited data
Lead	Not expected	Some data available, but being questioned	Some data available, but being questioned. In the re-refining options, lead ends up in the heavy residues which results in it being 'locked up' in a bitumen product
Manganese	Not expected		
Nickel	Not expected	yes, but no data	yes, but no data
Zinc	Not expected	Some data available	Some data available

Table 3.91: Common emissions from waste oil treatment plants
[5, Concawe, 1996], [6, Silver Springs Oil Recovery Inc., 2000], [14, Ministry for the Environment, 2000], [56, Babtie Group Ltd, 2002], [86, TWG, 2003]

The following Table 3.92 reflects how the components of the waste oil distribute emissions to air, sewer and products. As can be seen, most of the contaminants remain in the recovered oil. The main exception to this is VOCs, where there is a possibility of their transfer to the air, with the amount depending on the type of oil and whether the oil is heated during treatment.

Input substances	Hot processing			Cold processing		
	Air	**Products**	**Water**	**Air**	**Products**	**Water**
Benzene	0.6	0.3	0.1	0.2	0.7	0.1
Toluene	0.3	0.7	0	0.1	0.9	0
Xylenes	0.1	0.8	0.1		0.9	0.1
Naphthalene		1			1	
Biphenyl		1			1	
Benz(a)anthracene		1			1	
Benzo(a)pyrene		1			1	
Heptane	0.2	0.8			1	
Octane	0.1	0.9			1	
Nonane		1			1	
Decane		1			1	
Undecane		1			1	
Arsenic		1			1	
Cadmium		1			1	
Chromium		1			1	
Copper		1			1	
Lead		1			1	
Nickel		1			1	
Zinc		1			1	
Note: Figures correspond to the share distribution of substances in output streams. E.g. for each kg of benzene entering into the hot processing, 0.6 kg ends up as an emission to the air, 0.3 kg goes into the oil and 0.1 kg into the waste water. 1 means that all the input goes to that output						

Table 3.92: Matrix for allocating input species to air, oil and water streams for hot and cold processes
[56, Babtie Group Ltd, 2002]

	Point source emissions		
Activity/Plant	**To air**	**To water**	**To disposal**
Filter shredding	Oil mist		
Magnetic separation	Oil mist		
drum emptying/shredding	Oil mist		
Tanker unloading	Tank venting		
Coarse straining	Oil mist		
Bulk storage	Tank venting. Very few tank vents are linked together. Tank vents will discharge the 'air' that the tank contains when it is displaced during tank filling. This emission is unlikely to carry significant pollution unless the tank contents have been heated or agitated	Settled water (via treatment)	Settled sludge
Cold oil settling	Tank venting	Settled water (via treatment)	Settled sludge
Hot oil settling	Tank venting	Settled water (via treatment)	Settled sludge
Vibrating sieve	Mist and vapour		Sludge
Enclosed filters			Used elements and sludge
Bauxite towers			Spent bauxite
Vacuum dehydration	Vapour (via scrubbers)		
Product blending	Tank venting		
Pumped sludge storage/decanting	Tank venting		
Cold effluent settling	Tank venting		
Hot effluent settling	Tank venting		
Biological effluent treatment	Aeration air		
Filter press			Filter cake
Plate separator		Effluent	Settled sludges
Mechanically handled sludge/solids storage and loading			Mixed solid wastes
Waste oil fired boiler	Stack emissions		
Old interceptor waste	Since it usually comes from paved surfaces where it has already been exposured to air, it will probably have already emitted all that it is capable of emitting to the air at this stage unless it is heated during treatment		
Many sites have an accidental spillage of oils to the site base during unloading, or during the storage or transfer of materials on the site. The site base is usually designed to retain liquid spills and to return these to the plant, but there will be some evaporation in the air			

Table 3.93: Principal emission sources at oil recycling premises
[56, Babtie Group Ltd, 2002], [150, TWG, 2004]

The following table identify emissions to air, water and solid waste generated for each type of waste oil treatment. In some cases, the emissions are quantified with data in the table.

Process	Emissions (values in kg/tonne of WO if not otherwise specified)		
	Air	Water	Soil and residues
Oil separation from water stream	Could produce a range of other emissions such as metals, naphthalene, additional nitrogen, toluene, xylenes and PAHs	Could produce a range of other emissions such as metals, naphthalene, toluene, xylenes and PAHs	Could produce a range of other emissions such as metals, naphthalene, toluene, xylenes and PAHs
Laundering. Closed loop recycling of industrial oil	From the oil recovery process the emission is 20 – 40 mg/m^3 VOCs whilst heating. 262 kg VOC was released against 100 mg/Nm^3 and l0 t/yr limits	Waste water	Laundering can be considered as a closed loop system because it generates very little (if any) waste oil. The contaminated filter sludge contains 20 – 30 % oil. This waste stream is reprocessed with quicklime and made suitable for co-combustion in a cement kiln. The acceptability of one technique, which used a clay known as’fuller’s earth’ to remove contaminants, is waning as conditions for disposal to landfill become more stringent. The technique is still used in New Zealand, but disposal of the contaminated clay is likely to become an issue. Releases to land are: filter cake which includes solids and metal fines (<100 t/yr against a consent limit of 600 t/yr) and in some cases chlorinated solvent sludges. 80 – 85 % of drums are recycled while the others are scrapped
Reclaiming industrial lubricants		Waste water from dewatering processes	
Vacuum distillation	Vacuum distillation of waste oils produces sulphur compounds, mercaptans (odorous) and PAHs (some may be carcinogenic)		All the metals contained in the used oil end up in the vacuum residue. This residue may be blended with a crude vacuum residue in such a proportion so as to enable its use as a component in bitumen
Distillation/clay process			Produces large quantities of the oil-absorbed clay which need to be disposed of. High temperature activated clay allows a lower clay/oil ratio, thus increasing the overall yield and reducing the quantity of oily clay needing to be disposed of
Thin film evaporator (TFE) + clay treatment		Water: 90	Clay: 50 – 60 Bitumen (metals and additives): 130 Sludge and light ends: 35 The process produces residues (requiring disposal)

Process	Emissions (values in kg/tonne of WO if not otherwise specified)		
	Air	Water	Soil and residues
Acid/clay process			This process produces large quantities of sludges and solids requiring disposal. These sludges (acid tars) are highly acid and contain high concentrations of PAHs, sulphuric acid and sulphur compounds, as well as most of the metals from the used oils. These tars are unsuitable for landfill because of their physical and chemical properties. This latter constraint can sometimes be overcome by: • dispatching the acid sludge jointly with the oily clay, in granulated form, to cement factories or to contractors • incinerating, but the gases need to be treated with caustic soda and the resulting waste water needs to be dealt with. This neutralisation treatment generates in quantity as much inactive waste as the amount of acid tar treated • treating to produce sulphuric acid or SO_2. The used clay (4 % by weight of feedstock + absorbed oil content) also needs to be incinerated by the same method as described above
Vacuum distillation + chemical treatment or clay treatment.			Used clay and used chemicals need to be safely disposed of. The route currently in use is to burn them in cement kilns or in a chemical waste incinerator
Vacuum distillation and hydrotreatment	Emissions common to any process handling oil products		The disposal of spent hydrotreating catalysts needs to be handled by a specialised company familiar with this problem. The residue produced from the vacuum distillation stage is similar to asphalt and may be sold. Fuels that are taken out in the de-fuelling stage can also be used on site or sold. The catalyst used is nickel-molybdenum and is either recycled by a nickel smelter or landfilled
TFE + hydrofinishing		Water: 90	Sludge and light end: 30 Sulphur: 35 Bitumen: 130
TFE +solvent extraction		Water: 90	Sludge and light end: 30 Extract: 60 Bitumen: 130
TFE + solvent extraction + hydro-finishing		Water: 65	Sludge and light end: 20 Sulphur: 4 Bitumen: 160
TDA (thermal de-asphalting) + clay treatment		Waste water: 770	Light ends/solvents: 35 Clay: 130 Bitumen (metals and additives): 120
TDA + hydrofinishing (high pressure)		Waste waters: 770	Light ends/solvents: 35 Spent catalyst: 0.5 Bitumens: 120
PDA (propane de-asphalting) + hydro finishing (medium pressure)		Waste waters: 770	Light ends/solvents: 30 Bitumens: 130

Process	Emissions (values in kg/tonne of WO if not otherwise specified)		
	Air	Water	Soil and residues
Vacuum distillation + chemical treatment	1116 kg eq CO_2 2.8 kg eq SO_2 VOC: 0.04 kg eq. C_2H_4 3.6 g particulates	0.0011 kg eq phosphates in water	Waste to eliminate: 24 Waste to recover: 33
Distillation and alkali treatment (Vaxon-Cator)		None. Recycled to a product	Small
Solvent extraction and distillation (Sener-Interline)		Discharges to water are from the residuum/water separator	None
Direct contact hydrogenation (DCH)		Waste water: 60	Bitumens: 50 Spent catalyst: 0.75
Thin film evaporator (TFE)		Process water, water decanted from storage tanks and contaminated surface water is treated in the effluent plant. This presents a problem to the site; in that the water has a very high COD which can vary between 40000 to 100000 mg/l against a discharge consent limit of 80000 mg/l. It contains materials such as glycols, polyglycols, esters and glycerols	The residue from the TFE is extracted whilst still mobile and blended with other secondary fuel oils which are also produced on site. Most of the organometallic constituents of the additives end up in the residue, so their ultimate destination is in a secondary fuel oil released to air as combustion products. There is a high dilution of the residue into the secondary fuel oil formed and the blend meets fuel oil specifications. Other residues, which include storage tank and effluent plant sludges, are removed from the site and centrifuged for reclamation of the oil. The solid residue from that process then is being landfilled
Caustic soda and bleaching earth treatment (ENTRA)		Waste water: 60	Bleaching earth, caustic soda and residue: 150
Waste oil transfer station		Waste water: 102	Sludge and solids: 2.13 Shredded steel: 85
Treatment of transformer oils			Spent bauxite catalyst Non-returned drums and pallets
Treatment of oil interceptor waste, soluble cutting oils, Spray booth waste from water based paint, gully waste, leachates		Waste water: 1613	Pumpable sludge: 47 Tank and tanker 'dig out' and screened waste: 43
Re-refining of lubricant oil[1]	CO_2: 123 SO_2: 1.04 NO_x: 0.35	Waste water: 84	Oil/chemical waste – sludge: 0.088
Used solvent oils and oily waters		Waste water: 444	Solids and sludge: 171
Treatment of oil water mixtures and leachates		Effluent: 1042	Filter cake and sludge: 55

Process	Emissions (values in kg/tonne of WO if not otherwise specified)		
	Air	Water	Soil and residues
Integration in a mineral oil refinery	Provided that adequate pretreatment of used oils is performed to remove water and light ends and to reduce the organic chloride content the emissions are related to those occurring in a refinery (see Refinery BREF)		Metals are encapsulated in asphalt, so the leaching of metals will be extremely low. However some problems of corrosion damage to the plant and loss of cracking catalyst activity need to be solved before this can be considered a viable option
Integration to a lubricant part of a refinery	It could release particulates, sulphur, halides, heavy metals and their oxides to the air		Most of the lube oil additives are bottomed out in this cut. The metals in the residue after the solvent extraction process are still leachable. There could be problems in its disposal to asphalt, especially in winter, when the market may slow. This cut would not be fit for blending in heavy fuels, not only for failing the filtration tests, but also for environmental reasons. The aromatic extracts which are contaminated with chlorine are believed to be disposed of outside the refinery
Regeneration	CO_2 equivalent (kg eq. CO_2/kg of oil) 3.19 Acidification potential (g eq. H+/kg of oil) 0.06 VOC emissions (g/kg of oil): 9.05 CO emissions (g CO/kg of oil) 9.74	COD (g COD/kg of oil): 35.02	Waste (g/kg of oil): 411
Chemical treatment + distillation + HF			

[1] Calculations were made based on the yearly treatment/usage of 26000 tonnes dehydrated waste oil and producing 8000 tonnes of base oil, 12000 tonnes of fuel oil and 4000 tonnes of asphalt

Table 3.94: Environmental issues generated by different waste oil re-refining techniques
[6, Silver Springs Oil Recovery Inc., 2000], [7, Monier and Labouze, 2001], [11, Jacobs and Dijkmans, 2001], [12, Birr-Pedersen, 2001], [13, Marshall, et al., 1999], [14, Ministry for the Environment, 2000], [42, UK, 1995], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [139, UBA, 2003], [150, TWG, 2004], [152, TWG, 2004]

Emissions to air

The emissions to the air are partially controlled at some sites, but uncontrolled at others. VOCs are known to occur. Although the lubricating system is a semi-closed system, it is not gas tight, therefore it would be expected that the volatile gases would have boiled off and left the system during normal operating temperatures.

Abatement systems for reducing oil emissions to the air are in place in some plants. At other sites, the excess oil concentration in buildings is simply vented to the air through exhaust fans; with all the tanks having vents to the air.

Most plants will accept that there is an odour problem from the oil. The control of odour from such plants requires a high level of management control and attention. Odours are typically generated during the storage, e.g. odours problems can arise by leaving hatches open at the top of each settlement tank and oil storage tank, or in open vibrating sieves.

No generally recognised reliable figures have been found for the concentration of contaminants in the air emitted from waste oil re-refining processes. However, some matrix distributions are shown in Table 3.95.

Activity	**Oil filters**	**25 litre oil drums**	**205 litre oil drums**	**Bulk used engine oil**	**Used industrial oils**	**Oil y waters (interceptors)**	**Fuel oils**	**Electrical oils**
Filter bin unloading	▨							
Filter bin storage	▨							
Filter crushing	▨							
Filter shredding	▨ *							
Magnetic separation	▨ *							
205 litre drum unloading		▨	▨					
205 litre drum storage		▨	▨					
205 litre drum emptying		▨	▨					
25 litre drum unloading		▨	▨					
25 litre drum storage		▨	▨					
25 litre drum emptying/shredding		▨ *	▨					
Tanker unloading				▨	▨	▨	▨	▨
Coarse straining				▨	▨	▨	▨	▨
Bulk storage				▨	▨	▨	▨	▨
Cold oil settling				▨	▨	▨	▨	▨
Hot oil settling				▨ *	▨ *	▨	▨	▨
Distillation				▨ *	▨ *	▨	▨	▨
Vibrating sieve				▨	▨	▨	▨	▨
Centrifuge				▨	▨	▨	▨	▨
Bauxite towers								▨ *
Vacuum dehydration								▨ *
Product blending				▨	▨	▨	▨	▨
Pumped sludge storage/decanting				▨	▨	▨	▨	▨
Effluent incineration				▨ *	▨ *	▨ *	▨ *	▨
Cold effluent settling				▨	▨	▨	▨	▨
Hot effluent settling				▨ *	▨ *	▨ *	▨ *	▨
Biological effluent treatment				▨ *	▨ *	▨ *	▨ *	▨
Effluent clarification				▨	▨	▨	▨	▨
Effluent balance tank				▨	▨	▨	▨	▨
Plate separator				▨	▨	▨	▨	▨
Mechanically handled sludge/solids storage and handling				▨	▨	▨	▨	▨
Waste oil fired boiler				▨ *	▨ *	▨ *	▨ *	▨
Note: The grey blocks indicate emissions are likely and the asterisks indicate the locations that are thought to be the larger sources								

Table 3.95: Air emissions matrix for all common process in oil and solvent regeneration plants [56, Babtie Group Ltd, 2002]

Capacity	t/yr		6824	15000		17171	46208		90500	
Fumes generated		Million Nm^3/yr			14.89			175.4		210.5
Oxygen	%			4		7.4	3		10	
CO_2	t/yr						24000			
PM	mg/Nm^3	kg/yr	4	0		4.23	11.17	1960	28.4	
SO_x	mg/Nm^3	kg/yr	14	4000	60000		529.7	92910	4.2	884
NO_x	mg/Nm^3	kg/yr	63.7			90	225.8	39610	802.5	168891
TOC	mg/Nm^3			0					3	
CO	mg/Nm^3	kg/yr	501.6	0		193	7.4	1300	18.9	3978
HCl	mg/Nm^3	kg/yr		0		2.8	1.5	263	0.8	
HF	mg/Nm^3			0					0.08	
Total metals	mg/Nm^3			0					0.423	
Hg	mg/Nm^3			0					0.026	
Cd + Tl	mg/Nm^3	kg/yr		0			0.0008	0	0.0008	
PAH	mg/Nm^3	kg/yr	0.0008	0			8E-07	0.000175	0.0008	
PCB	mg/Nm^3	kg/yr		0			8E-07	0		
Chlorobenzenes	mg/Nm^3	kg/yr		0			0.08	0		
PCDD/PCDF	ngTEQ/Nm³	g/yr		0			0.008	0.00175	8	
CFC	mg/Nm^3	kg/yr		0			0	0		
Odour	EU O.U./Nm^3			0						
Noise	dB(A)			75			55			
Note: For the installations having only one column, the figures correspond to the concentration column										

Table 3.96 Air emissions from several re-refining waste oil installations operating in the EU [66, TWG, 2003]

Emissions to water

The emissions to water are generally well documented. This is due to regulations and enforced limitations regarding discharges to foul sewers or disposal by alternative routes. The quantities of effluent discharged are thus usually well known.

Discharges are typically sampled regularly, providing monitoring data to allow a calculation of emissions for the radicals on the analysis programme. Sites handling large volumes of water and that have a constant discharge to sewerage system are usually sampled daily; those where the water volume is small tend to be tested on a batch basis prior to each discharge. Table 3.97 and Table 3.98 show the concentrations of water parameters and the emission matrix of the emissions to water, generated by the re-refining of waste oil.

Water parameters	Oily water [2] (mg/l)	Process water[2] (mg/l)	Effluent concentration (mg/l)
Temperature			25 ºC
pH			7.8
Colour			clear
COD [1] (TOC)	120	17000	20 – 20000
Oil/grease			<10
Hydrocarbons			5 – 15
Anionic tensioactives			0.2 – 0.5
Non-anionic tensioactives			1.0 – 2.0
Total tensioactives			1.2 – 2.5
Benzene			364
Toluene			1306
Phenols	1.5	180	0.2 – 0.4
Naphthalene			283
Chlorinated solvents (various)			309 – 666
1, 2 Dichloroethane			<1.0
Hexachlorobutadiene			<0.001
Hexachlorobenzene			<0.001
1, 2, 4 Trichlorobenzene			<0.001
Various PCBs			<0.001
Benz(a)anthracene and benzo(a)pyrene			each below 0.02
Ammonia			4.0 – 6.0
Suspended solids			<400
Chloride			
Total nitrogen			
Total phosphorus			0.05 – 0.2
Total metals:			<10
• aluminium			<0.5
• arsenic			3.4
• barium			80
• cadmium			<0.01 – 0.34
• chromium			10
• copper			
• iron			<0.6
• lead			271
• zinc			250

[1] Partially are demulsifers and detergents
[2] Water parameters of the waste water sent to biological treatment after stripping treatment

Table 3.97: Waste water parameters from different re-refining processes of waste oil [42, UK, 1995], [56, Babtie Group Ltd, 2002], [66, TWG, 2003]

Activity	Bulk used engine oil	Used industrial oils	Oil waters (interceptors)	Fuel oils	Electrical oils
Cold effluent settling	*	*	*	*	*
Hot effluent settling	*	*	*	*	*
Biological effluent treatment	*	*	*	*	*
Effluent clarification	*	*	*	*	*
Effluent sludge filter press	*	*	*	*	*
Effluent balance tank	*	*	*	*	*
Plate Separator	*	*	*	*	*

Table 3.98: Water emissions matrix for all common process in oil and solvent recycling plants [56, Babtie Group Ltd, 2002]

Capacity	**t/yr**		**6824**	**15000**		**17171**	**19960**		**46208**		**90500**	
Waste water generated		m^3/yr			1800			6180		298287		375000
Waste water generated/plant capacity		m^3/t			0.12			0.3096		6.4553		4.1436
Suspended solids	mg/l	kg/yr						931	6860	22.99	0	0
TOC	mg/l	kg/yr							1490	4.99		
BOD_5	mg/l	kg/yr		4000	7200						13300	38
COD	mg/l	kg/yr		8000	14400	300		27703	25650	85.99	39550	113
Hydrocarbons	mg/l	kg/yr	0.18						430	1.44		0.4
Phenols	mg/l	kg/yr	0.4	0		0.8		42.58	14	0.04	105	0.3
AOX	mg/l	kg/yr							0	0		
BTX	mg/l	kg/yr	0.4						0	0		
Total Nitrogen (as N)	mg/l	kg/yr							10000	0.033		0.008
Nitrit N (NO_2 -N)	mg/l	kg/yr							180	0.6		0.32
CN, free	mg/l	kg/yr							0	0		0.008
Sulfid (free)	mg/l					1						0.4
F, total	mg/l											0.4
P, total	mg/l	kg/yr							2980	9.99	140	0.4
Total metals	mg/l			0.56								
Al	mg/l	kg/yr		0.08					476	1.6	140	0.4
Fe	mg/l	kg/yr		0.08					952	3.2	35	0.1
As	mg/l	kg/yr		0.08					116	0.4		0.0024
Cr, total	mg/l	kg/yr		0.08					952	3.2		0.08
Cr(VI)	mg/l	kg/yr		0.08					44	0.16		0.008
Cu	mg/l	kg/yr		0.08					92	0.32		0.024
Hg	mg/l	kg/yr		0.08					1.12	0.004		0.00032
Ni	mg/l	kg/yr		0.08					476	1.6		0.16
Pb	mg/l	kg/yr		0.08				0.291	68	0.24		0.04
Zn	mg/l	kg/yr		0.08				1.276	236	0.8		0.24
Note: when only one column exists for a certain capacity, it refers to concentration values												

Table 3.99: Water emissions from different re-refining installations operating in the EU [66, TWG, 2003]

Solid waste and discharges to land

Sludges are typically tested for metals content, oil content and moisture content. This is carried out less frequently than the testing of the aqueous waste to sewerage systems. Table 3.100 and Table 3.101 show the concentrations of water parameters and the emission matrix of the emissions to water, generated by waste oil re-refining.

Type of waste	**Waste parameters**				
	Metals	**Moisture**	**HC and TOC**	**S compounds**	**Other**
Sludges	Some toxic metals may be contained	X	X	X	
Tank bottom sludges			X		
Solid particulates from filters	X		X		PAH and PCBs
Interceptor waste	X	Low	X		Phosphates, PAH, non-lubricant related solids
Cleaned oil filters	X				

Table 3.100: Types of waste generated in re-refining processes of waste oil [42, UK, 1995], [56, Babtie Group Ltd, 2002], [66, TWG, 2003]

Activity	25 litres Oil drums	205 litres Oil drums	Bulk used engine oils	Used industrial oils	Oily waters (interceptors)	Fuel oils	Electrical oils
Bulk storage			*	*	*	*	*
Cold oil settling			*	*	*	*	*
Hot oil settling			*	*	*	*	*
Distillation			*	*	*	*	*
Vibrating sieve			*	*	*	*	*
Centrifuge			*	*	*	*	*
Enclosed filters			*	*	*	*	*
Effluent sludge filter press			*	*	*	*	*
Mechanically handled sludge/solids storage and handling	*	*	*	*	*	*	*

Table 3.101: Emissions to land matrix for all common process in oil and solvent recycling plants [56, Babtie Group Ltd, 2002]

Table 3.102 gives the environmental performance criteria of different treatment systems arising from an industry survey. In the survey, a profound discussion for each figure in the table is given. Each figure represents the absolute value that is assigned to that treatment system, concerning a specific criterion and estimating the performance of the system relative to the other systems for this said criterion.

	Environmental criteria				
Process	**S-compounds**	**Metals**	**Products of incomplete combustion + VOCs**	**Re-use of materials**	**Re-use of energy**
Laundering. Closed-loop recycling (re-use)	1	1	3	1	5
Chemical re-refining without distillation	2	2	3	1	5
Re-refining with distillation	1	1	1	1	5
Blending into vacuum residue of a refinery	5	3	4	5	1
Note: S-compounds: the ultimate destination of the sulphur content originating from the waste oil Metals: the ultimate destination of the metals originating from the waste oil Products of incomplete combustion + VOCs: the emission of VOCs or products of incomplete combustion (CO, PAHs, soot, dioxins, furans, etc.) originating from the waste oil Values: 1 best performance, 5 worst – on a relative scale					

Table 3.102: Evaluation of the environmental performance of several re-use and re-refining activities
[11, Jacobs and Dijkmans, 2001]

3.4.3.2 Emissions from the regeneration of waste solvents

The most important concern in the solvent recovery sector is the volatile organic emissions, which result from waste solvent reclamation. Acidic gaseous and particulate emissions can also result from solvent recovery operations.

Acidic gaseous emissions mainly consist of gaseous chloride, hydrogen fluoride, and sulphur oxides. Since the unit operation presenting the major source of acidic gases and particulate from the solvent recovery industry is that of incineration, this issue will be part of the waste incineration BREF. Incinerator stack emissions consist of solid contaminants that are oxidised and released as particulates, unburned organics, and combustion stack gases.

In solvent recovery operations, bottom streams consist of organics such as oily wastes and sludges or an aqueous residue. If water is treated on-site, sludges or other wastes may be created. Other emissions may come from discarded containers or samples, vessel washing residues, or from volatilisation to the air. Some residues and sludges are removed hot from stills into drums and allowed to cool and solidify. They may then be removed for further treatment or disposal. In industrial systems there can be traces of impurities, which can arise from inhibitors, denaturants or plant rinsing; these impurities can cause problems, particularly when using azeotropic distillation techniques.

Emission points include storage tank vents, condenser vents, incinerator stacks and fugitive losses. VOC emissions from equipment leaks, open solvent sources (e.g. sludge draw-off and the storage to material from distillation and initial treatment operations), solvent loading, and solvent spills are classified as fugitive.

Solvents may be accidentally spilled during handling, distillation, or purification activities. Materials that are spilled onto the ground may spread over an area, vaporise, and then result in air, water, or land emissions. Emissions resulting from significant accidental situations such as spills also need to be estimated.

Releases to the air may arise from a number of sources including non-condensable vapours from distillation/fractionation operations, and breathing losses from storage tanks and local extraction vents (LEV) located at material handling or drumming off points. Emission concentrations would be expected to be high except from sources such as LEVs. Concentrations and types of emitted compounds may vary significantly. The flowrates from continuous fractionation columns operating under vacuum at steady conditions are generally very low (1 – 10 m^3/hr). However, when manifolded together, emission flows could be up to 500 m^3/hr. Where LEV systems are tied into abatement equipment this can significantly increase flowrates and the dilution of vent gases. To minimise the size of abatement equipment there is a benefit in keeping process and LEV vents separate.

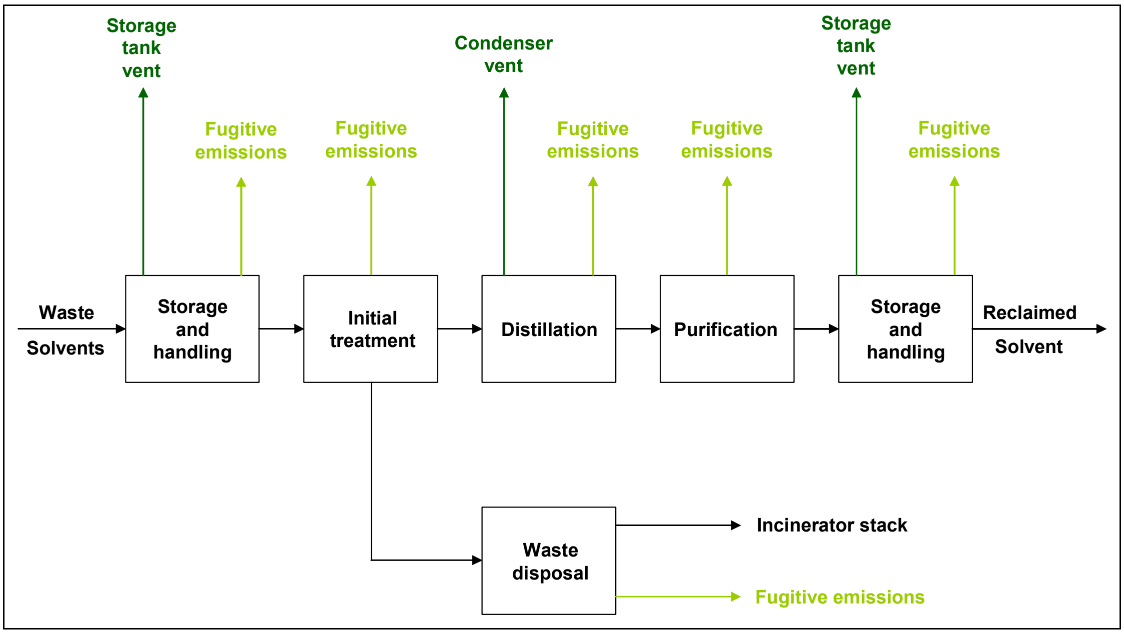


Figure 3.6: Example of a waste solvent regeneration scheme and emission points
[129, Cruz-Gomez, 2002]

Activity/Plant	Emissions			Accidental Emissions
	To air	To water	To landfill	
Filter bin unloading				Drainage, spillage and bursts discharging contents to ground
Filter bin storage				Spillage to ground
Filter crushing				Spillage to ground
Filter shredding	Oil mist			Spillage to ground
Magnetic separation	Oil mist			Spillage to ground
205 litre drum unloading				Spillage to ground
205 litre drum storage				Spillage to ground
205 litre drum emptying				Spillage to ground
25 litre drum unloading				Spillage to ground
25 litre drum storage				Spillage to ground
25 litre drum emptying/shredding	Oil mist			Spillage to ground
Tanker unloading	Tank venting			Spillage to ground
Coarse straining	Oil mist			Spillage to ground
Bulk storage	Tank venting	Settled water (via treatment)	Settled sludge	Spillage to ground
Cold oil settling	Tank venting	Settled water (via treatment)	Settled sludge	Spillage to ground
Hot oil settling	Tank venting	Settled water (via treatment)	Settled sludge	Spillage to ground
Distillation	Venting and fugitive			Spillage to ground
Vibrating sieve	Mist and vapour		Sludge	Spillage to ground
Centrifuge				
Enclosed filters			Used elements and sludge	Spillage to ground
Bauxite towers			Spent bauxite	Spillage to ground
Vacuum dehydration	Vapour (via scrubbers)		Spillage to ground	
Product blending	Tank venting			Spillage to ground

Activity/Plant	Emissions			Accidental Emissions
	To air	To water	To landfill	
Pumped sludge storage/decanting	Tank venting			Spillage to ground
Incineration	Stack emissions (NO_x, CO, VOC, HCl, SO_2, etc.)			
Cold effluent settling	Tank venting			Spillage to ground
Hot effluent settling	Tank venting			Spillage to ground
Biological effluent treatment	Aeration air			
Effluent clarification				
Filter press			Filter cake	
Effluent balance tank				Spillage to ground
Plate separator		Effluent		
Mechanically handled sludge/solids storage and loading			Mixed solid wastes	Spillage to ground
Waste oil fired boiler	Stack emissions			

Table 3.103: Principal emission sources and emissions matrices of oil and solvent recycling plants [56, Babtie Group Ltd, 2002], [150, TWG, 2004]

Parameter	Concentration value	Concentration units	Load value	Load units
Air emissions				
Fumes generated			14400000	Nm^3/yr
Oxygen	6	%		
CO_2			1268018	kg/yr
CO	49	mg/Nm^3	700	kg/yr
SO_2	86.9	mg/Nm^3	850	kg/yr
NO_x	44.1	mg/Nm^3	635	kg/yr
TOC	540	mg/Nm^3	237	kg/yr
Water emissions				
Waste water			2969	m^3/yr
Suspended solids	16	mg/l	47.5	kg/yr
COD	534	mg/l	1585	kg/yr
Phenols	0.08	mg/l		kg/yr
AOX	0.25	mg/l	0.742	kg/yr
Total N (as N)	16	mg/l	47.5	kg/yr
Total P	0.43	mg/l	1.27	kg/yr
Sulphide (free)	0.08	mg/l		kg/yr
Note: Capacity of the installation 27.5 kt/yr				

Table 3.104: Air and water emission from an EU solvent regeneration installation [66, TWG, 2003]

During storage and handling, and in the distillation process, hydrocarbons are emitted to the air. The emission of hydrocarbons (C_xH_y) through the distillation process is estimated to be 0.5 kg/t waste solvent.

Some contaminated solvents contain water. After dewatering, the water fraction contains traces of solvent. This water fraction ranges from a negligible amount to a maximum of 5 to 10 %. It is purified in a waste water treatment plant and discharged.

The amount of distillation bottom depends on the composition of the waste solvent. On average, the amount is estimated to be 25 % of the processed amount.

3.4.3.3 Emissions from the regeneration of waste catalysts

Knowing the source of the spent catalyst can often provide information on potential emissions due to the presence of acids, oils, organic contaminants (they may produce PCDD during melting processes), etc. This directly influences the potential emissions to air, water and land.

The physical state of the waste catalyst can also influence the emissions (e.g. the particulate emissions depend on the particulate size of the waste catalyst, oil content, etc.). Some potential emissions from different catalyst regeneration plants are shown in Table 3.107.

Air pollutant	**From**
Particulates	Fugitive emissions
SO_2	
NO_x	
VOC	
Dioxins	
Metals	
Water pollutants	
Suspended solids	
Oil	
TOC	
Metals	
Solid waste	
Oil	
Metals	
Dust	e.g. from abatement systems
Reference conditions of flue-gas: dry gas, 6 % O_2	

Table 3.105: Potential emissions found in different catalyst regenerators
[125, Ruiz, 2002]

3.4.3.4 Emissions from the cleaning and regeneration of carbon

The main environmental issues related to the thermal regeneration of activated carbon is primarily gaseous effluents such as carbon dioxide. Acidic gases and pesticides may prove a problem if there are no control measures such as afterburners and/or scrubbers.

Figure 3.7 shows a schematic of a generic activated carbon regeneration process, including the release routes that are listed in Table 3.106.

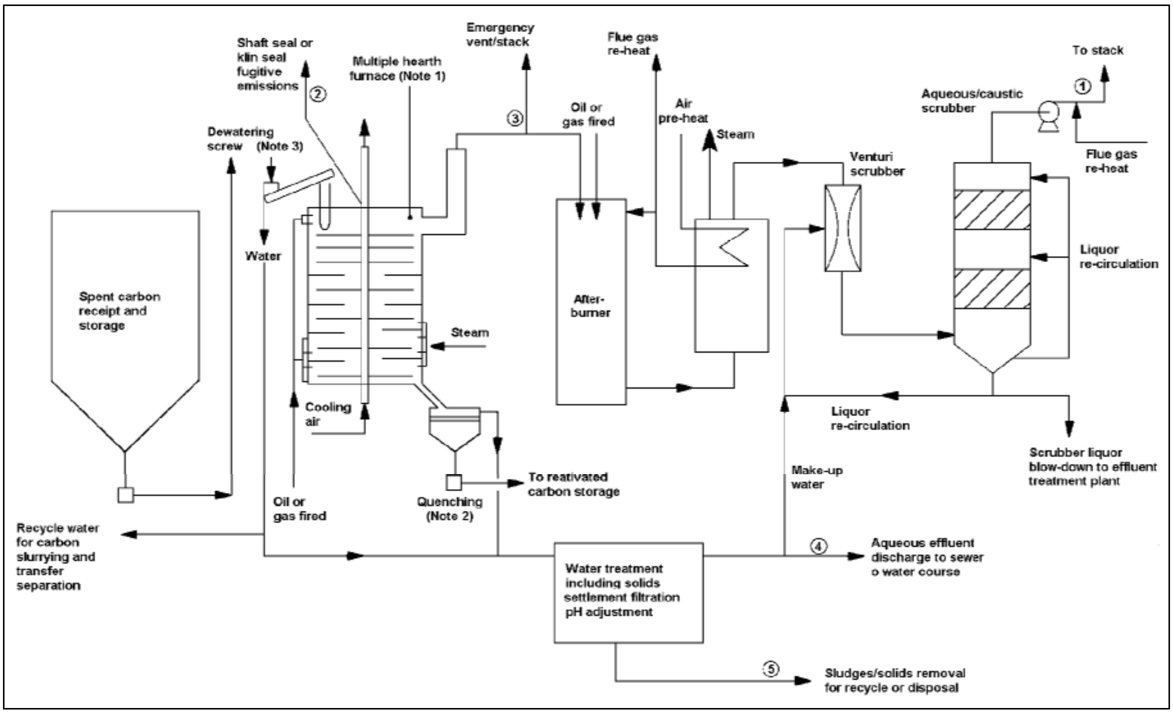


Figure 3.7: Schematic flow diagram of a generic carbon regeneration plant
[29, UK Environment Agency, 1996]
Notes: Numbers in the diagram refers to the numbers of the first column of the following Table 3.106.
Note 1 Multiple hearth furnace illustrated but thermal reactivation may also be carried out in a rotary kiln
Note 2 Carbon exiting the kiln may also be cooled by other means
Note 3 Other techniques for dewatering may be used.

Releases to the environment commonly associated with the regeneration of activated carbon processes are listed in Table 3.106.

	Source releases to:	**Dust/ solids**	**CO + CO_2**	**NO_x**	**SO_x**	**Halogens**	**Organic compounds or partial oxidation products**	**Metals, metalloids or compounds**
1	Flue-gases from flue-gas treatment	A	A	A	A	A	A	A
2	Fugitive emissions from seal leakages	A	A	A	A	A	A	A
3	Emergency vent stack (if applicable)	A	A	A	A	A	A	A
4	Aqueous effluent discharge	W					W	W
5	Effluent treatment plant sludge						L	L
Note: The releases to each medium will be determined to a significant degree by the application for which, the carbon has been used, and hence release of some substances to water and land are possible Legend: A: Air, W: water and L: residues (land)								

Table 3.106: Potential release routes for prescribed substances and other substances which may cause harm
[29, UK Environment Agency, 1996]

Emission results from different regeneration plants are shown in Table 3.107.

Air pollutant	**Concentration (mg/Nm^3)**
Particulates	1 – 34
CO	<3 – 160
NO_x (as NO_2)	126 – 354
SO_2	<2 – 60
HCl	<1 – 22
HF	<1
VOC (TOC)	5 – 15
Dioxins and furans PCDDs and PCDFs (TEQ)	<0.01 – 0.18 ng/Nm^3
Cd	<0.05
Hg	<0.05
Other heavy metals	0.1 – 0.5
Water pollutants	**Concentration (mg/l)**
Suspended solids	50 – 300
COD	400
Simazine	0.001
Atrazine	0.001
TEQ (TCDDs and TCDFs)	0.28 – 0.4 ng/l
Al	30
Cd	0.0005
Hg	0.0001
Mn	30
Solid waste	**Composition**
Refractory linings	
General industrial waste	
Sludge from settlement ponds	Mainly carbonaceous fines
Reference conditions of flue-gas: dry gas 6 % O_2	

Table 3.107: Range of emissions found in different carbon regenerators
[42, UK, 1995]

Liquid effluent from regeneration plant

Water is used for the transport of activated carbon as slurry to and from the regenerator. This gives rise to a black water effluent which should be clarified and recycled. Water separated from the slurry will contain suspended solids and possibly prescribed substances (e.g. pesticides) and are routed to the effluent treatment plant.

The clean hot activated carbon is either dry cooled or quenched in cold water. For the wet cooling system, the water becomes alkaline and is therefore dosed with acid. This water should be purged from the system to prevent accumulation of mineral salts, with fresh/recycled water make-up as necessary.

Water is also used intermittently in large amounts to backwash activated carbon storage hoppers both to remove fines and to level the top surface of the activated carbon. Sufficient water storage needs to be provided so that this water can be clarified and recycled.

Techniques for controlling releases to land

In the regeneration of activated carbon most deliveries of carbon are made in bulk tankers. In certain circumstances drums may be used. Where this is the case, drums should be reconditioned and re-used so that disposal is minimised. Other process waste includes sludge or filter cake from filter presses or settlement tanks in an effluent treatment plant. In the case where disposal is to land the method of disposal should ensure that if the cake or sludge were to dry out, windblown dust of fine carbon particulates cannot occur. Other wastes will include refractory bricks and linings where repairs to kilns and furnaces have taken place periodically.

3.4.3.5 Emissions from the regeneration of ion exchange resins

The releases from a process of this nature are small and confined mainly to those to water. Some emissions resulting from different regeneration plants are shown in Table 3.107.

Air pollutant	**From**	**Concentration (mg/Nm^3)**
HCl	from filling of a bulk storage	<5
Water pollutants		**Concentration (µg/l)**
Effluent flowrate [2]		5 – 10 m^3/h
Cd		<0.5 – 3[1]
Hg		0.86[1]
Organic Sn		<0.3 – 2.0[1]
Solid waste		
Waste resins		
Fines		
Backwash filter	When resin is combined with activated carbon as a guard or a backwash filter	
Reference conditions of flue-gas: dry gas, 6 % O_2 [1] Values that correspond to peak values [2] Steam regeneration can produce large quantities of contaminated aqueous effluent		

Table 3.108: Range of emissions found in different ion exchange regenerators
[41, UK, 1991], [42, UK, 1995]

3.4.3.6 Emissions from waste acids and bases treatments

Activity	**Air**	**Water**	**Soil and wastes**
Treatment of waste acids	Halogens: HCl and HF NO_x	Halogens: HCl and HF	
Treatment of sulphuric acid	Sulphur oxides		

Table 3.109: Emissions from the treatments of waste acids and bases
[55, UK EA, 2001]

3.4.3.7 Emissions from the treatment of photographic waste

Treatment of solid photographic waste

In shredding, emissions of dust occur. These are treated with a dust filter. The emission of dust to the air ranges from 2 to 5 mg/Nm^3. The amount is estimated to be 29 g/t film waste.

Treatment of liquid photographic waste

Emissions to air

Treatment of photographic waste, especially fixers, can generate emissions to the air of ammonia, acetic acid and VOCs.

The emissions from physico-chemical treatments are reduced by treating the exhausted air in a wet oxidising scrubber. The concentrations in the exit gases of C_xH_y are approximately 600 mg/Nm^3 and of NH_3 <2 mg/Nm^3. The emissions from the biological treatment are reduced by means of a continuous automatic monitoring and regulation of the air or oxygen supply. The total C_xH_y emission is estimated to have a maximum of 20 g/t waste water.

In evaporation, some compounds will evaporate together with the water. Most of them will condense. Not condensed compounds are passed through the biological treatment that functions as a scrubber. The emissions from the evaporation step are negligible.

Emissions to water

In Table 3.110, emissions to water from physico-chemical and biological treatments are presented. Desilvered photographic liquid waste is just one of the processed waste waters. Therefore, the presented emissions give a rough indication of possible emissions from the treatment of this waste stream.

Component	Emission (g/t waste water)
Suspended solids	9
Chloride	29
Sulphur	0.3
COD	172
BOD	4
N-total (Kjeldahl)	351
Phosphorus	2

Table 3.110: Emissions to water from the treatment of photographic liquid waste and other waste waters
[156, VROM, 2004]

3.4.4 Waste OUT from re-recycling/regeneration treatments

In some cases the materials obtained by these treatments are commercial products with only minor differences compared to virgin products.

Re-refined waste oil

The quality of the base oil obtained is dependent upon the level of treatment applied, for example, severe processing involving hydrotreatment will be required in order to significantly remove PAHs.

Used oils vary according to the origin and type of oil collected. These variations are reflected in the base oil products from acid/clay treatment plants, in terms of their density, viscosity, viscosity index, sulphur level, etc. Less variation occurs in these parameters in the base oil products from vacuum distillation/hydrotreating units, with the exception of the sulphur content. Re-refined base oils from different processes and production plants vary greatly in their characteristics.

Some re-refining technologies allow the production of premium quality base oils: i.e. at least Group I according to the API base oils classification; and, when resorting to a severe hydro or solvent finishing, Group II base oils (e.g. topping purpose). The base stocks produced by the European re-refining industry today belong to Group I. Group I base stocks are solvent refined mineral oils. They contain the most saturates and sulphur and have the lowest viscosity indexes. They define the bottom tier of lubricant performance. Group I stocks are the least expensive to produce. They currently account for about 75 % of all base stocks comprising the bulk of the ‘conventional’ base stocks.

Almost all waste oil re-refining installations test for chlorine content and water content, and usually for PCBs. The final recovered oil is analysed because it has to satisfy specifications from the end user, but not all oil treatment plants blend a final product for sale or carry out such analyses. Table 3.111 shows an example of an analysis of the product made in an oil recovery installation, where several degrees of hydrotreatment are carried out to three different types of base oil (spindle, light and heavy lube oil).

Type of feed	**Spindle lube oil**	Low severity ^{*1}	High severity $^{\#2}$	**Light lube oil**	Low severity ^{*3}	High severity $^{\#4}$	**Heavy lube oil**	Low severity ^{*5}	High severity $^{\#6}$
Density 15/4	0.8678	0.8606	0.8526	0.8767	0.8699	0.8604	0.8868	0.8786	0.8676
Viscosity @ 40 °C (cSt)	26.91	23.8	21.19	56.52	49.85	38.18	117.2	97.86	70.08
Viscosity @ 100 °C (cSt)	4.76	4.5	4.2	7.78	7.32	6.37	12.24	11	9.1
Viscosity index	93	103	100	102	107	117	94	97	105
Colour	6.5	L 0.5	L 0.5	7.5	L 1	L 0.5	>8	L 2	L 0.5
Asphaltenes (w/w-%)	0.0105	-	-	0.0092	-	-	<0.01	-	-
Carbon Conradson (w/w-%)	0.63	<0.1	<0.1	0.12	<0.1	<0.1	0.33	<0.1	<0.1
Nitrogen (ppm)	280	49	<1	312	57	<1	307	137	<1
Sulphur (ppm)	0.412	0.1025	0.0005	0.526	0.163	0.0008	0.7285	0.2735	0.0021
ndM method (w/w-%)									
Aromatic carbon	12.11	10.72	8.72	11.63	10.25	8.48	11.94	10.22	8.18
Parafinic carbon	71.20	72.06	72.76	72.66	73.42	75.09	72.68	73.75	75.57
Naphthelic carbon	16.70	17.22	18.52	15.70	16.32	16.43	15.38	16.03	16.25
Gas Chromatography analysis in ppm									
Anthracene	<1	<1	<0.5	<1	<1	<0.5	<1	<1	<0.5
Benzo(a)anthracene	37	<1	<0.5	4	<1	<0.5	3	<1	<0.5
Benzo(k)fluoranthene	5	<1	<0.5	2	<1	<0.5	<1	<1	<0.5
Benzo(b)fluoranthene	25	<1	<0.5	11	<1	<0.5	4	<1	<0.5
Benzo(ghi)perilene	16	<1	<0.5	40	4.7	<0.5	12	2.30	<0.5
Benzo(a)pyrene	16	<1	<0.5	11	<1	<0.5	4	<1	<0.5
Chrisene	3	<1	<0.5	2	<1	<0.5	-	<1	<0.5
Dibenzo-ah-anthracene	<1	<1	<0.5	2	<1	<0.5	<1	<1	<0.5
Fluoanthene	24	<1	<0.5	2	<1	<0.5	<1	<1	<0.5
Indeno(123-cd)pyrene	10	<1	<0.5	27	<1	<0.5	6	<1	<0.5
Phenanthrene	2	8.7	<0.5	<1	1	<0.5	<1	1.30	<0.5
Pyrene	34	5.8	<0.5	<1	<1	<0.5	2	<1	<0.5
PNA IP 346 (w/w-%)	2.8	1	0.2	1.3	0.6	-	1	0.6	0.2

* Low severity in the hydrotreatment of light fraction: Temperature of first catalyst: 300 °C. Temperature 2nd catalyst: 280 °C. H_2 partial pressure: 105 bar

\# High severity in the hydrotreatment of light fraction: Temperature of first catalyst: 340 °C. Temperature 2nd catalyst: 340 °C. H_2 partial pressure: 105 bar

Total LHSV (h^{-1}): ^{1} :0.507; ^{2} :0.5; ^{3} :0.507; ^{4} :0.292; ^{5} :0.481; ^{6} :0.295

Table 3.111: Effect of hydrofinishing on the pollutants of the feed after de-asphalting [36, Viscolube, 2002]

Base oil produced is more dependent on the technology used to treat the waste oil than to the differences of the waste oil collected. Some examples of this are shown in Table 3.112.

Process (de-asphalting, demetalisation + finishing)	Main products (Values correspond to kg/tonne of WO unless otherwise stated)
Sulphuric acid + clay treatment	Low quality re-refined base oil: 621 PAH content of the base oils produced can be comparatively high (4 to 17 times higher than virgin base oils) Gasoil: 70
Caustic soda and bleaching earth treatment (ENTRA)	High quality re-refined base oil (Group II): 520 Light ends: 170 Diesel: 170
Vacuum distillation	In modern vacuum distillation equipment designed for processing used oils, the distillate produced has a metals content of less than 1 ppm (according to licensors)
Vacuum distillation + chemical treatment or clay treatment.	The base oils produced by clay treating or by chemical treatment have a metal content of <1 ppm. This process may not reduce the PAH content of the oil by as much as hydrotreatment
Thin film evaporator (TFE) + clay treatment	Medium quality re-refined base oil: 530 – 650 Gasoil: 150
TFE + hydrofinishing	High quality re-refined base oil: 630 Gasoil: 100
TFE + solvent extraction	High quality re-refined base oil: 600 Gasoil: 120 – 150
TFE + solvent extraction + Hydro-finishing	High quality re-refined base oil • lubricant Group II: 370 • lubricant Group I: 300 Gasoil: 85
TDA (thermal de-asphalting) + clay treatment	Medium quality re-refined base oil: 500 - 600 Gasoil: 60 – 80
TDA + Hydrofinishing (high pressure)	High quality re-refined base oil: 670 Gasoil: 70
PDA (propane de-asphalting) + hydro finishing (medium pressure)	High re-refined base oil: 660 – 700 Gasoil: 43 – 55 This process yields more marketable products than regeneration by a chemical treatment
Distillation and alkali treatment (Vaxon – Cator)	
Vacuum distillation + chemical treatment or clay treatment	As much as by hydrotreatment or solvent extraction
Direct contact hydrogenation (DCH)	Base oil (group II): 770 – 820 Light ends: 20 – 40 Heavy fuel or diesel: 70 – 80
Thermal clay treatment	
Hydro-finishing	
Vacuum distillation + chemical treatment	Base oil: 540 kg Fuel oil: 6105 MJ Bitumen fluxant: 48 kg Other fuels: 3720 MJ Fuel saving

Table 3.112: Product issues related with different waste oil regeneration techniques
[6, Silver Springs Oil Recovery Inc., 2000], [7, Monier and Labouze, 2001], [11, Jacobs and Dijkmans, 2001], [13, Marshall, et al., 1999], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [139, UBA, 2003], [150, TWG, 2004]

Regenerated solvents

Probably the most desirable product of solvent recovery is one that can be used instead of a purchased new solvent in the place where it was used initially. This does not necessarily mean that the recovered solvent meets the same specifications as the virgin material. The specifications of new solvent will usually have been drawn up by a committee formed of representatives of both users and producers, who know what the potential impurities are in a product made by an established process route. The specifications have to satisfy all potential uses but for any given user, some specifications may be immaterial.

Product property	Unit	DIN 53978	PERC
Colour	HAZEN	<15	<5
Water	ppm	<50	<25
PERC	Area-%	≥99.9	>99.98
Sum of 1,1,1-trichloroethane and trichloroethylene	Area-%	0.025 ± 0.003	<0.02
Relative density	g/ml	1.620 - 1.625	1.624
Alkalinity	ppm NaOH	≤30	25
Evaporation			
Residue	ppm	≤50	25
Free chlorine		0	0
Information on a chlorinated hydrocarbon distillation installation			

Table 3.113: Specification of products for treatment of chloro-organic compounds versus DIN-Standard
[147, UBA, 2003]

Regenerated catalysts

Table 3.114 shows carbon and sulphur levels, the surface area, and the average length of the spent catalyst feed and the regenerated product from the belt-only and fine regenerations. The spent catalyst was analysed for its surface area after laboratory regeneration.

Product quality	Spent catalyst from top bed of second reactor	Belt only regeneration	Fine regeneration
Carbon, w/w-%	22	0.7	0.9
Sulphur, w/w-%	7.5	0.9	0.8
Surface area, m^2/g	185	190	197
Average length, mm	2.56	2.72	2.68
The values above correspond to the regeneration of more than 580 tonnes of spent CoMo hydrotreating catalyst from a customer's distillate hydrotreater in 1997. The unit had two reactors with two catalyst beds per reactor. The pre-job analyses showed that the catalyst could be recovered from all four beds, but, as expected, the highest quality catalyst was toward the back end of the unit			

Table 3.114: Commercial regeneration of CoMo catalyst
[125, Ruiz, 2002]

Overall, the spent catalyst was heavily loaded with hydrocarbon (15 w/w-%) and coke (total loss on ignition 30 %). The company started regenerating the highest quality catalyst from the bottom bed of the second reactor and worked back toward the catalyst at the front of the unit. The job began prior to the fine regeneration installation, so initially the catalyst was being stripped with inert gas in the belt-stripping unit.

The properties of both regenerated products compare favourably with that of the spent catalyst. The surface areas of the regenerated samples are slightly higher than those from the laboratory regeneration.

3.5 Emissions and consumptions from waste treatments aimed to produce a material to be used as fuel

[4, Langenkamp, 1997], [6, Silver Springs Oil Recovery Inc., 2000], [7, Monier and Labouze, 2001], [[8, Krajenbrink, et al., 1999], Jacobs, 2001 #11], [12, Birr-Pedersen, 2001], [14, Ministry for the Environment, 2000], [16, ÖWAV Working Commitee, 2002], [37, Woodward-Clyde, 2000], [52, Ecodeco, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [57, EIPPCB, 2001], [58, CEFIC, 2002], [64, EIPPCB, 2003], [81, VDI and Dechema, 2002], [86, TWG, 2003], [119, Watco, 2002], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [128, Ribi, 2003], [150, TWG, 2004], [152, TWG, 2004]

This section contains the emissions and consumptions of treatments mentioned in Section 2.5, i.e. those devoted to processing waste in order to produce a material that will be used as fuel. The following sections (Sections 3.5.X) detail information available to site operators from their current recording record systems and highlights the areas where emissions are likely to occur. Emissions associated with ancillary treatments, e.g. transfer station operation are covered in Section 3.1.

3.5.1 Waste IN for the preparation of waste fuels

Table 3.115 shows some examples of the types of waste used for the production of solid or liquid waste fuel.

Type of waste fuel to be prepared	Type of waste	Examples
Solid waste fuel	Pasty wastes (mainly from hazardous waste)	High viscosity solvents, oil sludges, distillation residues, sludges from the treatment of industrial sludges (mechanical industry, chemical industry, pharmaceutical industry, etc.), paint and varnish sludges, ink sludges, polyol, glues, resins, grease and fats, other pasty wastes
	Powder wastes (mainly from hazardous waste)	Carbon black, toner powder, paints, spent catalysts, tensides, other powders
	Solid wastes (mainly from hazardous waste)	Polluted polymers, impregnated sawdust, sludges from waste water treatment, resins, paints, glues, spent activated carbon, polluted soils, hydrocarbon sludges, polluted absorbents, organic residues from the chemical and pharmaceutical industries, spent plastic packaging, waste woods, other solid wastes
	Liquid wastes which are not suitable for preparation of liquid waste fuel (mainly from hazardous waste)	Liquids with risk of polymerising
	Non-hazardous solid waste	Household and commercial solid wastes, packaging wastes, wood, paper, cardboard, cardboard boxes (02, 03, 15, 17, 19, 20), textiles, fibres (04, 15, 19, 20), plastics (02, 07, 08, 12, 15, 16, 17, 19, 20), other materials (08, 09, 15, 16, 19), high calorific fractions from mixed collected wastes (17, 19, 20), construction and demolition waste, source-separated fractions from MSW, monostreams of commercial and industrial waste

Liquid waste fuel by blending	Organic liquid waste fuel	Solvents, xylenes, toluenes, white-spirit, acetone, cleaning and degreasing solvents, petroleum residues, distillation residues, off-specification organic liquid products
Liquid waste fuel by fluidification	Organic liquid waste fuel	Used solvents, pasty organic wastes (ink sludges, paint sludges, adhesives wastes, etc.), oils residues, pulverulent wastes such as paint powder, filter cakes, residues from organic chemical synthesis, oil and fat, spent ion exchange resins, distillation residues, wastes from cosmetic industries
Liquid waste fuel by emulsions	Organic liquid waste fuel	Oils emulsions from mechanical and metallurgy industries, wastes and sludges containing oil from petroleum refining, from the collection and storage of oil products, wastes from oil distillation and regeneration, production failures, pasty wastes such as grease, ink and adhesives wastes, pulverulent waste such as paint powder, washing powder wastes, used bases such as sodium, used oils
Note: Numbers within brackets correspond to EWL codes chapters		

Table 3.115: Some examples of the types of waste used for the preparation of solid and liquid waste fuels
[21, Langenkamp and Nieman, 2001], [50, Scori, 2002], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004]

Table 3.116 shows the typical heating values of some types of waste.

Type of waste	Heating value (MJ/kg)
Hazardous waste	21.0 – 41.9
Non-hazardous industrial waste	12.6 – 16.8
Municipal waste	7.5 – 10.5
Plastic	21.0 – 41.9
Wood	16.8
Tyres	25.1 – 31.4

Table 3.116: Typical heating values of different types of waste
[4, Langenkamp, 1997], [150, TWG, 2004]

Fuel preparation plants and combustion installations that may use waste as (part of) fuel generally take in more than one type of waste. Some types of waste materials that are used for co-incineration are shown in Table 3.117.

Type of waste	Combustion plants (including district heating and marine engines)	Cement kilns	Iron and steel (blast furnaces)	Ceramics (brick kilns)	Lime kilns	Asphalt production	Pulp and paper
Animal products	Animal meal Meat and bone meal Tallow Manure Chicken litter Fat	Meat and bone meal					
Charcoal residues	Charcoal residues[1]						
Chemicals	Organic acids Liquid solvents Phosphorus oven gas	Spent solvents Paint sludges Hydrocarbons Distillation residue					
Municipal waste	RDF Waste paper Packing materials Plastics Textiles Wood	RDF Waste paper Plastics Textiles Wood	RDF Plastics Textiles Wood	RDF Textiles Wood	RDF Textiles Wood	RDF	Waste paper
Oily materials	Tar Waste oil	Waste oils Cutting oils	Waste oils		Waste oils	Waste oils	
Rubber	Shredded tyres	Used tyres Rubber Car shredding residues Carpets		Used tyres			
Sludge	Sewage sludge	Sewage sludge Paper sludge					
Vegetables	Energy crops such as willow Agricultural residues such as straw, cereal plants, pasture from landscape cultivation						
Wood	Wood residues Demolition wood Forest residues Wood chips Biomass pellets/briquettes	Waste woods					

[1] Some trials have been made on the use of waste in cupola furnaces in foundries.

Note: Table should not be interpreted as exhaustive. Other combinations not mentioned in this table may actually be used.

Table 3.117: Some types of materials used in some co-incineration processes [4, Langenkamp, 1997], [57, EIPPCB, 2001], [64, EIPPCB, 2003], [81, VDI and Dechema, 2002], [150, TWG, 2004], [152, TWG, 2004]

The following sections which have titles in bold give more detailed information on each type of waste used as fuel. Typical compositions of the type of waste are in some cases made available.

Chemicals

Paint and solvent wastes have a heating value of more than 21 MJ/kg wet matter. The contents of chlorine, cadmium and zinc may be high.

Municipal solid waste

Table 3.118 shows some characteristics of municipal solid waste, and some of its fractions which can be used as fuel.

Municipal solid waste	Heating value (MJ/kg wet matter)	Other components
Generic municipal solid waste	5 – 8	Cl: 0.5 – 1.0 % The content of some metals may be high
Residual municipal solid waste	8 – 11	Cl: 0.5 – 1.0 % The content of some metals may be high
Paper	11 – 14	0.5 % of Cl, 33 ppm of Pb and 0.3 ppm of Cd
Celulose (20 w/w-% ash content and moisture of 5 %)	12.3	
Celulose (20 w/w-% ash content and moisture of 40 %)	5.7	
Polyethylene (20 w/w-% ash content and moisture of 40 %)	16.5	
Polyethylene (0 w/w-% ash content and moisture of 40 %)	25.3	
Polyethylene (0 w/w-% ash content and moisture of 5 %)	41.5	
Polyethylene hard density (printed)		Volatiles[1] 97 %, ash[2] 2 %, fixed carbon 0.3 %
Polypropylene		Volatiles 100 %, ash <0.05 %
Polystyrene (white)		Volatiles 97 %, ash 3 %
PVC		Volatiles 92 %, ash <0.05 %, fixed carbon 8 %
Plastics	23.7 – 28.4	Cd: 0.7 - 72 ppm Cl: 1 – 4.5 % Cr: 48 ppm Hg: 1.3 ppm Pb: 98 - 739 ppm Tl: 0.3 ppm Zn: 550 ppm
Composites	13.3 – 16.2	Cd: 0.2 - 37 ppm Cl: 0.5 – 4.0 % Pb: 48 - 500 ppm
Textiles, leather and shoes	17.1	Cd: 2.2 ppm Cl: 1.2 % Pb: 96 ppm

[1] Plastics volatilise after melting by depolymerisation
[2] The pure polymer is ash free, but ash comes from printing and pigments

Table 3.118: Important characteristics of MSW, and some of its fractions, for use as fuel [4, Langenkamp, 1997], [8, Krajenbrink, et al., 1999], [16, ÖWAV Working Commitee, 2002], [81, VDI and Dechema, 2002], [150, TWG, 2004]

Waste plastic

The demonstration of energy recovery for specific waste plastic streams in full-scale tests has been going on over a sufficiently long time period to prove: the repeatable and stable operating conditions; to document the effect the waste plastics have on the operation; and also to indicate what materials and emissions will arise. An overview of the APME TEC programme is sketched out below.

Burning technology	Energy use	Packaging	Com-mercial	Automotive	Electrical and electronics	Agricultural	Building and cons-truction
Grate type	District Heat and Heat/power	MPW		SR			Foams
Fluidized bed (FB)	Heat/Power	MPW, SR					
Pulverized coal	Power	MPW				Films	
Rotary kiln	Cement	MPW			Foam		
Industrial furnace	Non-Ferrous				ESR		
Circulating FB	Pulp Paper	MPW	Curb side	SR			
Note: MPW: municipal plastic waste (sometimes needs to be shredded before use); SR: shredder residue; ESR: shredder residue from white goods							

Table 3.119: The use of waste plastics from different industrial sectors as fuel [58, CEFIC, 2002] [86, TWG, 2003], [150, TWG, 2004]

Oily materials

Waste oils

More information on the composition of waste oils can be found in Section 3.4.1. Used oils may have a significant, but variable, chlorine content, including organochlorines. The fate of these chlorine compounds will vary, not only with the treatment route, but also with the form in which the chlorine is present. It is, therefore, difficult to make any general comments on the effects of chlorine other than that in the combustion routes there is a risk of dioxin formation and that in the reprocessing options there are risks of corrosion problems, acid gas emissions and contamination of the output streams.

Waste lubricating oils and oils recovered from interceptors are sold for use as fuel. Because these oils can create carbon deposits when burned, they tend to be used in applications where this is of no concern. The main users are the road stone industry and coal fired power stations, who use it for flame stabilisation and power boosts.

Waste fuel oils

Waste fuel oils arise from a variety of situations such as tank drainage from vehicle fuel tanks, when a boiler fuel store is drained when the plant converts to natural gas, or when tanks are removed during site clearances. These oils are generally not contaminated although they may have deteriorated with age and sometimes carry the ‘tank bottom dirt’ settled from many years of filling. In most plants, comparatively little of this type of material is accepted and it will be reasonable to consider its analysis comparable to fuel oils ‘as sold’.

Gasification is specially designed to process heavy fuels, as well as a wide range of hydrocarbon wastes.

Fuel oils range in specification but, in general, they are used rather than sent for treatment and so the quantities will be small. They typically have a lower boiling point than lubricating oils, contain more of the lower chain hydrocarbons and have a higher risk of VOC emissions during treatment. However, the content of the metals is typically low (although vanadium and nickel have been found in fuel oils). PAHs are typically stable and non-volatile. Unused fuel oils have a lower boiling point range than lubricating oils. Comparisons between the compositions of fuel oils and lubricants are shown in Table 3.120 below.

	Normal carbon chain length	Boiling point range (ºC)	Important compounds
Kerosene	Middle distillate, C_6 to C_{16}	150 – 300	N alkanes, cycloalkanes, low concentrations of mono aromatics, low concentrations of BTEX and PAHs
Fuel oil (Nº 2)	Middle distillate, C_8 to C_{21}	200 – 325	Very low BTEX, toluene 0.06 %, ethyl benzene 0.034 %, xylenes 0.23 %, high concentrations of n-alkanes, C_8 0.1 %, C_{20} 0.35 %), lower concentrations of branched alkanes, cycloalkanes monoaromatics, napthalenes (0.22 %) and PAHs, nickel 0.00005 %
Fuel oil (Nº 6)	Residual oil, C_{12} to C_{34}	350 – 700	Very low BTEX, low naphthalenes and PAHs, high n-alkanes (C_9 0.0034 % -C_{20} 0.1 %) and cycloalkanes, nickel 0.0089 %
Lube oils	Heavy end distillate, C_{18} to C_{34}	326 – 600	Low concentrations of BTEX, high concentrations of branched alkanes and cycloalkanes

Table 3.120: Typical composition of fuel oils and lube oils
[56, Babtie Group Ltd, 2002]

Rubber

Table 3.121 shows some characteristics of tyres used as fuel.

Parameter	Value	Units
Calorific value	36 – 38	MJ/kg
Chloride	0.15 – 0.25	%
As	<2	ppm
Cd	<5 – 10	ppm
Co	<5 – 27	ppm
Cr	<5 – 97	ppm
Cu	10 – 30	ppm
Hg	0.17 - <1	ppm
Mn	6 – 11	ppm
Ni	<5 – 40	ppm
Pb	<5 – 410	ppm
Sb	55 – 410	ppm
Sn	14 – 21	ppm
Tl	0.25 – 75	ppm
V	<5 – 60	ppm
Zn	14.5 – 16.1	g/kg

Table 3.121: Fuel characteristics of tyres
[4, Langenkamp, 1997]

Sludge

Sludge typically contains water. An increase in the content of water for a given dry composition of sludge decreases its heating value. For example, sludge with a content of 33 % dry matter has a heating value of less than 5 MJ/kg wet matter. The content of chlorine is typically low but the mercury content may be significant in certain sludges.

Wood

Sawdust, sawmill chips and PVC have a heating value of between 14 and 21 MJ/kg wet matter. Construction waste has a heating value of between 14 and 17 MJ/kg wet matter. Some physico-chemical parameters of scrap wood are shown in Table 3.122.

Metals	Concentration (ppm)
Lower heating value (MJ/kg)	17.3
Cl	0.1 %
Cd	0.7 – 3.4
Cr	50
Hg	0.2
Pb	53 – 1000
Tl	<0.1
Zn	1500

Table 3.122: Metals' content of scrap wood
[4, Langenkamp, 1997], [81, VDI and Dechema, 2002]

3.5.2 Consumptions of preparation of waste fuel

Consumptions in the preparation of waste oil to be used as fuel

Material consumed	Application
Chemicals antioxidants	Added to light fuel oils and light distillates fractions in order to stabilise the products

Table 3.123: Consumptions in the thermal treatment of waste oils
[119, Watco, 2002]

Waste OUT	Mainly to produce fuel oil [1]	Units (per tonne of input waste oil)
Fuel oil (700 MJ and <0.5 % S)	849	kg
Secondary fuels[2]	63	kg
Consumptions		
Fossil fuel consumption	4	eq. crude oil
Primary energy	343	MJ
Water consumption	431	kg
1 Thermal cracking: Thermal + chemical treatment (with H_2SO_4) 2 Many of them are waste fuels generated during the process		

Table 3.124: Consumptions generated by the thermal cracking of waste oils
[7, Monier and Labouze, 2001], [152, TWG, 2004]

Output	Amount (per tonne of input waste oil)	Units
Methanol	1080	kg
Savings in the primary input of fuels typically used in gasification		
Consumptions		
Fossil fuel	109	kg eq. crude oil
Primary energy	7110	MJ
Water consumption	1350	kg

Table 3.125: Outputs generated by the gasification of waste oils
[7, Monier and Labouze, 2001]

Consumptions in the preparation of hazardous waste to be used as fuel

Consumptions	Solid waste fuel	Liquid waste fuel
Electricity (kWh/tonne waste fuel produced)	5 – 25	5 – 20
Fuel (litre/tonne waste fuel produced)	0.15 – 3	0.05 – 2
Adsorbents	Between 20 and 40 % of absorbents per tonne of waste fuel produced are used, depending on required specifications. The types of absorbents are fresh sawdust, sawdust from wood recovery, polyurethane, paper by-product, textiles, etc.	
Water (litres/tonne of waste fuel - for cleaning installation, trucks and eventually drums; maintenance, spraying installations for dust abatement)[1]	5 – 20	5 – 20
Nitrogen m^3/tonne waste fuel produced (inertising mixers, shredders or liquid storage)	1 - 2.5	1 - 2.5
Others raw materials for effluent treatment		

Notes: Energy data do not include energy consumption for ventilation and air treatment.
The electricity consumption varies widely according to the type of wastes, the packaging and on the level of automation. For example, in the case of packaged drums to be shredded, the electricity consumption can reach 25 kWh/t, while in the case of bulk wastes in a non automated process line it will be between 5 and 10 kWh/t. Moreover, when the electricity consumption is high, the fuel consumption is usually on the low side.
The fuel consumption is mainly for utility vehicles and will decrease with the automation level.
The total energy consumption represents less than 5 % of the total energy content of the waste fuel.
[1] Water consumption is related with good housekeeping of the installation. It varies widely according to the type of wastes, the packaging and the eventual use of recovered rainwater. If drums or containers need to be cleaned or rinsed for further use, an additional consumption of 2 to 20 l/tonne is required.

Table 3.126: Consumptions in the preparation of hazardous waste to be used as fuel
[122, Eucopro, 2003]

Consumptions in the preparation of waste fuel from municipal solid waste
Table 3.127 below gives an overview of the plants that have provided data for this section.

Type of plant	Kind of solid waste fuel production	Capacity (kt/yr)	Energy consumption (MWh/yr)	Specific energy consumption (kWh/t input material)
Commercial waste processing plants	Soft/hard pellets	40	2400	109
Mechanical-biological waste treatment	Soft pellets, fluff	55	2300	38 – 56
Commercial waste processing plants	Soft pellets, fluff	65	1268 – 1902	40 – 59
MSW processing without a biological decomposition step		80	781	40
Mechanical-biological waste treatment	Fluff	100	5800	92
High calorific fraction from MSW processing and commercial waste processing plant	Soft pellets, fluff	100	315 – 405	32 – 41
Commercial waste processing plants	Soft pellets, fluff	100	1080 – 1620	36 – 54
Mechanical-biological waste treatment	High calorific fraction in bales	110	1870	17
Mechanical-biological waste treatment	Soft pellets, fluff	110	4000	33 – 40
Mechanical-biological waste treatment	Fluff	600	2760	
MSW processing without a biological decomposition step	Fluff	840	23650	30
Residual municipal solid waste treatment				60 Separation: 8 – 15

Table 3.127: Consumption examples for the preparation of fuels from MSW
[52, Ecodeco, 2002], [66, TWG, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004], [156, VROM, 2004], [157, UBA, 2004]

Capacity (kt/yr)	Fuel consumption (GJ/yr)	Electricity consumption (MWh/yr)	Specific electricity consumption (kWh/t)	Specific water consumption (m^3/t)
65	38475	3575	55	0.078
86	0	5831	68	0.0019
100		1050	10.5	

Table 3.128: Consumption examples for the preparation of fuel from non-hazardous waste
[66, TWG, 2003]

The big difference in energy consumption in relation to the amount of input material relates to the kind of processing plant applied and the type of generated solid waste fuel used; for instance, whether drying facilities are installed or if the generated solid waste fuel is made in different grain sizes and shapes.

Except for thermal drying processes, fuel is not required for solid waste fuel production; fuel is only necessary to run vehicles at the process area, such as fork-lift trucks or wheel loaders. One producer for thermal drying reported a gas consumption is about 21250 GJ per year. This specific consumption amounts to 1390 MJ/t input material.

In general, no further ingredients besides waste are deployed and which end up in product. To ensure failure-free operation, the process and material handling equipment have to be lubricated. Several detergents are applied. Furthermore, there are auxiliary materials applied to support the exhaust gas cleaning process, such as sodium hydroxide (consumption: 18 kg/kt) and phosphate (consumption: 3 kg/kt).

Separation, digestion and biological degradation require energy. The consumption of electricity by separation and digestion is approximately 60 kWh/t input material, of which the separation accounts to about 8 to 15 kWh. Through the incineration of the biogas in a gas engine, with an efficiency of 35 %, approximately 120 kWh$_e$/t waste are produced. This results in a net production of approximately 60 kWh$_e$/t waste. Producing the digestate requires approximately 100 MJ$_e$/t input materials. Biological drying requires also approximately 100 MJ$_e$/t input materials.

3.5.3 Emissions from the preparation of waste fuel

Emissions from the preparation of solid waste fuel from municipal solid waste
The material balance of the production of a RDF is shown in the next table.

Combustable product (e.g. RDF)	Organic matter	Non-combustable waste with an inorganic base	Metals	Water evaporated and CO_2	Others
55 – 50	20		5	20 – 25	
53 [1]		Glass: 4 White: 3 Brown: 0.5 Green: 0.5 Minerals: 4 Fine grain and dust to be disposed off: 4	Ferrous metals: 4 Non-ferrous metals: 1		Batteries: 0.05
Values in kg/100 kg of waste entrance [1] calorific value 15 – 18 MJ/kg					

Table 3.129: Examples of the emissions from the production of RDF from MSW [52, Ecodeco, 2002], [81, VDI and Dechema, 2002]

Table 3.130 gives an overview of the plants that have provided data for this section.

Type of plant	Kind of solid waste fuel production	Capacity (kt/yr)	Amount of solid waste fuel products (t/yr)	% product/ waste	Amount of exhaust gas (m^3/h)	Dust (kg/yr)	Odour (OU/m^3)	Noise distance to the location of immission (m) Acoustic pressure level day/night as technical approval (dB(A))
MSW processing without biological decomposition step	Fluff	23	17400	76.7				
Commercial waste processing plants	Soft/hard pellets	40	15300	69.5	18000			<40/<40
Commercial waste processing plants	Soft pellets, fluff	65	31700	99.1	48000			10 <70/<70
MSW processing without biological decomposition step	n.a.	80	16300	84.0				
Mechanical-biological waste treatment	Fluff	100	30700	48.7	45000	394		
High calorific fraction from MSW processing and commercial waste processing plant	Soft pellets, fluff	100	9000	90.0	48000			1000 <50/<35
Commercial waste processing plants	Soft pellets, fluff	100	27000	90.0	48000			1000 <50/<35
Mechanical-biological waste treatment	High calorific fraction in bales	110	19500	17.7	120000		406	200 50/39
MSW processing without biological decomposition step	Fluff	840	90000	11.5	90000		220	650 38/37.5

Table 3.130: Overview of some solid waste fuel production plants in the EU [126, Pretz, et al., 2003]

	Units	Installation A		Installation B		Installation C	
Capacity	kt/yr	65		86		98	
		Conc.	**Load**	**Conc.**	**Load**	**Conc.**	**Load**
Fumes	million Nm^3				394.2		
Oxygen	%			19		1.4	
CO_2	t/yr		11765		8428		
PM	mg/Nm^3 - kg/yr	0		1	394.2		
SO_x	mg/Nm^3 - kg/yr		1820	18.6	7332		
NO_x	mg/Nm^3 - kg/yr	80	4699.5	47	18527	12.5	
N_2O	mg/Nm^3 - kg/yr				0		
TOC	mg/Nm^3 - kg/yr	40	2340	1.7	670.14		
CH_4	kg/yr		26715				
CO	mg/Nm^3 - kg/yr	80	4699.5	8.4	3311.28	16	
HCl	mg/Nm^3 - kg/yr		78				
HF	mg/Nm^3 - kg/yr		26				
Total metals	mg/Nm^3 - kg/yr			0.4	197.1		
Hg	mg/Nm^3 - kg/yr			3.7	1.46		
Cd + Tl	mg/Nm^3 - kg/yr			0.4	0.197	0.08	
Chlorobenzenes	mg/Nm^3 - kg/yr			0	0.0047		
PCDD/PCDF	ngTEQ/Nm^3 - g/yr		0.0026	0.002	0.00079		
CFC	mg/Nm^3 - kg/yr			0.044	17.345		
Odour	EU O.U./Nm^3 - MGE/yr	0		110	43362		
NH_3	mg/Nm^3	0					

Table 3.131: Examples of air emissions from the preparation of fuel from non-hazardous waste [66, TWG, 2003]

	Units	Installation A		Installation B		Installation C	
Capacity	kt/yr	65		86		160	
		Conc.	**Load**	**Conc.**	**Load**	**Conc.**	**Load**
WW generated	m^3/yr		16965		30100		8000
BOD_5	mg/l - kg/yr			21			
COD	mg/l - kg/yr		34450	40			
Total N (as N)	mg/l - kg/yr			230			
Nitrit	mg/l - kg/yr			1.8			
Nitrates	mg/l - kg/yr						
Ammonia	mg/l - kg/yr		10400				
Nitrates	mg/l - kg/yr		650				
Sulphates	mg/l - kg/yr		325				

Table 3.132: Examples of water emissions from the preparation of fuel from non-hazardous waste [66, TWG, 2003]

Depending on the type of plant a great difference can be found in the ratio between the amount of treated waste and the solid waste fuel products. This is explained by the fact that some plants treat commercial waste and other plants treat MSW. Additionally, the producers have different ways to produce their solid waste fuel. For instance, if the fine material is added to the solid waste fuel product and this is not disposed in a landfill, the amount of product increases but the quality decreases significantly. Other plants are building up their capacities by modifications of their operation or produce solid waste fuel in a combined production with MSW processing plants.

The declared values are taken from the technical approvals. The differences seen by the wide range of the values can be explained by the location of the processing plants, and their different input materials and operating times, e.g. in some cases one, two or three shift operations.

With reference to Table 3.130, the difference between the amount of input and the amount of product output must be adjusted taking into account the amount of potential recyclables such as ferrous and non-ferrous metals in the waste. The content of potential recyclables depends on each waste composition, which can vary widely. Furthermore, residues may accrue during the waste gas cleaning process.

Depending on the processing method, there may also be some by-products generated. Depending on the quality of the by-products they might be recycled directly or treated after a further processing. The current by-products are typically ferrous and non-ferrous metals and an inert fraction. The quality of the ferrous and non-ferrous metal product depends on the waste content and on the processing method applied. Higher quality products are applicable for material recycling.

The inert fraction is sometimes used as construction materials, e.g. as road construction material or for landfill. In rare cases, a recycling material may be produced which is used directly as a raw material, e.g. some kinds of plastics and glass. Furthermore, by application of an air separator a heavyweight fraction can accrue which is applied for energetic utilisation.

The composition of the waste that is not used as fuel is different than that of the waste IN and the waste OUT. It depends on the waste IN but also the type of treatment given. Material balances showing such differences as well as showing where the different components of the waste IN end up, have not been provided.

Emissions from the preparation of hazardous waste to be used as fuel

Emissions to air

Emissions	From	Solid waste fuel	Liquid waste fuel
Dust, absorbents mainly from sawdust, powdery wastes (paints, resins, washing powder, catalysts, etc.)	Unloading and handling of absorbents and/or pulverulent wastes	m	n/a
	Processing	l/m	l (mainly for fluidification)
	Loading	m	n/a
	Achieved performance (mg/Nm^3) [1]	1 – 10	1 – 5
VOC and odour	Sampling	l/m	m/h
	Unloading operation (truck, drums, and containers)	m	m/h
	Processing	m (sieving)	l
	Achievable performance NMVOC (mg/Nm^3) [2]	10 – 50	10 – 110

Notes:

[1] by use of bag filters

[2] by regenerative thermal oxidiser for solid waste fuel and by regenerative thermal oxidiser or by activated carbon treatment for liquid waste fuel

l: low emissions – m: medium emissions – h: high emissions – n/a: not applicable

Table 3.133: Air emissions from the preparation of waste fuel from hazardous waste [122, Eucopro, 2003]

VOCs and odour

Most accepted wastes contain organic compounds. In certain circumstances, according to vapour pressure and temperature, they are more or less volatile. These volatile organic compounds (VOCs) can be potentially harmful for the environment and workers health and can also cause a bad smell. This is why these emissions need particular attention and follow up. The level of VOC emissions depends on the nature of the waste, its flashpoint, the vapour pressure of the components, and their concentration. VOC emissions are also influenced by the type of process applied and by the prevailing climatic conditions.

Noise

All the process lines and equipment need to be designed and built according to EU noise regulations for operators inside the plant and for neighbours. Incoming and outgoing transport vehicles are the main source of noise around and inside the plants.

Other noise sources include handling machines such as mechanical shovels, loaders, hydraulic shovels, screeners, shredders, grinders, pumps, agitators, motors used for the ventilation network, and VOC treatment units.

Emissions to water

The sources of waste water are cleaning water from drum cleaning, truck cleaning, the cleaning of facilities, road tankers and skips, and process water (from wastes settling during transport, from drying, etc.). In the absence of measured water parameters of the waste water from these installations, Table 3.134 shows a compilation of ranges from some permits applied to installations. With the exceptions of major accidents, these installations have no impact on groundwater. A piezometer network with analysis once or twice a year is generally used for the survey.

Physico-chemical parameters	**Permit limit values (mg/l)**
pH	5.5 – 9.5
Maximum temperature	30 – 45
TSS	30 – 60
COD	50 – 300
Hydrocarbons	2 – 10
BOD_5	30 – 40
N-kjeldahl	n.a. – 40
N global	10 – 50
Total phosphates	1 – 10
CN (free)	0.1
Cd	0.05 – 0.2
Cr(VI)	0.01 – 0.1
Cr total	0.02 – 0.5
Cu	0.03 – 0.5
Fe	10 – 15
Hg	0.05 – 0.15
Ni	0.05 – 0.5
Pb	0.05 – 0.5
Sn	0.01 – 2
Zn	0.3 – 2
Total Metals*	10 – 15
* Sb + Co + V + Tl + Pb + Cu + Cr + Ni + Zn + Mn + Sn + Cd + Hg + Se + Te	

Table 3.134: Ranges of values given in permits for some installations
[122, Eucopro, 2003]

By-products and wastes generated

Effluents treatment wastes and other wastes for disposal	Composed of	Amount (kg/tonne of waste fuel produced)
Residues coming from the packaging of the delivered wastes		1.5 – 20
'Consigned' IBCs, containers or drums		
Metallic containers and drums		
Plastic containers and drums		
Palettes		
Big bags		
Plastic sheet		
Scrap extraction during the production stage	These residues are composed of metallic parts which can be voluminous	
Rotating, vibrating and static sieve/screen rejects	These residues are composed of blocks of different solid wastes (such as resins, paintings, glues, tars, bitumen, polluted soils, etc.), pieces of wood, sand, polluted plastics, lining, pieces of textile sheets	0 – 3
Effluent treatment residues	For example, activated carbon from waste water and air effluent treatment	
Laboratory residues and rejected samples		0.015
Note: the amount of by-products is strongly linked with the type of packaging. For example, in the case of small packaged wastes, the iron scrap fraction can reach up to 150 kg/tonne of waste fuel		

Table 3.135: Wastes generated in the preparation of hazardous waste to be used as fuel [122, Eucopro, 2003], [150, TWG, 2004]

The control of soil quality can be assured by the follow up/monitoring of air emissions, effluents, and groundwater quality.

Preparation of solid waste fuel by the carbonisation of contaminated wood
Contaminated wood may contain POPs, mercury, arsenic and other typical contaminants

Emissions from the treatment of waste oil to be used as fuel
Table 3.136 shows the emissions of the preparation of waste oils when producing a liquid fuel.

Emission Pathway	Medium	Through
Waste oil storage	Air	Displacement of vapour during loading 'Breathing' via vents
Boiler	Air	Combustion gases via stack. Most oil re-processing facilities generate steam from in-house boilers
Heating vessels	Air	Heating vessels are typically insulated mild steel tanks. Heat is delivered to the oil by a heat exchange system typically based on internal or 'blind' steam coils. This arrangement can be difficult to clean and maintain. This may lead to inefficient energy use related to raising steam. VOCs are emitted during the heating of oil to drive off water vapour. Emissions may consist of displaced vapour comprising water vapour and VOCs. Carbon absorption could be used but may be affected by water vapour. Condensation needs to be considered to collect the organic fraction, which can be used as boiler feed or incinerated
Warm oil receiving tank	Air	VOCs from the transfer of warm oil to receiving tanks
Warm oil filtration	Air	VOCs emitted when warm oil is passed through filters to remove solids. Warm oil from the heating vessels is typically passed over open filters to remove solids. These are situated either in open yards or buildings. The filters used are typically vibrating metal mesh more commonly used in relation to mineral aggregates. It is crucial to the sale of the recovered fuel oil that the high solids content that the warm oil retains, is removed. The action of the removal of solids is aggressive and the filters need to be robust to deal with the solids and also the warm oil. This stage is a source of VOCs and odour
Removal of oil from effluent	Air	Oil is removed from liquid effluent prior to discharge to foul sewer or other waters, usually by oil/water interceptors, tilting plate separator and or by filtration techniques. VOCs are a significant emission when drawn off from a process tank into open channels and also when this is warm and passed over a tilting plant separator
Removal of oil from effluent	Water	Effluent to sewer. VOCs are released from warm water to sewer
Separation water	Air	VOCs released during watering off
Recovered oil storage	Air	VOCs displacement
	Land	Removal of sludge from storage and heating vessels and filtration units

Table 3.136: Emissions generated from the preparation of waste oils to be used as fuel [55, UK EA, 2001]

Table 3.137 shows some mass balances of four different treatment plants (A - D).

Site	Waste IN (excluding non oil/solvent items such as batteries)	Products	Discharge to sewer	Waste for processing off-site	Waste to landfill
A	Bulk waste oil: 14340	Fuel oil for the asphalt industry: 12800			
	Hydraulic fluid: 15				
	Mixed oily waste: 100				
	Used oil filters: 1355				
	Paints and solvents 100				
B	Mixed waste oils: 15000	Fuel oil: 13000	Waste water: 700	Compacted oil filters: 30	Sludge: 500
	Used oil filters: 90				
C	Contaminated water from factory interceptors: 14000	Fuel oil for further treatment or blending: 2000	High COD waste water: 13600		Pumpable sludge: 300
	Used oils from garages and factories: 2000				
	Surplus fuel oils: 100				
D	Used motor lubricating oil (In tankers): 80000	Used lube oil treated for use as fuel: 72000	Waste water with traces of hydrocarbons: 2500		Sludge from sieves: 6
	Used lube oils in drums: 100				Tank bottom sludge: 6
	Surplus fuel oils: 300	Kerogas (mixed lube and fuel oil): 1000			Cut pieces of 25 litres oil drums: 10
					Debris, rags, etc: 5
Note: Values within cells correspond to the annual amount in tonnes of the mentioned material					

Table 3.137: Inputs and outputs for waste oil treatment plants producing a material to be used as fuel
[56, Babtie Group Ltd, 2002]

Waste IN			
Type of waste oils	**Annual amount (tonnes)**	**Oil content (% oil)**	**Water content (% water)**
Waste motor oil	62000	97	3
Interceptor waste	25000	4	96
Soluble oils	16000	25	75
Fuel oils	7000	98	2
Oils from transfer stations or the processing of oil filters	4000	97	3
Other oil bearing waste streams	200	99	1
Waste OUT and residues			
Product			
Cleaned waste oil to be used as fuel	75150	99.5	0.5
Disposal to sewer		**Oil (mg/l)**	**COD (mg/l)**
Sewer discharge	40000	200	
Disposals to landfill		**% Oil (dry solids)**	**Water content (% water)**
Landfill: screenings	6000	11	25
Landfill: process sludge	12000	5	50
Landfill: other waste	4000	2	40
Other liquid disposal	4000	2	98
Other solid disposal	3000	5	95

Table 3.138: Example of emissions from an oil recycling plant that heats the oil during the process
[56, Babtie Group Ltd, 2002]

Outputs	Mainly to produce fuel oil [1]	Mainly to produce gasoil [2]	Units (per tonne of input waste oil)
Fuel oil (32 of 700 MJ and <0.5 % S)	849		kg
Secondary fuels [3]	63		kg
Gasoil		706	kg
Naphtha		51	kg
Bitumen		38	kg
Emissions			
CO_2	2845		eq. kg
SO_2	9.8		eq. kg
VOC	0.08		kg eq. C_2H_4
Particulates	0.4		g
Phosphates in water	0.0012		kg eq.
Waste to eliminate	18		kg
Waste to recover	24		kg
Waste water		50	kg
Solvents		29	kg
Heavy residues		61	kg
Naphtha		36	kg
Off-gases		29	kg

[1] Thermal cracking: thermal + chemical treatment (with H_2SO_4)
[2] Thermal cracking adjusted to produce primarily gasoil. Finishing with purification and stabilisation stages
[3] Many are waste fuels generated during the process

Table 3.139: Emissions generated by the thermal cracking of waste oils
[7, Monier and Labouze, 2001], [152, TWG, 2004]

For co-gasification with coal, the metals contained within the used oil can be fixed in an inert, non-hazardous bottom ash. Sulphur compounds are converted to hydrogen sulphide and removed by conventional scrubbing and converted to elemental sulphur. There are no metals, fugitives or dioxin emissions from the gasification process.

Outputs	Amount (per tonne of input waste oil)	Units
Methanol	1080	kg
Saving of primary input of fuels typically used in gasification		
Emissions		
CO_2	1431	kg eq.
SO_2	0.21	kg eq.
VOC	0.05	kg eq. C_2H_4
Phosphates	0.0079	kg eq phosphates in water
Waste to eliminate	1	kg
Waste to recover	36	kg

Table 3.140: Outputs generated by the gasification of waste oils
[7, Monier and Labouze, 2001]

Emissions to air

Some emissions commonly caused by the processing of waste oils to produce a product that can be used as fuel are shown in the following table (Table 3.141).

Environmental issue in the processing of waste oil	Comments
Chlorinated hydrocarbons	They increase the level of chlorine in the waste oil
Dioxins	They have been cited by environmental health officials in a recent used oil regeneration and basestocks fire
Lead	In the reprocessing option, lead will end up in the heavy residues, which will result in it being 'locked up' in a bitumen product. Due to the changing of gasoline specifications, lead contamination is of diminishing importance
Metals	In the thermal cracking process, at least 98 % of the metals are removed as a non-leachable solid powder, collected in sealed containers, and used as an additive to asphalt
Non-volatile metals	The other metals likely to be present may be retained in the bitumen residue, as with lead
PAHs	PAHs used to be a problem in processing base oils from a health and environmental point of view. These are formed during an incomplete combustion of organic matter. PAHs are relatively difficult to break down. However, recent tests indicate that it is possible to remove PAHs in the regeneration process of modern plants, thus avoiding the accumulation of PAHs
Sulphur compounds	Odour and SO_x emissions, if used as fuel within the processing plant

Table 3.141: Environmental issues related to the processing of waste oils to be used as fuel
[6, Silver Springs Oil Recovery Inc., 2000], [11, Jacobs and Dijkmans, 2001], [56, Babtie Group Ltd, 2002]

Emissions to water

Waste oil preparation may give rise to miscible or dissolved organic substances, for example, demulsifers and detergents, within the effluent.

3.5.4 Waste fuels (waste OUT)

The intention of this section is to give an overview of the type of specifications that waste fuel typically has to have in order to be used in different combustion processes. Waste fuel is the term used in this document to name the fuel prepared from waste. As stated in the Scope chapter, descriptions of the combustion processes themselves are not covered in this document. Combustion is covered in the other industrial sector BREFs covered by IPPC.

The co-incineration of waste materials impacts on plant efficiency, and/or emissions to air and water, and also effects the quality of combustion residues and by-products. The impact of using waste as a fuel instead of using conventional fuels is determined by the different properties of the waste from the main fuel. For example, the emissions caused by the burning of waste oils in a coal fired power plant, in a fuel oil fired power plant or in a cement kiln are different because the nature of the process and the applied abatement techniques, e.g. solid vs. liquid fuel, end-of-pipe techniques, alkalinity of the cement kilns, temperature of the combustion (from 800 °C for fluid bed furnaces up to 2000 °C for cement furnaces), and the type of combustion plant (power plant, district heating or CHP) can be very different in each case. Consequently, those issues are covered in each industrial sector BREF, together with the discussion on the applied combustion process; and hence these issues cannot be covered here.

Part of the heating value of the waste to be used as fuel and the other important fuel properties that determine whether a specific fuel can be applied in a combustion plant arise from its chemical composition and physical properties. Fouling, slagging and corrosion of the boiler, when used in combustion power/heat plants, are possible negative aspects that are also related to its chemical composition, in particular to the presence of certain components in the total fuel mix such as alkali metals, chlorine and sulphur. These components may therefore have great influence on the availability of the combustion power/heat plant – as they can lead to plant downtime; they can also affect the ash characteristics, e.g. sintering and melting behaviour. Ash composition can be an important factor in the economics of the combustion plant. Polluting elements, such as heavy metals, can negatively influence the options for ash use, resulting in high costs for ash disposal. The physical form in which the fuel occurs is also of importance because the feeding systems must be capable of handling the fuel without problems and particles must be small enough for complete burn out in the relevant combustion technology. Pellets, fluff, briquettes and bales are the most commonly applied physical forms for solid waste fuel.

Futhermore, for combustion process the volatiles are an important fuel parameter with regard to flame stability and burn out of the fuel. Generally, solid waste fuels consist of wood, paper and plastics which are high in volatiles, e.g. compared to coal.

3.5.4.1 Solid waste fuel prepared from municipal solid waste

The range of compositions of solid waste fuel in Europe is shown in Table 3.142 below

Property	Range	Units
Dry matter	75.3 – 78.0	%
Humidity	1.6 – 50	%
Calorific value	10 – 40	MJ/kg
Ash	0.7 – 20	w/w-%
Composition of the ash		w/w-%
aluminium	6.9 – 9.2	
calcium	17.6 – 21.8	
iron	1.6 – 2.2	
potassium	1.9 – 2.2	
magnesium	1.4 – 1.7	
sodium	1.9 – 2.7	
silicon	17.9 – 20.8	
titanium	1.0 – 1.6	
Chlorine	<0.01 – 1.77	w/w-%
Fluorine	0.001 – 0.02	w/w-%
Sulphur	0.02 – 0.6	w/w-%
Carbon	47.1 – 50.7	w/w-%
Hydrogen	6.6 – 7.0	w/w-%
Nitrogen	0.5 – 0.8	w/w-%
Oxygen	30.4 – 34.4	w/w-%
As	<0.4 – 160	ppm
Be	0.2 – 0.3	ppm
Cd*	0.16 – 6	ppm
Cd + Hg	7	ppm
Co	0.4 – 7.4	ppm
Cr	2.5 – 226	ppm
Cu	6.8 – 1340	ppm
Hg	<0.02 – 1	ppm
Mn	22 – 590	ppm
Ni	<2.5 – 40	ppm
Pb	2.4 – 300	ppm
Sb	1 – 39	ppm
Se	0.8 – 1.7	ppm
Sn	2 – 27.6	ppm
Te	0.6 – 1.58	ppm
Tl	<0.1 – 0.8	ppm
V	2.3 – 10.2	ppm
Zn	225 – 500	ppm
EOX	31 – 42	ppm
* Around 70 % of the Cd that may be present in the MSW is transferred to the combustible products.		

Table 3.142: Ranges from the analyses of solid waste fuel prepared from MSW in Europe [4, Langenkamp, 1997], [8, Krajenbrink, et al., 1999], [21, Langenkamp and Nieman, 2001], [81, VDI and Dechema, 2002]

Parameter	Units	Median	80th percentile	Number of samples
Net calorific value	MJ/kg	20.6	25.1	179
Moisture content	%	13.4	18.8	346
Ash content	% DM	13.8	20.6	151
Chlorine total	%	0.7	1.1	171
Fluorine total	mg/kg DM	100.0	400.0	55
Sulphur total	%	0.1	0.4	110
Antimony	mg/kg DM	10.8	42.4	284
Arsenic	mg/kg DM	1.0	2.0	257
Beryllium	mg/kg DM	0.2	0.3	230
Cadmium	mg/kg DM	2.2	4.9	266
Chromium	mg/kg DM	48.0	82.9	259
Cobalt	mg/kg DM	2.9	4.7	245
Copper	mg/kg DM	97.5	560.0	286
Lead	mg/kg DM	89.0	160.0	265
Manganese	mg/kg DM	61.0	94.0	229
Mercury	mg/kg DM	0.2	0.3	249
Nickel	mg/kg DM	13.1	26.3	243
Selenium	mg/kg DM	0.4	1.7	235
Tellurium	mg/kg DM	0.4	1.0	222
Thallium	mg/kg DM	0.4	0.5	241
Tin	mg/kg DM	4.0	12.2	192
Vanadium	mg/kg DM	3.6	5.3	241
PCB	Sum DIN 51527	0.2	0.5	21

Notes: DM = dry matter
All percentages are by mass
The MSW used at this time did not include the high calorific fraction of household waste. It contained the high calorific fraction from construction and demolition waste and from commercial waste, which explains the stated value of the net calorific value.

Table 3.143: Solid waste fuel produced from the high calorific fraction of demolition waste [21, Langenkamp and Nieman, 2001]

Parameter	Units	Source-separated raw materials from apartments, offices, etc.[1]	Source-separated raw materials from industries and companies[2]
Moisture	%	33.6	16.6
Gross calorific value	MJ/kg DM	23.1	21.2
Net calorific value	MJ/kg DM	22.3	20.1
Net calorific value	MJ/kg	14.0	16.8
Energy content	MWh/tonne	3.9	4.7
Ash content	%	10.2	6.7
Volatile matter	%	74.8	78.3
Chlorine	%	0.4	0.3
Aluminium	%	0.6	0.2
Metallic aluminium	%		0.03
Sulphur	%	0.2	0.1
Nitrogen	%	1.5	1.4
Sodium	%	0.4	0.1
Sodium soluble	%	0.3	0.1
Potassium	%	0.3	0.1
Potassium soluble	%	0.2	0.1
Mercury	mg/kg DM	0.3	0.1
Cadmium	mg/kg DM	1.2	
Chromium	mg/kg DM	140	
Copper	mg/kg DM	80	
Nickel	mg/kg DM	20	
Zinc	mg/kg DM	340	
Manganese	mg/kg DM	210	
Arsenic	mg/kg DM	8.8	
Lead	mg/kg DM	52.4	

Notes: DM = dry matter
All percentages are by mass
[1] Mean derived from 742 samples
[2] Mean derived from 490 samples

Table 3.144: Recovered fuel produced from source-separated fractions from MSW and other combustible waste (Finland)
[21, Langenkamp and Nieman, 2001]

Parameter	Units	Median	80th percentile	Number of samples
Net calorific value	MJ/kg	22.9	25.3	1402
Moisture content	%	11.5	17.2	1849
Ash content	% DM	9.6	11.6	1308
Chlorine total	%	0.4	0.7	1475
Fluorine total	mg/kg DM	100	400	200
Sulphur total	%	0.1	0.1	307
Cadmium	mg/kg DM	0.8	3.2	443
Mercury	mg/kg DM	0.2	0.4	402
Thallium	mg/kg DM	0.5	1.5	410
Arsenic	mg/kg DM	1.5	1.7	394
Cobalt	mg/kg DM	2.0	3.8	383
Nickel	mg/kg DM	6.2	16.0	384
Selenium	mg/kg DM	1.0	2.5	318
Tellurium	mg/kg DM	1.0	5.0	322
Antimony	mg/kg DM	9.4	33.9	547
Beryllium	mg/kg DM	0.2	0.3	343
Lead	mg/kg DM	25.0	64.4	406
Chromium	mg/kg DM	20.0	43.9	417
Copper	mg/kg DM	48.0	118	504
Manganese	mg/kg DM	28.0	47.0	369
Vanadium	mg/kg DM	3.3	10.0	347
Tin	mg/kg DM	7.0	12.4	114
PCB	Sum DIN 51527	0.2	0.5	134
Notes: DM = dry matter All percentages are by mass				

Table 3.145: Recovered fuel produced from monostreams of commercial and industrial waste (data from one German company)
[21, Langenkamp and Nieman, 2001]

Solid waste fuel to substitute coal
The main difference between coal and solid waste fuels is the contents of sulphur, chlorine and heavy metals. In many cases, for instance, if solid waste fuels with plastics are considered and compared to coal, the chlorine of the recovered fuels are higher (typically 0.5 – 1.0 %) and the sulphur is lower. Also generally, the heavy metals content will be in a similar range (ppm range) or may even increase. Solid waste fuel is sold in different physical forms. Table 3.146 gives an overview of the different physical forms of waste fuel.

Waste fuels	Determining physical and chemical characterisation
Fluffy	Particle size, bulk density, moisture content, net calorific value, ash content, chemical composition
Soft pellets	
Hard pellets	
Chips	
Powder	

Table 3.146: Overview of the different physical forms of the waste fuel (waste OUT)
[126, Pretz, et al., 2003], [152, TWG, 2004]

The user requirements often define the product quality and the waste fuel characterisation. Power plants, cement and lime works, gasification plants, multifuel boilers etc. have different standards for the use of solid waste fuel dependent on their technology, waste gas treatment and product specification.

Dried sewage sludge
Large volumes of dried sewage sludge with calorific values between 3 and <10 MJ/kg are used in power plants.

3.5.4.2 Specifications of waste fuel to be used in cement kilns

The two tables below (Table 3.147 and Table 3.148) contain examples of specifications used by cement kilns in some countries. These tables do not contain the full picture of what is actually happening in Europe, so it should be considered that the information given here is not exhaustive.

The sampling and measurements required for accepting substitute fuels in cement kilns in some countries is shown in Table 3.147.

Substances or criteria to be measured	Units	United Kingdom	Flanders[1] (Belgian region)	Italy[2]	New Zealand[3]
Calorific value	MJ/kg	23 – 29	>15	>15	
Water/solvent separation		not detectable			
Water content	%			<25	
Total S	%	<0.3	<0.4	<0.6	0.1 – 2.8
Total Cl	%	<2	<0.5	<0.9	0.03 – 0.76
Total F, Br, I	%	<0.5			
F	%		<0.1		
Total Br, I	%		<0.01		
Total N	%		<1.0		
Al	ppm				10 – 1000
As	ppm	<50	<10	<9	<50 – 60
Be	ppm		<1		
Cd	ppm		<10		<10 – 20
Cd + Tl	ppm	<40			
Cd + Hg				<7	
Co	ppm	<100			
Cr	ppm	<200		<100	<10 – 80
Cu	ppm	<600		<300[6]	<10 – 165
Hg[4]	ppm	<20			<10
Hg, Tl	ppm		<2		
Mn	ppm	<250		<400	
Mo	ppm		<20		
Ni	ppm	<50		<40	
Pb	ppm	<500	<200	<200[5]	10 – 1080
Sb	ppm	<50			
Sn	ppm	<100			
V	ppm	<50	<200		
Zn	ppm		<500		108 – 3670
Sb, As, Cr, Co, Cu, Pb, Mn, Ni, Sn, V	ppm	<1800			
Solid and ash content	%	Depends on the type of waste fuel		<20	
PCB content					<10
Other species		Depends on the type of waste fuel			

[1] It has been reported that no cement kiln is now operating in Flanders

[2] An SRF producer reported production of a waste fuel with the following characteristics: calorific value of more than 18.8 MJ/kg, water content of less than 20 %, total chlorine content of less than 1 % and an ash content of less than 6 %

[3] For waste oil used in a cement kiln

[4] Lower values have been reported (2 – 5 ppm if the facility is equipped with a bag house filter with activated carbon and less than 1 ppm if such equipment is not implemented) but no reference to any country or installation was given

[5] refers only to volatile Pb

[6] refers only to soluble Cu compounds

More data can be found in the German legislation (Table 1 of Stellungnahme der LAGA zu RAL GZ 724) and in the work carried out by CEN/TC 343 WG 2

Table 3.147: Examples of specifications of a waste to be accepted as fuel in some countries' cement kilns
[4, Langenkamp, 1997], [37, Woodward-Clyde, 2000], [52, Ecodeco, 2002], [150, TWG, 2004], [152, TWG, 2004]

Table 3.148 shows some examples of specifications applied to different types of waste to be accepted in French cement kilns.

Substances or criteria to be measured	Units	Catalysts	Industrial sludges	Polluted water with high COD contents (>10000 ppm)	Animal meal	Animal fat	Waste oil
PCB/PCT	ppm	<50	<50	<50			<50
Pentachlorophenol		none	none	none			none
Hg	ppm	<10	<10	<10			
Hg + Cd + Tl	ppm	<100	<100	<100			
Sb + As + Pb + Cr + Co + Ni + V + Sn + Te + Se	ppm	<10000	<2500	<2500			
Heavy metals	%						<1
pH			3 – 12	3 – 12			3 – 12
Calorific value	kJ/kg		8400	8400	18800	38500	38500
Total hydrocarbons	%	<0.5					
$CaO + SiO_2 + Fe_2O_3 + Al_2O_3$	%	>80 *					
Water	%	<10	40 – 70				<15
Alkalis ($Na_2O + K_2O$)	%	<5	<1.5	<5			<5
Total Cl	%	<0.6	<0.3	<0.6	<0.6	<0.1	<0.6
Total S	%	<5	<2	<2	<0.4	<0.1	<2
Total P (as P_2O_5)	%	<2	<5				
F	%	<2					
Br	%	<0.5					
I	%	<0.5					
F + Br + I	%		<1	<1			<1
Solid residue at 900 °C	%		<30	<5			<5
Viscosity at 20 °C	cp			250			250

Notes:
* on a dry basis
The types of wastes not accepted for processing in cement kilns in France are radioactive products, explosives, peroxides, perchlorates and strong oxidants, tear compounds, mineral cyanides, hospital waste, waste polluted with pathogenic microbes and highly flammable liquids.
Some of the wastes listed here correspond to wastes that are directly sent from the waste producer to the cement kiln, and then, these are not treated before being used in the cement kilns. Some wastes listed here do not correspond strictly to use of waste as fuel.
Some substances mentioned here have an impact on the cement kiln process or product (e.g. alkalis, phosphorous, viscosity). For more information see the Cement and Lime BREF.

Table 3.148: Examples of specifications of different types of waste to be accepted as waste fuel in the French cement kilns
[46, Szabo, 2002], [150, TWG, 2004], [152, TWG, 2004]

Substance	A		B	C
	mg/MJ	**mg/kg (at 25 MJ/kg)**	**mg/kg**	**mg/kg**
Ag	0.2	5	-	-
As	0.6	15	20	30
Ba	8	200	600	1000
Be	0.2	5	3	3
Cd	0.08	2	0.8	1
Co	0.8	20	30	100
Cr	4	100	100	200
Cu	4	100	100	200
Hg	0.02	0.5	0.5	0.5
Ni	4	100	100	200
Pb	8	200	50	75
Sb	0.2	5	1	5
Se	0.2	5	1	5
Sn	0.4	10	50	30
Tl	0.12	3	1	2
V	4	100	200	300
Zn	16	400	400	400
Toxic organic compounds	No standard value. However, some restrictions are mentioned if PCB, dioxins or similar toxic compounds are suspected or organic compounds are present			
Column A applies to wastes used as fuel introduced either in the main burner at the clinker outlet of the rotating kiln or the inlet of the rotating kiln. The standard values in colum A (mg/MJ) are based on the lower calorific value of the waste. For reasons of clarity, the standard values in (mg/kg waste) are based on a lower calorific value of 25 MJ/kg. The value of 25 MJ/kg corresponds to the calorific value of hard coal. If the calorific value of the waste is less than or greater than 25 MJ/kg, the permissible heavy metal content changes proportionally Column B applies to wastes used as alternative raw materials in producing clinker. This waste substitutes part of the raw material normally used or serves to correct the raw meal composition, i.e. the calcium, iron, silicon or aluminium content Column C applies to waste used at the grinding stage in the production of Portland cement. Portland cement consists of 90 – 95 % ground cement clinker and 5 – 10 % gypsum, as well as other materials added at the grinding stage				

Table 3.149: Standard values for pollutant content of waste used in the cement kilns used in Switzerland
[150, TWG, 2004]

3.5.4.3 Waste oil used as fuel

Used oils have some valuable properties for their use as a fuel oil blendstock, e.g. they have a lower sulphur content and viscosity in comparison to other heavy fuels. Blending into fuel oil at the refinery could be a viable option for oils when it can be shown that the contaminant levels are within acceptable limits for the fuel oil specification.

Waste oil is used as a fuel in a number of power stations in the UK. A typical specification is shown in Table 3.150 below. It is reported that waste oil suppliers consistently have difficulty in meeting the chlorine specification because of the contamination of used oils in the UK. This arises from other wastes such as transformer oils and chlorinated greases.

PROPERTIES	Units	Min.	Max.
Physical			
Density at 15 °C	g/cm^3	0.88	0.95
Flashpoint	°C PMCC	65	
Net calorific value	GJ/tonne	40	
Viscosity @ 40 °C	Centi Stokes	30	55
Chemical			
Water content	w/w-%	0	3
Sulphur	w/w-%	0	1
Chlorine	ppm	0	1100
PCB	ppm	0	10
Lead	ppm	0	200
Vanadium	ppm	0	50
Copper	ppm	0	50
Cadmium	ppm	0	10
Chromium	ppm	0	30
Nickel	ppm	0	50

Table 3.150: Typical specification for recovered fuel oil supplied to UK power stations [56, Babtie Group Ltd, 2002], [67, DETR, 2001]

Waste OUT from the mild reprocessing of waste oils

The cleaned waste oils from these processes are typically blended with other fuel oils. The processed waste oil will still contain heavy metals, halogens and sulphur.

Waste OUT from the thermal cracking of waste oils

Table 3.151 gives a summary of the components present in the products from the thermal cracking of waste oils.

Environmental issue	Comments
Chlorinated hydrocarbons	If the cracked fuel is hydrotreated, chlorinated compounds are removed. Heavy PCBs (boiling point higher than the waste oil) are destroyed during this process. Light PCBs are only partly destroyed during this process. Organic chloride compounds may still remain in the distillate
Chlorine	A maximum specification for chlorine of 50 ppm was set by the Dutch government
Metals	The efficiency of the vacuum column enables the production of distillates with metal contents of less than 1 ppm. All metals present in the used oil end up in the bottom of the cracking section
PAHs	The heavy PAHs are cracked, and are burned with light naphtha. The lighter PAHs are added to the pool of light fuels
Sulphur	The gasoline will have a sulphur content that depends on the sulphur level in the used oil feed and the stabilisation method applied

Table 3.151: Components of waste OUT from the thermal cracking of waste oils [6, Silver Springs Oil Recovery Inc., 2000], [150, TWG, 2004]

It is likely that in order to meet EU requirements for the sulphur content in liquid fuels (automotive and/or heating oil) that the resulting cracked products will require either treatment for sulphur reduction or will have to be blended away in lower sulphur products (thereby making use indirectly of someone else’s desulphurisation capability).

Outputs	Units (per tonne of input waste oil)	Mainly to produce fuel oil [1]	Mainly to produce gasoil [2]
Fuel oil (32 of 700 MJ and <0.5 % S)	kg	849	
Secondary fuels [3]	kg	63	
Gasoil	kg		706
Naphtha	kg		51
Bitumen	kg		38
1 Thermal cracking: Thermal + chemical treatment (with H_2SO_4) 2 Thermal cracking adjusted to produce primarily gasoil. Finishing with a purification and stabilisation stage 3 Many are waste fuel generated during the process			

Table 3.152: Outputs generated by the thermal cracking of waste oils
[7, Monier and Labouze, 2001], [152, TWG, 2004]

Waste OUT from the gasification of waste oil
For co-gasification with coal, the metals contained within the used oil can be fixed in an inert, non-hazardous bottom ash. Sulphur compounds are converted to hydrogen sulphide and removed by conventional scrubbing and converted to elemental sulphur. There are no metals, fugitives or dioxin emissions from the process.

Outputs	Units	Amount (per tonne of input waste oil)
Methanol	kg	1080
Saving of primary input of fuels typically used in gasification		

Table 3.153: Outputs generated by the gasification of waste oils
[7, Monier and Labouze, 2001]

3.5.4.4 Quality assurance systems

The information given in this section presents a survey about existing quality assurance systems and the recent developments.

European CEN/BT/TF 118
The CEN Task Force 118 ‘Solid Recovered Fuels’ was established in April 2000. The Task was to prepare a technical report about the production and the application of solid waste fuel within the EU as well as the development of a work programme as the basis for an European standard in the future. The European classification model is based on solid waste fuel characteristics, source material and origin. The report concluded that it is necessary to develop a European standard. CEN was given the mandate to develop, as a first step, a set of technical specifications concerning solid waste fuel, and produced exclusively from non hazardous wastes, for energy recovery in waste incineration or co-incineration plants. As a second step, CEN was given a mandate to transform this set of technical specification into European Standards.

German RAL
Early in 1999, a german association started its endeavours to install the quality label for solid waste fuel from non-hazardous waste. The label is awarded to solid waste fuel producers which comply to the requirements by guaranteeing constant qualities. The standards firstly relate to cement industry and power stations. Accordingly, solid waste fuel has to fulfil the criteria given in annexes 1 and 2 to the quality assurance system. Annex 1 contains a list with all allowed wastes which are applicable as a basic principle. In annex 2, values are given which have to be met. These values are shown in Table 3.154. The inspections in acknowledging as well as in the supervision procedure occur in two phases. These systems include sampling matters, how to calculate mean values, acknowledging procedure (first inspection), self-monitoring, independent supervision and re-inspection.

	Content of heavy metals 4)	
Parameter	**Median (mg/kgDM)**	**80th percentile (mg/kgDM)**
Calorific value		
Humidity		
Ash content		
Chlorine content		
Cadmium	4	9
Mercury	0.6	1.2
Thallium	1	2
Arsenic	5	13
Cobalt	6	12
Nickel	25 1) 80 2)	50 1) 160 2)
Selenium	3	5
Tellurium	3	5
Antimony 5)	50	120
Lead	70 1) 190 2)	200 1) - 3)
Chromium	40 1) 125 2)	120 1) 250 2)
Copper	120 1) 350 2)	- 3) - 3)
Manganese	50 1) 250 2)	100 1) 500 2)
Vanadium	10	25
Tin	30	70
Beryllium	0.5	2

1) For solid recovered fuel from production specific waste

2) For solid recovered fuel from the high calorific fractions of municipal waste

3) Restriction not until a secured database is given by the fuel processing

4) The heavy metal contents are valid up to a calorific value NCV_{DM} of ≥ 16 MJ/kg for the high calorific fractions from municipal waste and up to a calorific value NCV_{DM} of ≥ 20 MJ/kg for production specific waste. For calorific values falling below, the values need to be lowered accordingly, an increase is not allowed.

5) Values adapted in case of digestion with aqua regia in a closed microwave system

Table 3.154: Heavy metal contents which have to be complied with according to BGS/12/ [126, Pretz, et al., 2003], [150, TWG, 2004]

Finnish SFS 5875

The Finnish waste disposal system is based on a separate collection of wastes for the recycling and for solid waste fuel production. Different solid wastes and Finnish boilers with a high technical standard are used for a highly efficient production of energy followed by low emission levels. The application of solid waste fuel in the Finnish multifuel boiler is estimated as ‘well suited’. The regulations concern separate collected, dry solid, high calorific fractions or for dry, high calorific fractions derived from household wastes. The regulation defines operations and demands to control the solid waste fuel production and also refers to the complete waste management chain, from the waste recovered paper source up to the disposal. For each part of the disposal chain, the standard requires a person in charge to monitor the technical and quality requirements.

Analogical to the German standard, the annexes of the Finnish standard define concrete requirements concerning thresholds for heavy metals as well as for the framework of analysis, sampling, etc. The thresholds are predefined which have to be adhered to as well as regulations as regard to the matter of contracts. It includes supervision operation, quality requirements and quality classes.

In comparison to the German standard, the Finnish standard divides wastes into three quality classes. For categorisation of solid waste fuel in Finland, seven elements are analysed. Table 3.155 presents the criteria for the classification of quality classes.

Parameter	Unit	Quality classes		
		I	II	III
Chlorine	weight -%	<0.15	<0. 5	<1.5
Sulphur	weight -%	<0.2	<0.3	<0.5
Nitrogen	weight -%	<1.0	<1.5	<2.5
Potassium and Sodium	weight -%	<0.2	<0.4	<0.5
Aluminium (metallic)	weight -%	- 1)	- 2)	- 3)
Mercury	mg/kg	<0.1	<0.2	<0.5
Cadmium	mg/kg	<1.0	<4.0	<5.0

1) Metallic aluminium is not allowed, but is accepted within the limits of reporting precision.
2) Metallic aluminium is minimised by source-separation and by the fuel production process.
3) Metallic aluminium content is agreed separately.

Table 3.155: Quality classes according to SFS 5875/13/
[126, Pretz, et al., 2003]

Austrian ÖG SET

Within a joint project of the Austrian association (Österreichische Gütegemeinschaft für Sekundärenergieträger), a quality assurance concept for solid recovered fuels (SRF) has been worked out.

Objective

In order to meet the requirements for the thermal utilisation of wastes/residues in industrial co-incineration, the waste/residue quality has to be accurately defined. During production of waste fuels, special attention has to be given to the quality assurance of these predefined fractions. For the technical feasibility on an industrial scale, practical experience showed that not only the chemical contents and the composition, defined by the origin of the waste, but also the physical parameters like particle size and agglomeration, defined by the mechanical pretreatment, in order to comply with these requirements of the ÖG-SET are decisive.

In order to reach those requirements, the ÖG-SET aims with the following as the basis for a quality mark:

- preparing regulations for sampling and sample preparation
- evaluating the implications of the prepared regulations on the application of solid recovered fuels in industrial co-incineration, power and heat production
- preparation of a quality assurance concept.

Organisation

The main prerequisite to put the resulting regulations in action is a wide support from the companies concerned who deal with the production and the thermal utilisation of solid recovered fuels.

Activities

The following activities are carried out:

- catalogue criteria for the utilisation of SRF in different industrial incineration/energy and heat production plants
- preparation of regulations for the sampling of SRF
- carrying out an inter-laboratory test for the determination of standard deviations in mean contents resulting by sampling, sample preparation and analysis
- preparation of a quality assurance concept
- definition of the basic requirements for a quality mark.

Taking into account five industrial branches and the applied technologies for thermal utilisation (e.g. coal dust burners, rotary ovens, fluidised beds), five working groups (cement industry, pulp/paper and board industry, electric power stations, steal industry and wood industry) were established. In each group producers and users of SRF were taking part to ensure a holistic approach. For the different utilisation technologies, essential criteria were gathered and defined for the thermal utilisation of waste and residues. Principally, three different types of quality attributes were distinguished:

- exclusion criteria
- physico-chemical quality attributes
- other quality attributes.

These quality attributes contain a compendium of the criteria and quality attributes defined by the working groups. Every plant manager taking into account his plant's requirements, can choose attributes for his required SRF quality from the lists. For sourcing, the criteria can be included in the specification of the SRF.

Preparation of the basis for specification
The preparation of a specification sheet facilitates the communication between the SRF producer and user. For the sourcing of SRF, additional criteria like the following ones can be made:

- transport and storage criteria (e.g. bulk density)
- type of transport (e.g. by road, by rail).

The additional information can ease the handling of SRF considerably.

Inter laboratory test
Two SRF (one less and one more heterogeneous) test schemes have been worked out. One test was carried out for guide parameters defined with the statistic evaluation of existing data. The chemical parameters from the criteria list were investigated as well. The first step was the calculation of the sample mass and sample number, based on the framework provided by CEN TC 292 WG1 'Characterisation of waste – Sampling techniques for waste' (draft from 02/2001). The sample volume and sample number were calculated by using a targeted total deviation, the particle size, the bulk density and the heterogeneity of the waste expressed by the standard deviation reached in earlier examinations. Based on the results of the inter laboratory test, the guidelines for sampling and sample preparation were defined.

Preparation of a quality assurance concept
To ensure the required quality criteria, a quality concept is currently under preparation, which takes into account the special demands of the application and utilisation of SRF.

Company quality assurance
There are internal quality assurance systems existing in some companies. Table 3.156 gives an overview about the system.

Process step	Measures	Supplementary measures
Origin (waste producer, sorting plant, mechanical biological processing)	Collection of wastes, avoidance of impurities, contractual arrangements about allowed qualities of wastes, declaration analysis, documentation of disposed amounts	Instruction courses for waste producers, periodic controls of the waste producing company by the disposer
Processing plant (delivery)	Regular sampling and analysis, reserve samples, documentation of input and processed amounts	Regular sampling and analysis of the outgoing materials by an external official expert
Processing plant (output)	Regular sampling and analysis, reserve samples, documentation of the delivered amounts	
Cement and lime kilns, power plants	Regular sampling and analysis, reserve samples, documentation of the input amounts	

Table 3.156: Quality assurance system of RWE Umwelt AG (Germany)
[126, Pretz, et al., 2003]

3.6 Emissions and consumptions from end-of-pipe treatments (abatement)

[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [116, Irish EPA, 2003]

This section covers the emissions arising from those processes/activities, commonly called end-of-pipe or abatement techniques, used in the waste sector for the treatment of waste gas, waste water and process produced solid waste before those streams are disposed of. The main objective of these processes is to reduce the concentration of pollutants in the output streams. The loads and concentrations of pollutants in these streams will be reduced by end-of-pipe and abatement processes, but some pollutants may remain in the streams and others may be generated. The actual techniques are not decribed in this section, since they are techniques to consider in the determination of BAT and, thus they are analysed in Chapter 4. Some of the descriptions given are only in shortened forms in this document since they are available in other BREF documents (e.g. waste gas and waste water BREF).

Emissions and consumptions of waste water treatments
Effluents from waste treatment installations typically contain organic chemicals (e.g. measured as TOC or COD), nitrogen, phosphorus, and chloride, since most wastes originally contain some organic materials, even if only in association with fuel/oil spills from vehicles at the site or from surface de-icing. Large quantities of COD, nitrogen, phosphorus and chlorine could affect the performance of the sewage treatment works.

The main emissions from waste water treatment systems will be carbon dioxide, methane and nitrous oxide to air, and TOC, nitrogen, phosphorus and chloride to water or sewer. The aqueous discharges are usually monitored, but emissions to the air are rarely monitored. There is generally some information on waste input that would allow large inputs of nitrogen rich wastes to be identified, and a minimum emission of nitrogen to the air to be calculated on a mass balance basis using the discharge data. If there is TOC/COD information at the waste IN, then a rough calculation of carbon dioxide emissions could be made.

In addition, there could be any number of additional emissions depending upon the waste IN, as indicated in Table 3.157 or depending on the waste water treatment plant step.

<table>
<tr><th>WWTP part</th><th colspan="3">Emissions</th></tr>
<tr><td>Reception</td><td colspan="3">It is important in liquid waste biotreatment systems that the flow of substrate is relatively constant, so reception pits or equalisation tanks are an important feature of the process. These are usually filled from road tankers or from a pipe to the source. There is potential for spillage and emissions to the air (potentially air stripping) when the waste is transferred or mixed by aeration units within these tanks. Volatile chemical constituents are the most likely to result in fugitive air emissions if any</td></tr>
<tr><td>Primary processes</td><td colspan="3">The initial stages of treatment usually provide for the removal of gross or fine solids. These may include coarse and/or fine screening, primary sedimentation or dissolved air flotation. The main potential sources of emissions are from transfer activities to and from these processes. Some components may preferentially concentrate in the solids, which are collected and stored after primary treatment. Flocculants or other additives may be used in clarification and can add additional species to the flow</td></tr>
<tr><td>Secondary processes</td><td colspan="3">Predominantly these include an aerobic stage where the effluent is aerated with oxygen or air (HRT 0.5 – 3 days) to convert soluble organics to micro-organisms (sludge) and final effluent. Emissions can occur from the vigorous activity in the aeration tank and may result in an air stripping of volatiles. It is usually assumed that if the waste is treatable in this way, the emissions are not hazardous since the process is biological. Although this is the usual case, it is not necessarily the case and in one (past) instance, a known carcinogen was released through air stripping in the aeration tank, while the performance of the plant remained unimpaired.
It is not easy to determine all the potential intermediate compounds that can occur as complex organics are broken down during the process, or their volatility under these circumstances.
After the aeration tank, the final effluent is invariably separated in another clarifier or sedimentation tank. Again, some organic constituents and metals can bioaccumulate in the sludge</td></tr>
<tr><td></td><td><i>Gaseous emissions to air *</i></td><td><i>Aqueous emissions to sewer or controlled waters</i></td><td><i>Sludge/compost for re-use or for onward disposal to landfill</i></td></tr>
<tr><td>Aerobic waste water systems</td><td>Carbon dioxide, odours (mainly due to organic compounds), microbes</td><td>TOC/N/P/Cl</td><td>TOC/N/P</td></tr>
<tr><td>Anaerobic waste water systems</td><td>Methane, carbon dioxide, microbes</td><td>TOC/N/P/Cl</td><td>TOC/N/P</td></tr>
<tr><td colspan="4">* The actual range of gases produced is much larger and is likely to include ammonia and carbon monoxide in all processes, but these are small compared with the main degradation products.</td></tr>
</table>

Table 3.157: Emissions from the different steps of a waste water treatment plant
[56, Babtie Group Ltd, 2002]

Table 3.158 gives some qualitative values of the emissions from waste water treatments and advises how these can be calculated.

	Emission to air	Emission to surface waters/sewer	Emissions to land and solid waste
Ammonia	Low. Where high ammonia wastes are accepted it may be possible to do a mass balance at some sites. Ammonia may be also generated in the removal of colloidal solids when using vacuum filtration		
Carbon dioxide (kg)	It may be possible to estimate the emission from $TOC_{output} – TOC_{input}$		
Methane	Low		
Nitrous oxide	Low		
Other species: metals and organics		It may be possible to estimate the intake from waste analysis and then to either undertake calculations based on analytical data from the outlet at the site, or the review the likelihood of discharges to air, water and sludge	
TOC			
COD			
BOD		10 – 20 mg/l (flow weighted monthly average), for any incoming load	
Total N			Nitrogen and phosphorus in the effluent will arise from the treatment of nitric acid, ammonia compounds, amines, etc. and phosphoric acid
Total P			
Chloride			
Fluoride		Fluoride is not a common part of the effluent, unless the site actively accepts wastes with this content	
Heavy metals			Where sources of mercury or cadmium cannot be eliminated or reduced by control at source, abatement will be required to control releases to water. In biological treatment 75 - 95 % of these metals will transfer to the sludge. Levels are unlikely to cause problems for the disposal of sludge but care will need to be taken to ensure that levels in the receiving water are acceptable

Table 3.158: Relevant emissions for waste water treatment
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003]

VOC emissions

Emissions from aerobic treatment can occur from the aeration tank as the aeration is vigorous and may result in the air stripping of volatiles. It is often assumed that if the waste is treatable in this way, the emissions are not hazardous since the process is biological. This is not necessarily true and in one (past) instance, a known carcinogen was released (through air stripping in the aeration tank) while the performance of the plant remained unaffected. It is not easy to determine all the potential intermediate compounds that can occur as complex organics are broken down in the process, or their volatility under different circumstances. It can be expected that feedstocks containing a known volatile organic contaminant would release air emissions at this point in the process. A similar scenario would occur for feedstocks with excess nitrogen.

Emissions of ammonia to the air

Ammonia is often generated by air stripping systems in waste water treatment plants treating high nitrogen wastes such as landfill leachate.

Sludge

After the aeration tank, the final effluent is invariably separated in another clarifier or sedimentation tank. Once again, some organic constituents can bioaccumulate in the sludge.

3.7 Monitoring

[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [122, Eucopro, 2003], [150, TWG, 2004]

This section gives an outline of the monitoring and reporting practices found in the waste treatment sector. This section aims to cover practices already in use in Europe in order to provide better guidance to the permitting authorities on the selection of the appropriate monitoring methodologies, the frequency of monitoring, compliance assessment criteria and appropriate environmental monitoring. However, this section does not select any specific type of measurement methology, frequency or evaluation procedures or discuss specific compliance assessment criteria. Some guidance information on these issues may be found in the Monitoring reference document (see back of the front page).

The compounds or parameters monitored and the frequency of monitoring are very variable in the waste treatment sector. They depend on the type of waste processed, as well as on the type of processes/activities carried out. Monitoring should be adapted to the type of emissions (e.g. batch release or continuous release) and on the type of treatment (e.g. whether there is likely to be NO_x emissions). Table 3.159 and Table 3.160 indicate some monitoring practices applied in some EU countries.

Compound or parameter to monitor	**Purpose and/or typical monitoring frequency**
Process variables	
Efficiency of the treatment process as a whole. The precipitation of metals from solution for removal in the filter cake. The degree of transfer between the incoming waste and the emissions (to air, solid waste to land and liquid effluent to sewer of, for example, pesticides or solvents)	Continuous
Reaction monitoring (acid/alkali neutralisation) to ensure that the reaction is under control and proceeding towards the anticipated result	Continuous and automatic monitoring of pH and temperature
Cyanide treatment. pH to be maintained at >10	Continuous pH; continuous free chlorine and continuous CN content
Treatment of phenolic solutions. Reaction monitoring	Process temperature, pH and redox potential continually monitored
Waste oil reprocessing. Temperature in heating vessels and condenser outlets at <90 °C	Continuous and recorded
Stabilisation	To ensure product (from each batch) meets declared specification
Fresh water use across the installation and at individual points of use	Normally continuous and recorded
Energy consumption across the installation and at individual points of use	Normally continuous and recorded
Air emissions	
Point source emissions, e.g. scrubbers from reactors, mixing vessels, storage vessels, drum crushers, vents from extraction systems, biofilters, e.g. total carbon and speciated VOCs	Daily to weekly – under a representative range of operating conditions
Waste oil reprocessing – heating vessels, warm oil receiving tanks and filtration plant	Weekly – under a representative range of operating conditions
Oil process tanks and condenser outlets	Continuous temperature
Combustion emissions	Quarterly, or less frequent stack testing for CO, NO_x, and possibly SO_x, particulates depending upon process
Fugitive emissions: boundary fence monitoring to detect releases from, for example, drum storage areas, total carbon and speciated VOCs	Weekly – under a representative range of operating conditions
Odour	Daily as well as dynamic dilution olfactometry at appropriate intervals

Compound or parameter to monitor	Purpose and/or typical monitoring frequency
Noise	Usually only if required by regulator or if there is a potential for community nuisance. Normally takes the form of a one-off survey by external consultants
Dichloromethane	Most sites that are expected to receive cleaning solvents are required to monitor this compound
Water emissions	
AOX	
BTEX	
COD/BOD	Flow weighted sample or composite samples, weekly analysis, reported as flow weighted monthly averages
Dissolved oxygen	Continuous
Flowrate	Continuous and integrated daily flowrate. Flow proportional samplers are commonly used to take composite samples. These may be supplemented as well by spot samples on bulk tanks ready for discharge
Metals	Daily, twice a week, weekly or monthly depending upon process. In some countries, this depends on the effluent rate (e.g. <10 m^3/day, <100 m^3/day, >100 m^3/dday)
Nitrogen	Daily, twice a week, weekly or monthly depending upon process. In some countries this depends on the effluent rate (e.g. <10 m^3/d, <100 m^3/d, >100 m^3/d)
Odour	
PAHs	
pH	Continuous
Phenols	
Phosphorus	Daily, 2 times per week, weekly or monthly depending upon process. In some countries this depends on the effluent rate (e.g. <10 m^3/d, <100 m^3/d, >100 m^3/d)
Suspended solids	Continuous
Temperature	Continuous
TOC	Continuous. This parameter is typically easier to control than COD or BOD when there is chlorine in the water release
Turbidity	Continuous
Waste emissions	
Amount	These data are reported at least annually to the authorities

Table 3.159: Monitoring practices applied to waste treatment plants in the EU
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [122, Eucopro, 2003], [150, TWG, 2004]

Waste treatment sector	Monitoring practices
Chemical plants	Sites that have extensive abatement systems are unlikely to undertake regular monitoring of the exhaust gases. A typical monitoring programme is a quarterly stack analysis, however this is highly unlikely to coincide with any peaks in the discharge rate of particular species
Transfer stations, bulking processes and storage	Simple formulae are available to assess the discharge of VOCs through the filling of storage tanks, decanting liquids into bulk containers, venting of liquids from containers, and washing of tanks, drums or tankers. Essential data will depend on the activity concerned, but will generally consist of information such as numbers of tankers/drums/containers, their size and the composition of the waste stream. As waste generally originates from a number of different sources and is usually mixed, data pertaining to composition of the waste stream are likely to be difficult for operators to accurately determine and detailed records are not routinely kept. Without these data, emission calculations will need to be based on the primary constituent of the waste or on the waste source. There are four types of techniques for emission estimation: sampling or direct measurement; mass balance; fuel analysis or other engineering calculations; or by emission factors (see the Monitoring BREF)
Oil treatment plant	A draft computer model has been developed in the UK to calculate emissions from basic information about intake tonnage and the quantity and oil content of discharges to sewer and landfill. The model requires adjustment to give answers that are compatible with the specification for residual fuel oils used in power stations and the known content of residuals in sewer discharges and sludges to landfill. The computer model does not provide an estimation for total nitrogen, phosphorus, chloride or COD to sewer and these will have to be calculated from monitoring data where this is available
Waste oils processing	Discharges to the air are more complex to calculate only having the knowledge from input, as releases are less defined and the behaviour of oils undergoing different processes is not clear
Waste solvent	Rigorous daily sampling regimes at tank vents and biofilters (where applicable) for TOC. Also an analysis of chemical compounds every fortnight at a series of process and fenceline monitoring points.

Table 3.160: Monitoring practices for some waste treatment processes used in the EU [56, Babtie Group Ltd, 2002], [86, TWG, 2003]

Monitoring practices in physico-chemical treatment plants of waste waters

The monitoring issues with the physico-chemical treatment of waste waters cover:

- wastes containing phosphorus: not all sites are required to monitor regularly for total phosphorus so it may be easier to make an estimate of this emission from the intake of phosphoric acid
- occasional inorganic wastes: for example wastes containing arsenic. Again, it is easier to calculate the annual emission from occasional waste IN data than to extend the monitoring programme.

Emissions to the air are the least well monitored discharges from physico-chemical treatment plants.

The main discharges to the air could be based on monitoring, but fugitive emissions will need to be estimated, as will the possibility of organic contaminants.

Almost all Ph-c sites have a complex set of conditions relating to water discharge that regulate sampling and monitoring frequency, and which set both the maximum concentration allowed for different species in the effluent and a maximum daily, weekly or monthly quantity of different species. This requires flow proportional monitoring, or the monitoring of each batch before discharge of a set volume. Either system provides the data to calculate annual emissions for a number of main species. The problem in estimating emissions to water is restricted to those species that are known to exist, but for which there is no monitoring data, and to unexpected species that arrive with particular waste streams. Other inorganic species, such as arsenic, could probably be estimated from site intake data since treatments of wastes contaminated with those components are typically occasional activities.

Monitoring and sampling practices applied to the preparation of waste fuel from hazardous waste

More information on sampling is available in Section 2.1.1. Each type of waste needs a specific sampling protocol based on the physico-chemical properties of the waste [150, TWG, 2004].

Sampling of individual waste deliveries

Liquids (from tank trucks, i.e. solvents, waste oil)

Samples are taken with the 2.5 m sampling tube from each compartment of the truck or container (around 1 – 2 litres each). The sampling tube has to be rinsed with the liquid prior to sampling. The tube is inserted slowly down to the bottom of the tank with the valve end down. After closing the valve, the tube is lifted and the liquid is filled into an aluminium can.

Samples are combined and, after homogenisation (agitation), a volume of around 0.5 litre is transferred to a plastic bottle and sent to the laboratory for analysis. The tube must be cleaned after each set of samples to avoid contamination of the next sample.

The plastic bottle must be carefully labelled with sample identification, date, etc.

Bulked solids (e.g. from open containers)

6 – 8 samples of around 0.5 - 1 kg each are taken with the sampling shovel from different parts and levels of the container. The samples are combined, manually homogenised and split by quartering. The finished sample of around 1 kg (plastic bottle or bag) is adequately labelled and transferred to the lab.

The sampling shovel must be cleaned with a rag after each set of samples. The rags are disposed of in a separate waste bin.

Drums (200 litres)

Depending on the nature of the waste (liquid, pasty or solid), samples are taken with either the short sampling tube, the aluminium shovel or the spoon from each drum (around 0.125 litres each). One sample of around 1 litre per every eight drums is combined and homogenised. One finished sample of around 1 litre is blended and homogenised from several individual batches of eight drums and transferred to the lab. The remaining sample quantity is returned to a selected disposal drum.

Drums with liquid and pasty materials together in one shipment batch must be sampled separately. The prepared sample must be carefully labelled.

Cans (small volume)

A representative and random sampling of each load must be carried out. The sampling procedures correspond to the procedures applied in the sampling of drums.

Blended and homogenised samples of around 1 litre for each physical state (liquid, pasty, solid,) are transferred to the lab. Several spot samples should be kept for reference.

Due to the inherent problems in sampling heterogeneous wastes from a large number of small volume containers, it is recommended to add a secondary (automatic) sampling station prior to the pre-mixer of the blending installation.

Upon receipt in the laboratory, all samples are registered in a specific receiving log.

Storage of samples

Samples must be retained in carefully labelled and sealed bottles in a separate storage room close to the lab. The storage room must be equipped with adequate air ventilation, temperature/humidity control and an exhaust air filter system (active carbon) to the outside.

Duration of sample storage (if not otherwise specified in the operating permit):

- around 3 years for reference samples from the waste qualification tests
- around 3 months for daily delivery samples
- around 3 months for finished product or dispatch samples.

Parameters	Examples of analysis principles
Density	Weighing
Viscosity	Viscosimeter
Flashpoint	Open or closed cup
LHV	Calorimeters
Water content	Karl Fisher
pH	pH meters
Ash contents	Calcination at 900 – 975 °C
Chlorine	Calcination/titrimetry, ionic chromatography
Fluor	Calcination/potentiometry, ionic chromatography
Brome	Calcination/titrimetry, ionic chromatography
Iode	Calcination/titrimetry, ionic chromatography
Heavy metals	ICP, fluorescence X
PCB	GC/ECD
PCP	GC/ECD
Sulphur	ICP, fluorescence X, ionic chromatography, colorimetry
Alkalis	ICP, fluorescence X, atomic absorption
Compatibility test	Function of waste received

Table 3.161: Examples of parameters and analysis principles used in sampling
[122, Eucopro, 2003], [150, TWG, 2004]

One of the most important measures is environmental monitoring by collecting samples of the environmental media and testing for the presence of hazardous substances that may have been released by the facility. The objective is to detect potential problems before they impact on human health and the environment. Early detection should allow sufficient time for the adequate warning of potentially affected individuals and allow effective implementation of remedial measures. Important monitoring points are groundwater wells for storage, land disposal facilities, and air monitoring stations at critical locations around the facility. Monitoring could also include surface water, employees (e.g. blood samples), and flora and fauna.

Air emission monitoring

Dust monitoring (for all types of substituted fuel production)

- channelled emissions: one control per year carried out at a certified laboratory
- air treatment systems: follow up of the efficiency of the cyclone and bag filters by pressure drop or opacity measures
- diffuse emissions of dust can be assessed by measurements with an owen gauge located on the site.

VOC monitoring

- odour: standardised tests for odour detection (e.g. EN 13725, European Reference Odour mass, EROM) can be used to identify the influence of the process on neighbours and on the workers environment. Bag samples may also be made for qualification and quantification of the pollutants in a laboratory
- diffuse emissions: diffuse emissions are measured inside and outside workshops by taking samples. Quantitative and qualitative analyses can be carried out
- channelled measures: VOCs are measured either continuously by a FID system or according to spot measurements campaigns. These conditions are defined in the permit.

Noise monitoring

Due to the relatively low noise level, no specific monitoring is usually requested. But, measures can be carried out for workers health and safety and especially for environmental impact evaluation, notably when new equipment is commissioned.

4 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT

This chapter sets out techniques considered generally to have potential for achieving a high level of environmental protection in the industries within the scope of this document. Management systems, process-integrated techniques and end-of-pipe measures are included, but a certain amount of overlap exists between these three when seeking the optimum results.

Prevention, control, minimisation and recycling procedures are considered as well as the re-use of materials and energy.

Techniques may be presented singly or as combinations to achieve the objectives of IPPC. Annex IV to the Directive lists a number of general considerations to be taken into account when determining BAT and techniques within this chapter will address one or more of these considerations. As far as possible a standard structure is used to outline each technique, to enable comparison of techniques and an objective assessment against the definition of BAT given in the Directive.

The content of this chapter is not an exhaustive list of techniques and others may exist or be developed which may be equally valid within the framework of BAT.

Generally a standard structure is used to outline each technique, as shown in Table 4.1:

Name of the type of information	*Type of information included*
Description	Technical description of the technique
Achieved environmental benefits	Main environmental impact(s) to be addressed by the technique (process or abatement), including emission values (normally a range) achieved and efficiency performance. Environmental benefits of the technique in comparison with others
Cross-media effects	Any side-effects and disadvantages to other media caused by implementation. Environmental problems of the technique in comparison with others and how to prevent or solve them
Operational data	Performance data on emissions/wastes and consumption (raw materials, water and energy). Any other useful information on how to operate, maintain and control the technique, including safety aspects and operability constraints of the technique
Applicability	Techno-economic applicability. Consideration of plant age (new or existing), plant size (large or small) and factors involved in retrofitting (e.g. space availability). Also included is information on which waste treatment activity is applied in each case
Economics	Information on costs (investment and operation) and any savings (e.g. reduced raw material consumption, waste charges) related to the capacity of the technique (e.g. EUR/tonne). Values in currencies different to EUR have been converted according to 2002 annual average conversion factors for the EUR. In such cases, the original cost data along with the year and the currency have been also included (between brackets)
Driving force for implementation	Local conditions or requirements which have led to implementation of the technique. Information on the reasons other than environmental ones for implementation (e.g. improvement in product quality, increased yield)
Example plants	Reference to the plants operating the technique in Europe and in the rest of the world. If the technique has not yet been applied in the sector or in the EU, a brief explanation as to why
Reference literature	Literature source for more detailed information on the technique

Table 4.1: Information breakdown for each technique included in Chapter 4

When possible, this chapter provides information from real activities that can be, or are being, implemented by this sector, including the associated costs. Wherever possible, the information provided gives the context in which the technique can be used effectively.

Organisation of the chapter

As in previous Chapters 2 and 3, each section of this chapter deals with a specific waste treatment activity and contains the process and abatement techniques worth considering in the determination of BAT. If different process techniques may be applicable for one activity, they are discussed within each section. Sections in sections from 4.1 to 4.5 in this chapter have been structured in the same way, i.e. the section first addresses the pollution prevention techniques applicable in the specific process/activity section referred to, and secondly the end-of-pipe techniques that may be applicable to reduce the emissions coming from that process/activity. These end-of-pipe (EOP) techniques are grouped on a media/pollutant bases to clarify the sequence of techniques applicable as, in some cases, the number of EOP techniques that may be applicable is quite extensive. This structure should not be interpreted as any attempt to give guidance if a waste treatment is (R)ecovery or (D)isposal under the EC waste legislation.

At the end of this chapter, there are three sections which contain the end-of-pipe (EOP) techniques applicable to waste gas, waste water and process generated waste. These sections describe the ‘common’ EOP techniques that may be applicable to more than one type of process/activity. Consequently, the descriptions of those EOP techniques are found in their own sections, i.e. Sections 4.6, 4.7, and 4.8, and not in the separate activities/process sections.

In some cases, techniques/procedures are grouped together and analysed under the same heading in this chapter. This is the result of finding a right balance between the necessary information to determine BAT and keeping this document to a user-friendly size. For example, this document contains a lot of information on acceptance procedures applied to waste treatment installations. In this instance, it has been decided to include all these procedures together under the same technique heading and to then discuss all the related items/topics under that heading. If this approach was not applied, this document would be much bigger and much repetition could occur.

4.1 Common techniques to consider in the determination of BAT

This section contains techniques considered to have a good environmental operating performance (e.g. use of a good energy system) or that can help lead to a good environmental performance (e.g. environmental management systems). The majority of these techniques are applied at an installation level and are not specific to any of the particular processes described separately in Sections 4.2 to 4.5.

4.1.1 Techniques to improve knowledge of the waste IN

This section covers those techniques that help the operator to characterise the waste input to be treated. The rigour with which this characterisation is done is essential to the subsequent waste treatment operations. Failure to adequately screen waste samples prior to acceptance and to confirm its composition on arrival at the installation has often historically led to subsequent problems, including an inappropriate storage and mixing of incompatible substances, an accumulation of wastes and an unexpected treatment, and hence unexpected emission profiles.

4.1.1.1 Waste composition characterisation

Description

The varied nature of the waste industry and the large differences in waste generated by each economic sector dictates that most waste streams handled on a site for treatment will usually be varied. Waste consists of complex mixtures of sometimes unknown constituents. For this reason, it is important to have an improved knowledge of the primary constituent(s) as well as the source of the waste. Besides the direct way of determining waste composition, e.g. by analysing the waste, there are other indirect approaches that can be taken, including:

- analysing market research data. This technique focuses on the goods after production; on the basis that all goods result in waste sooner or later and by considering certain influencing facts, and by utilising market research it is possible to calculate the amount of goods that end up as MSW, for example. A similar method can be applied by looking at the input into private households
- analysing waste treatment outputs. According to the balance principle, elemental input equals elemental output. By focusing on the products of waste treatments, it should thus be possible to determine the input waste composition in terms of substances by carrying out routine measurements
- in addition it is worth noting that there are, of course, some wastes that are composed of a mix of wastes mixed at the source where they originate. Usually, the waste producer will know the composition of this waste stream. If the waste producer adopts a good waste management system, he will inform the waste collector of the waste composition. This is important as the classification and identification of the waste should not be first given to the waste collector, but should primarily be the responsibility of the waste producer. This system is related with the one mentioned in Section 4.1.2.9.

Indirect analysis methods for determining the waste composition can supplement the direct analysis method. Some techniques to particularly consider are noted in Table 4.2 below:

Technique	Information
Identify the primary constituent(s)	Where the main constituents of the waste stream are known, it is possible to categorise it as having a ‘high’, ‘medium’ or ‘low’ emission potential. An example of this could be to base the assessment on the volatility of the constituent elements as notified by the waste producer
Identify the waste source	Knowledge of the waste source (e.g. paint industry, pharmaceutical, automotive, etc.) provides a good guide to the type of components that may be present in the waste. This will allow adoption of a simpler method to categorise the waste. EWL uses this system. However, available data are usually insufficient to allow this method to be developed at present. It would be necessary to undertake further research to establish the most common sources of waste streams; their compositions; and the consistency of that composition
Knowledge of the organic content of the waste	Some colorimetric methods, for example, may provide an indication of the organic content of incoming wastes. However, these may not be suitable for organic solvents (in such cases, gas chromatography is more adequate)
Ensure adequate transfer of knowledge between holders of the waste	As with other waste streams, a crucial control measure is to ensure an adequate transfer of knowledge between holders of the waste. This should ensure that the constituents of all wastes bulked together to form a blend are known and recorded

Table 4.2: Waste composition characterisation techniques
[56, Babtie Group Ltd, 2002], [86, TWG, 2003], [150, TWG, 2004]

The type of analysis required to accurately characterise the waste will vary depending upon the nature of the waste, the process to be used and what is known about the waste already. The results of all analyses need to be kept within the tracking system. These details can include information on:

- checks carried out on the constituents declared by the waste producer/holder to ensure permit compliance, and that it is suitable for the treatment plant specification and final disposal option. This check will also cover checks on the presence of any constituents that may be potentially damaging to the treatment process
- all hazardous characteristics (e.g. flammability, explosivity, infectivity)
- physical appearance (e.g. consistency)
- compatibility assessment (e.g. reactions with water and other substances)
- colour
- acidity or alkalinity
- presence, strength and description of odour assessment
- presence of oxidants
- TOC
- COD
- ammonia
- flashpoint and combustion properties under normal conditions
- presence of sulphide(s)
- presence of cyanide(s)
- compounds containing halogen
- sulphur
- metals (e.g. heavy metals)
- VOCs
- POPs (e.g. PCBs).

A list of the parameters which may be analysed for the production of fuel from hazardous wastes is shown in Table 4.3.

Parameters	Pre-acceptance	Acceptance	Waste fuel preparation process[1]	Dispatch
Density	Yes	Optional	Optional	Optional
Viscosity	Optional	Optional	Optional	Optional
Flashpoint	Yes	Yes	Optional	Yes
LHV	Yes	Yes	Yes	Yes
Vapour pressure	Optional	Optional	Optional	Optional
Water content	Yes	Yes	Optional	Yes
pH	Yes	Yes	Optional	Yes
Ash contents	Yes	Optional	Optional	Yes
Ash composition	Optional	Optional	Optional	Optional
Chlorine	Yes	Yes	Yes	Yes
Fluorine	Optional	Optional	Optional	Optional
Bromine	Optional	Optional	Optional	Optional
Iodine	Optional	Optional	Optional	Optional
Heavy metals				
• volatile (Cd, Hg, Tl)	Yes	Yes	Optional	Yes
• others	Yes	Yes	Optional	Yes
PCB	Yes	Yes	Optional	Yes
Pentachlorophenol (PCP)	Optional	Optional	Optional	Optional
Sulphur	Yes	Optional	Optional	Optional
Alkalis	Optional	Optional	Optional	Optional
Corrosion test	Optional	Optional	Optional	Optional
Compatibility test	Yes	Yes	-	-
Radioactivity	Optional	Yes	-	Optional
Notes: [1] depends on the type of production Optional depends on the type of wastes, operating processes (liquid or solid substituted fuel preparation) and according to the requirements / specifications of the final users. *In italics* minimum controls required in standard procedure				

Table 4.3: List of analysis parameters typically considered in the production of fuel from hazardous waste
[122, Eucopro, 2003]

Typically a good acceptance criterion includes the knowledge of the following parameters for waste oils.

Parameter	Acceptance	Dispatch
Water content	Yes	
Solid content	Yes	
Flashpoint	Yes	
Distillation curve	Yes	
PCB	Yes	
Total Cl	Yes	
S	Yes	
Pb, Cr, V, Cu, Ni	Yes	
Synthetic esters and fatty oils	Yes	
Colour		Yes
Viscosity		Yes
Viscosity index		Yes

Table 4.4: List of analysis parameters typically considered in the treatment of waste oils
[42, UK, 1995], [55, UK EA, 2001], [119, Watco, 2002]

Achieved environmental benefits

It improves the knowledge of the potential environmental issues related with the waste to be treated and reduces the risk of accidents or bad operations.

Cross-media effects

Not identified.

Operational data

Sites undertake screening tests to confirm that the waste is within plant parameters, but usually these cannot identify all the potential contaminants in the waste stream. Therefore, characterisation by waste producers and WT operators is part of a general requirement for all sites, and provides guidance on effective screening methods. For example, a full set of analysis for waste oils takes around 2 hours.

Applicability

This technique is fully applicable for all waste treatment facilities receiving waste. The disadvantage of the waste product analysis is the fact that full determination of the constituent materials is generally not accomplished, e.g. it is not possible to calculate the contents of paper, plastic or organic substances from the composition of the products of combustion. This method is limited to the analysis of elemental composition and parameters such as energy content, water content and the content of inorganic and organic matter.

Economics

An estimation shows that the investment in analytical equipment for a waste oil treatment facility is in the order of EUR 75000 (GBP 50000) per site.

Driving force for implementation

Better operability reduces process and economic risks. The water and solid content is analysed in waste oils because of quality and payment purposes. This has been encouraged in part by the quality requirements of the users of the treated oil, but this is not always a uniform requirement.

Example plants

The analysis of waste treatment products has already been applied in many countries. In some cases there is a first initial analysis (e.g. sulphur, total chlorine, water and flashpoint for waste oil treatments). If the oil passes these tests, it is quarantined before further analyses are performed. These include viscometry and infrared analysis to check for certain compounds including synthetic esters and fatty oils. Within the work carried out by CEN/TC 343, WG 2 ‘Specifications and classes’ some extra information can be found for solid recovered fuels (SRF). Also more specific information for waste fuels can be found in Section 4.5.1 of this document.

Reference literature

[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [81, VDI and Dechema, 2002], [86, TWG, 2003], [119, Watco, 2002], [131, UBA, 2003], [122, Eucopro, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.1.1.2 Pre-acceptance procedure to assess if waste is suitable to be stored or/and treated in the installation

Description

Systems and procedures can be put in place to ensure that wastes are subject to the appropriate technical appraisal to ensure the suitability of the proposed treatment route. Some pre-acceptance techniques and procedures applied to assess wastes are:

a. carrying out suitable checks before any decision is made to accept the waste
b. having an initial screening step, involving the provision of information and representative samples of the waste. The waste producers and operator at the receiving site will both ensure that reliable and comprehensive information has been provided to determine the suitability of the waste for the treatment (or recovery) process in question. This also applies if wastes are only to be stored or bulked at the installation, so that the information can be provided to the next holder of the waste and the ultimate disposal route identified
c. providing details on the nature of the process(es) producing the waste, including the variability of the process. As the circumstances of waste production may vary, sound professional judgement is required to ensure that the relevant questions are asked. Operators need to ensure that a technical appraisal is carried out by suitably qualified and experienced staff who understand the capabilities of the site. These staff ought to be independent of the sales staff responsible for obtaining the customer’s business
d. providing the chemical composition of the waste, its handling requirements and its hazards
e. providing and analysing a representative sample(s) of the waste from the production process producing such waste from the current holder
f. undertaking a comprehensive characterisation of the waste for each new waste enquiry
g. requiring a verification of the written information provided by the waste holder. This may require a visit to the waste producer, as additional factors may become apparent when dealing directly with staff involved in the waste production
h. carefully verifying the information received at the pre-acceptance stage, including the contact details for the waste producer and a full description of the waste regarding its composition and hazardousness. This can also be carried out by dealing directly with the waste producer
i. maintaining all records at the installation relating to the pre-acceptance for cross-referencing and verification at the waste acceptance stage. The length of time that the records need to be held needs to be determined, taking into account whether the waste is actually delivered to the site or when it is likely to be delivered
j. applying odour criteria to reject mercaptans, low molecular weight amines, acrylates or other similarly highly odorous materials that are only suitable for acceptance under special handling requirements
k. providing and checking details of the waste code according to the European Waste List (EWL)
l. making inquiries to the operator of the WT plant about whether the WT installation in question is permitted to treat the declared waste and whether the WT operator is prepared to accept the waste. (see comments in the operational data section)
m. carrying out a procedure for risk assessment
n. issuing an acceptance declaration by the WT operator which describes all necessary conditions and measures to be taken into account by the waste customer (e.g. waste producer). Also all internal rules within the receiving plant to treat the waste stream should be laid down in written form at the same time.

Achieved environmental benefits

These techniques can help operators identify and then not accept unsuitable wastes which could lead to adverse reactions or uncontrolled emissions during the WT activity. They will thus ensure that only waste suitable for the specific WT activity is accepted into the site for that WT.

Actual experience of these techniques has shown that reliance cannot be placed solely upon these techniques to always provide sufficient information. It is not unusual for the waste producer and the operator to be separated by a third party and in some cases even three or four different parties. These may be haulage contractors, brokers, or waste transfer operators. Where there is a lengthy chain, information may be lost or inaccurately reproduced. These techniques however can allow operators to determine the suitability of the waste for the activity before arrangements are in place to accept the waste. Other benefits include:

- the provision of information keeps the number of links in a chain down. This helps avoid information loss or misrepresentation
- helping operators to screen out unsuitable wastes to prevent potential problems
- confirming the composition details, allowing identification of a number of verification parameters to test the waste arriving at the site
- helping to identify any substances within the waste which may affect the treatment process or which may react with other reagents
- helping to accurately define any hazards related to the waste
- identifying any substances within the waste which might be unaffected by the treatment process and which could, therefore, be transferred in an unaltered state to the residues or effluent
- helping to determine the cost of the disposal option identified
- ensuring regulatory compliance (depending on the country).

Cross-media effects
These are related with the specific physico-chemical analysis performed.

Related with technique k (see description above), waste codes do not give much information in many cases about the composition of the waste classified. Wastes with the same waste code may have totally different compositions and qualities.

Operational data
Includes administrative and laboratory work.

Related to technique c (see description above), there are cases where the composition of the waste cannot be known (i.e. collection of hazardous waste from households). In these cases, the operators collecting and accepting such waste need to have the necessary experience to handle it safely.

Related to technique k (see description above), it is the duty of the waste producer to decide on the appropriate waste code of the EWL. This is not a task for the WT operator.

In some cases, the verification referred in technique l of the description above may take place before the first contact with the WT operator for the pre-acceptance procedure and/or before signing the agreement.

Applicability
The requirement to characterise the waste, including sampling and analysis, equally applies to waste transfer as well as treatment facilities. There is often a reluctance amongst third parties to divulge the identity of the waste producer as this may be of commercial benefit. This however cannot override the fundamental requirement on the operator to check the information on the waste provided by the waste producer (not just the current holder), who is naturally in the best position to verify the waste. Some application examples are shown below:

Pre-acceptance for waste oil treatment

As a general requirement, this step is not critical for a waste oils treatment plant, but it would be required if the waste is destined for treatment at a mineral oil refinery for example. Typically the waste comes from a large number of small volume sources, such as garages, but its composition is essentially fixed. Pre-acceptance procedures relating to information collection need to be applied for one-off industrial arisings of waste oil and arisings from sources where other chemicals and potential contaminants may be handled, for example, from chemical manufacturing. Contamination of waste oil by substances such as solvents does occur and although relatively low levels of contamination can be accommodated by the operator, in so far that it may not affect the sale of the recovered oil, the contamination still needs to be identified. Low flashpoint solvents will give rise to handling difficulties as the installations are not set up for dealing with flammable materials. Petrol contamination often occurs, this significantly reduces the flashpoint of the material and will thus significantly increase the risk of accidents. Care should be taken in choosing and interpreting the most appropriate flashpoint determination. Solvents will also be driven off in the heating process, therefore increasing VOC emissions. Contamination with PCBs can transfer those PCBs to either the product, which may give rise to dioxin formation if used in a subsequent combustion, to the tank bottoms oil sludges or to the effluent.

Pre-acceptance of ‘Laboratory smalls’

If drums are used for laboratory smalls, a list of the contents is created and stored within the drum below the lid. Similarly for other types of packages containing laboratory smalls, a list of contents is created and appropriately stored within or attached to the packaging. Each packed drum (or other package) is then labelled with respect to the hazard for carriage (e.g. ADR regulations). The level of supervision or management of this type of situation depends on a number of factors. In any case a full list of the contents needs to be produced. For operators who accept wastes packaged by their customers, packing guidance is typically provided to the customer. Waste producers need written procedures regarding the segregation, packaging and labelling of laboratory smalls.

Scoping study for physico-chemical plants

Sites need to undertake a scoping study to identify materials that are not covered by their effluent monitoring programme but are accepted at the site. The main areas to consider are:

- aqueous wastes containing solvents that may then be emitted due to the heat of the process
- high nitrogen wastes with a potential for ammonia emissions to the air
- wastes containing phosphorus: not all sites are required to monitor regularly for ‘total phosphorus’ so at these sites it may be easier to estimate this emission from the intake of phosphoric acid
- occasional inorganic wastes, e.g. wastes containing arsenic. Again, in most cases it will be easier to calculate the annual emission from occasional waste IN data rather than to extend the monitoring programme.

Economics

Extra administration costs (e.g. packaging, labelling).

Driving force for implementation

Typically these procedures are included in the national legislation of various countries, in guidance notes or in the operating permits of the plants. The chemical components and parameters which have to be analysed are also often defined.

Taking samples of heterogeneous wastes is especially difficult and needs experienced operators. The work of CEN TC 292 or the German LAGA papers on waste samples may give some guidance.

Example plants

Many of these techniques are commonly used in the WT sector. For example, the merchant UK physico-chemical sites require all customers to provide a good waste description and a sample for analysis prior to acceptance at the site. The sites need to know the waste composition in order to be able to create a suitable end-product at the site that can meet sewer discharge standards and produce a cake suitable for landfill.

Reference literature

[16, ÖWAV Working Commitee, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [131, UBA, 2003], [150, TWG, 2004], [153, TWG, 2005]

4.1.1.3 Acceptance procedures when the waste arrives at the WT installation

Description

On-site verification and compliance testing needs to take place to confirm: 1) the identity of the waste, 2) the description of the waste, and 3) the consistency with the pre-acceptance information and proposed treatment method. Some acceptance techniques and procedures (after the pre-acceptance) applied to assess waste are given in the lists below, these include:

a. not accepting wastes at the installation unless a clearly defined treatment method and disposal/recovery route is determined, together with there being sufficient capacity available at the installation before the waste is accepted. Other than pure product chemicals and laboratory smalls, no wastes should be accepted at the installation without sampling, checking and testing being carried out. Reliance solely on the written information supplied is not acceptable and physical verification and analytical confirmation is required
b. implementing of sampling procedures (see Section 4.1.1.4)
c. for waste treatment or transfer, carrying out the bulk of the characterisation work at the pre-acceptance stage. This ensures that the acceptance procedures carried out when the waste arrives at the site can serve to confirm the characteristics of the waste
d. putting in place measures to fully document and deal with acceptable wastes arriving at the site, such as a pre-booking system, to ensure, e.g. that sufficient capacity is available
e. enforcing requirements that the waste is accompanied by information describing the physical and chemical composition, hazard characteristics, the presence of incompatible substances and any handling precautions. Hazardous wastes also need to be accompanied by consignment notes and this information should specify the original waste producer
f. having clear and unambiguous criteria for the rejection of wastes and reporting all non-conformances
g. utilising a laboratory with suitably accredited test methods to carry out the analyses
h. checking the details of the waste code according to the European Waste List (EWL)
i. using a risk assessment procedure to select and, if necessary, to perform analysis of the waste. An example is shown in the Example plants section.

Other issues which may be addressed by the acceptance procedure concern:

- vehicle waiting, load inspection, sampling and off-loading areas
- traffic control
- procedures for checking paperwork arriving with the load
- procedures for unloading to allow inspection and sampling
- location of designated sampling point(s)
- visual / organoleptic load inspection (for some liquid and hazardous waste loads, this may not be applicable)
- drum and package labelling procedures
- infrastructure, such as bunds and sampling areas
- assessing consistency with pre-acceptance information and the proposed treatment method
- sample retention systems, that is with regard to determining the appropriate period of retention
- record keeping in relation to waste producer details, analysis results and treatment methods
- procedures for periodic reviews of pre-acceptance information
- dispatch conditions.

Achieved environmental benefits
This second acceptance stage, includes procedures for when the waste arrives at the site, and serves to confirm the characteristics of the pre-accepted waste, without the time pressure and potential hazard of checking a waste from scratch at the gate. These techniques prevent unsuitable wastes being accepted, which could otherwise lead to adverse reactions or uncontrolled emissions, and these techniques therefore ensure that the accepted waste is suitable for the WT activity. Moreover, this minimises the time the vehicle delivering the waste is kept waiting preventing problems due to, e.g. accidents, leaks. This procedure also prevents waste being rejected and being sent back out onto the public highway.

Cross-media effects
Equal to pre-acceptance procedures.

Operational data
Equal to pre-acceptance procedures. In some cases, it may be difficult to perform a proper sampling (e.g. drums with used and contaminated clothes or gloves).

Applicability
Some examples of industrial applicability are described below:

Waste oil treatment plants
Typically these plants place a greater emphasis on the final acceptance procedures than those at the pre-acceptance stage.

Acceptance of laboratory smalls
The procedures for accepting laboratory smalls into a site are essentially identical to those for drummed wastes. They differ from the ‘normal’ waste inputs to the site, in that they are in a pure concentrated form. In situations where the operator has undertaken the identification and packaging on behalf of the customer, the on-site verification can be restricted to opening the drums to check that the containers are undamaged. In such cases, the load is accompanied by documentation confirming the checking and packing. In situations where the drum has been packed by the customer, full checking and verification need to be adequately undertaken by the operator. Checking the packaging and segregation needs to include emptying the drum as soon as possible (for example, within a matter of days), and repackaging the waste once all the necessary checks have been made. If, on opening a drum, it is found that it contains incompatible substances, or that the substances have not been packaged adequately, then the drum needs to be sorted and repacked immediately, and the site non-conformance procedures followed.

Physico-chemical treatment sites

These sites check the waste on arrival by visual inspection and by sampling. The sampling system varies in the breadth of analysis and in the frequency of sampling. There may be a simple screen for flashpoint and pH or a sample taken for rapid laboratory determination of these elements and the metals content and also a rough organic screening. The frequency of sampling is partly determined by the source of the waste: most sites focus their sampling and analysis on one-off fluctuating streams and reduce the sampling frequency for process streams that are regularly accepted.

	Percentage of plants where this practice occurs (%)
Site enclosed or on a fully impermeable base	77
Return of rainwater (except of administration, buildings, roofs) and tanker washings to plant	77
Sampling of larger waste streams, or a fixed proportion	62
Input tonnage weighed	54
Partial scrubber systems	38
Full scrubber systems	15
Sampling of all wastes	8
Note: Data correspond to 13 different physico-chemical treatment sites that were analysed.	

Table 4.5: Control procedures identified at physico-chemical treatment plants
[56, Babtie Group Ltd, 2002], [86, TWG, 2003]

Physico-chemical plants test a proportion of the incoming waste streams, although they always test new waste streams, and need to know a reasonable amount about the intake waste in order to operate their process effectively. Sites require samples of the waste to carry out a preliminary screening prior to acceptance of any waste on site and, furthermore, they undertake checking routines when the waste actually arrives.

Waste catalyst

Materials are checked for unforeseen impurities and contamination and this can be cost effective in maintaining a cleaner product and reducing emissions.

Waste activated carbon

Activated carbon received for regeneration needs be identified as a discrete batch and analysed, so that the substances to be desorbed during the treatment are known and it can be confirmed that the plant has the capability to process them within the constraints of the authorisation. The applicant should set out clearly the types of contaminant on the activated carbon that it is intended to be regenerated.

Economics

Waste characterisation and analysis costs for protecting the works are typically high. It may cost up to EUR 3000 (GBP 2000) per analysis for a rig test mimicking the effect of a waste on the waste water treatment works.

Driving force for implementation

Such analyses are commonly regulated by national legislation and permits. Hazardous waste legislation, for example, ensure that storage, handling, classification, packaging and labelling of waste is carried out correctly.

Example plants

Applied across the whole WT sector. An example for using a risk assessment procedure to select and, if is necessary, to perform analysis of the waste may be 1st case: wastes with high risk classification are always analysed at delivery; 2nd case: wastes with a low risk classification are occasionally tested on conformity with the data of the pre-acceptance phase.

Reference literature

[29, UK Environment Agency, 1996], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [116, Irish EPA, 2003], [125, Ruiz, 2002], [131, UBA, 2003], [150, TWG, 2004], [152, TWG, 2004], [153, TWG, 2005]

4.1.1.4 Sampling

Description

Sampling is typically based on a risk approach considering the hazardousness of the waste as well as the knowledge of the previous waste holder. A good sampling procedure considers the following issues:

a. the physical state of the waste (homogeneity/heterogeneity)
b. the number of samples and sample sizes for waste materials not delivered in containers
c. the number of samples and sample sizes for waste materials delivered in containers
d. sampling procedures for all incoming wastes including bulk (liquids and solid) wastes and wastes in drums and containers, and laboratory smalls. The number of samples taken increases with the number of containers. In extreme situations, small containers must all be checked against the accompanying paperwork. The procedure should include a system for recording the number of samples and degree of consolidation
e. having a system to ensure that the waste samples are analysed
f. details of the sampling of wastes in drums within designated storage, e.g. the time-scale after receipt
g. verification and compliance testing to confirm the identity and description of the waste
h. maintenance at the installation of a record of the sampling regime for each load, together with the justification for the selection of each option
i. sampling tankered wastes prior to acceptance. This way there is no storage pending sampling
j. retaining samples on-site for a certain period of time (e.g. 0.5 – 2 months) after the waste has been treated or removed off site, including all the residues from its treatment
k. externally taken samples or analysis reports, i.e. the driver of the vehicle carrying the waste may arrive at the installation with a sample or with an analysis that has been taken at some stage beforehand. This is typically an exception and is only considered if:
    - there are health and safety and environmental control considerations, for example, water reactive substances which would make sampling difficult
    - the following written information has been supplied: the physical and chemical composition, hazard characteristics, the presence of incompatible substances and any handling precautions, and information specifying the original waste producer and process
    - the waste has been taken directly from the production site to the waste treatment installation
    - the sampling staff can provide proof of adequate qualifications and/or training.

For the sampling of bulk liquid wastes, some specific issues to note are:

l. deliveries in bulk road tanker may be accompanied by a 'wash-out' certificate or a declaration of the previous load so that contamination by this route can be checked
m. samples are usually taken from one of three points on the tanker:
    - top hatch
    - back valve
    - sight glass

n. the key requirement is to obtain a sample that is representative of the load, that is, the sample needs to take account of the full variation and any partitioning within a bulk load so that 'worst case' scenarios are accounted for. Taking a sample through a top hatch of the surface of the liquid may not be representative, but may be useful in establishing whether there may be a layer of, for example, solvent or some other immiscible substance, which may be unsuitable for treatment. Top samples need to be obtained from the cross-section of the load, that is, a core sample should be taken
o. gantries can be constructed to avoid the need for taking samples from the back valve of tankers, which would likely result in small spillages.

For sampling drummed waste (depending on the type of packaging), some specific issues to note are:

p. the contents can only be identified with certainty if every container is sampled. Acceptance therefore involves sampling every container, however, the analysis of composite samples is usually acceptable with such a sampling regime. This way a representative sample is obtained by taking a core sample from the base of the container
q. ensuring that lids, bungs and valves are replaced immediately after sampling
r. visual controls for every container and the sampling procedure need to be defined under the supervision of the operator
s. utilising the opening, visual control and adapted sampling of all drums above a certain capacity, for example of more than 200 litres
t. sampling packaged wastes in closed areas kept in depression or inside dedicated chambers with extractor hoods in case that waste contains fugitive materials.

For example, for digestion of sludges, sampling is carried out to ensure batches are neither toxic nor inhibitory to digestion. In addition, generally for all types of waste sampling, the sampling procedure should ensure that adequate sampling and analysis is carried out to characterise the waste. The number of samples taken is based on an assessment of the risks of potential problems. Sampling regimes at the pre-acceptance stage do not necessarily have to include sampling of every drum, for example, 'the square root of (n+1)' rule may be applied provided acceptance screening includes the sampling of every container. In some instances, physical sampling may not be necessary, for example in the case of gas cylinders or scrap batteries. In other cases such as for drummed wastes, large numbers of samples will be necessary as characterisation requires the sampling of all containers. The sampling of process wastes must take account of the variability of the process, and several samples may be required to sufficiently characterise the waste. The waste producer can ensure that the sample is representative of the waste, reliable and obtained by a person with a technical appreciation of the sampling process by including the following information:

- location of the sampling point, e.g. the effluent tank
- capacity of vessel sampled (for samples from drums, an additional parameter would be the total number of drums)
- method of sampling, e.g. sampling tap (mid flow), 'top' sample
- number of samples and degree of consolidation
- operating conditions at the time of sampling, e.g. normal operation, shutdown, maintenance and/or cleaning.

In addition, the waste producer can ensure the sample is representative by:

- clearly labelling samples and any hazard identified
- including systems to allow sample tracking and auditability within the installation.

Achieved environmental benefits
Sampling is a key issue in building up a good knowledge of the waste to be treated, and therefore in preventing problems during the treatment. Some techniques also prevent fugitive emissions (e.g. causing odour) during sampling.

Operational data
Specific laboratory equipment is necessary to practice sampling.

Applicability
Some sort of sampling is applicable to all types of waste.

Driving force for implementation
A series of drafts focused on European sampling standards are available, e.g. 'sampling of liquid and granular waste materials including paste-like materials' prepared by the Technical Committee CEN/TC 292 - Characterisation of waste. The CEN/TC 343 has also prepared a technical specification on the sampling of solid recovered fuels.

Other internationally consolidated standards are, for example, ISO 10381 (soil sampling) and ISO 5667 (waste water, sludge and sediments sampling). These standards include technical specifications for sample handling and preservation.

Example plants
All waste plants do some kind of sampling.

Reference literature
[16, ÖWAV Working Commitee, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [116, Irish EPA, 2003], [122, Eucopro, 2003], [131, UBA, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.1.1.5 Reception facilities

Description
There is usually a reception area for incoming waste where visual checks are made against the special waste consignment note and where some further sampling is undertaken before the waste is allocated. Sites tend to sample specific waste streams. Some good environmental practices applied to reception facilities are:

a. to have an accredited laboratory on site to analyse the waste samples for pre-acceptance and acceptance. This may be accomplished by ensuring that the laboratory carrying out the analysis has a roboust quality assurance system, quality control methods and suitable record keeping of the analysis
b. to equip laboratories with the control equipment and devices necessary for quality assurance. Self-regulation is commonly not officially recognised
c. to have a dedicated quarantine waste storage area, so that if the inspection or analysis indicates that the wastes fail to meet the acceptance criteria (including, e.g. damaged, corroded or unlabelled drums) then the wastes can be safely temporarily stored. Such storage needs to be for a maximum of five working days. In the case of cold ambient temperatures, this storage time may exceed five working days to allow for sampling after defrosting. After acceptance, the waste can be moved to another storage area (for bulk waste, this is typically a bulking area). Written procedures need to be in place for dealing with wastes held in quarantine, and also for detailing and monitoring the maximum storage volume. Written procedures need to be put in place for the repackaging of the waste before return to the waste holder, as well as for the packaging procedures
d. to mark on a site plan the inspection, unloading and sampling areas and having a suitably sealed drainage system. Having a separate collection system for spills which is separated from rainwater collection drains and having a sealed underground area which is safely protected against the wastes needing to be treated (related with techniques in Section 4.8.2)

e. to offload wastes in containers in a dedicated reception area pending acceptance sampling. Such storage needs to be for a maximum period of one week. During this period there needs to be no bulking-up or mixing of drums or decanting of the contents into bulk storage. Wastes need to be segregated within this reception area according to compatibility, with the segregation being carried out immediately upon offloading
f. to immediately assess the wastes deposited within the reception area
g. to immediately segregate wastes, to remove possible hazards due to incompatibility, which could result in the waste failing to meet acceptance criteria
h. to have a designated sampling point/s or reception area. These need to be in close proximity to the laboratory/checking facility and need to be visible
i. to ensure that the offloading, sampling point/reception and quarantine areas have an impervious surface with self-contained drainage, to prevent any spillage entering the storage systems or escaping off site
j. to ensure that incompatible substances do not come into contact with spills from sampling, for example, within a sump serving the sampling point. Absorbents need to be made available to deal with any spills
k. to ensure that the installation personnel who are involved in the sampling, checking and analysis procedures are suitably qualified and adequately trained, and that the training is updated on a regular basis
l. once the analysis has confirmed the waste is acceptable, to create a batch for treatment or a load for off-site removal. Once a batch has been assembled for treatment, the operator can create a composite sample for analysis prior to treatment. The actual scope for the analysis depends upon the intended treatment but always needs to be specified
m. to ensure that at every step of the waste receipt at the WT plant (pre-acceptance procedures, acceptance procedures, reception facilities) the staff taking and handling the samples have the necessary knowledge and expertise
n. to have a designed storage area at the facility that is suitable for the wastes received
o. to have a clear procedure dealing with wastes where inspection and/or analysis prove that they do not fulfil the acceptance criteria of the plant or do not fit with the waste description received during the pre-acceptance procedure. This procedure should include all measures required (e.g. by the permitting or national/international legislation) to inform competent authorities, to safely store the delivery for any transition period or to reject the waste and send it back to the waste producer or to any other authorised destination.

Some specific techniques applied to load arrival are:

p. weighing all incoming loads, unless alternative reliable volumetric systems linked to specific gravity data are available
q. not accepting any load on the site unless sufficient storage capacity exists
r. ensuring that all documents are checked and approved, and that any discrepancies need to be resolved before the waste is accepted
s. visually inspecting the load - where possible inspection checks need to be undertaken before off-loading. In any event though, the inspections need to be carried out immediately upon the arrival of the load at the installation
t. checking every container to confirm the quantities against the accompanying paperwork. All containers need to be clearly labelled and need to be equipped with well fitting lids, caps and valves, secure and in place. Containers not having the right specifications need to be rejected. Following inspection the waste needs to then be off-loaded into a dedicated sampling/reception area
u. applying a waste tracking system from the point of acceptance until the first treatment step which changes the physical or chemical character of the waste, e.g by an identifying system (e.g. label, code) for any container or drum stored in the plant. The information may contain any necessary data regarding health and safety, further treatment, waste code, original producer, date of arrival on site, etc.
v. where containers are bulked, transposing from the original container onto the bulk container the earliest date of arrival of the bulked wastes.

Achieved environmental benefits

Identifies the source, composition and hazard of the waste. Prevents wastes being accepted without written information.

Most spills and leaks during sampling only occur on a small scale, e.g. resulting from releases from the back valve of a tanker if the sample is obtained in this way.

Operational data

A laboratory for chemically analysing the samples is needed. Related to technique a (see description above), some samples are not taken for immediate controls and analysis. Some samples, for example, are kept in case authorities require further controls.

Applicability

Fully applicable to all sites however in some situations (e.g. non-hazardous waste treatment facilities) it may not be practicable or economic to have the laboratory on-site.

Economics

Reception facilities for waste water treatment works, for example tanker unloading and storage may cost around EUR 1.5 million (GBP 1 million). Operational costs are relatively low and mainly involve administrative costs.

Techniques	Capital cost (GBP)	Operating cost (GBP)
Analytical laboratory [1,2]	40000	20000
Continuous monitoring equipment [2]	10000	1000
Technical Specification		
Capacity	10000 t/yr	
Oil types	used lubricating oils	
Process operation	batch	
Waste gas flow	0 – 50 Nm^3/hr	
Age of plant	10 years old	
Age of pollution control equipment	2 years old	

Notes:
1. Assumes no new building required and relatively simple laboratory equipment. Staffing includes one full time technician.
2. The costs of continuous monitoring equipment vary enormously according to the number of substances monitored, analytical techniques used and the supplier selected.

Table 4.6: Economics of laboratory and monitoring equipment in a waste oil treatment facility [42, UK, 1995], [150, TWG, 2004]

Driving force for implementation

Some sort of reception facilities for the waste to be treated is necessary in all WT installations. In some countries, it is not obligatory to have a quarantine storage area, and externally accredited laboratory is not legally required.

Example plants

All WT installations have some sort of reception facilities. Many sites have a pre-booking system for wastes and the reception area will then have a list of the contents of each load expected that day. Some sites have one bunded and covered reception area, others have different bunded and covered reception areas for different groups of waste. Gas chromatography and mass spectroscopy can be used to identify components of solvents and waste oils but its use requires skilled interpretation and costs are high.

Depending on the delivered wastes, the receiving area/bunker can be equipped with technical installations to fight fires, because some wastes tend to auto-ignite especially wastes with a high organic content. Biological degradation may cause high temperatures and, in some cases, this can cause fire. Moreover, the disposed wastes can already contain glowing particles, e.g. incompletely burned coal.

The receiving area is normally covered and the doors are often closed because of odour, dust and noise emissions. The receiving area or bunker has an air ventilation installation which collects the exhaust air. To prevent leaking air from the inside, some plants are equipped with an air ventilation system which creates a negative pressure in the receiving area or bunker.

Reference literature

[29, UK Environment Agency, 1996], [55, UK EA, 2001], [86, TWG, 2003], [119, Watco, 2002], [121, Schmidt and Institute for environmental and waste management, 2002], [126, Pretz, et al., 2003], [131, UBA, 2003], [150, TWG, 2004], [152, TWG, 2004], [153, TWG, 2005]

4.1.2 Management systems

Managerial techniques typically applied to the waste treatment installations as a whole are included in this section.

4.1.2.1 Techniques to determine the type of waste treatment applied to each waste

Description

Once the composition and characteristics (e.g. content of hazardous compounds) of the waste has been established, and it is confirmed that the waste is as described in the delivery/reception area (acceptance procedure), a treatment method or option for the waste should be determined. There are three fundamental principles for selecting the appropriate waste treatment for a specific waste: 1) to adequately characterise the waste, 2) to ensure that the waste is suitable for the proposed treatment activity and 3) to ensure operational control of the treatment process, including inputs and reaction monitoring and to have clear end-point objectives. Some techniques applicable to help achieve these goals are to:

a. describe and consider the installation’s activities and the proposed techniques to prevent and reduce the waste arisings, the emissions of substances and heat (including during periods of start-up or shutdown, momentary stoppages, leaks or malfunctions)
b. identify the waste types subject to each process, including all the contaminants
c. identify the chemistry of the process and the fate of all the waste components and any reaction products
d. identify suitable recovery or abatement options, especially for components which may be harmful to the environment and which are not destroyed in the treatment but are displaced from one medium to the other. This can involve tracking those substances capable of pollution and that may be released unchanged from the treatment process
e. identify a suitable treatment method for each new waste enquiry
f. be sure that the process feedstock does not include substances such as solvents that could be recovered at a subsequent stage, by, for example, drying and subsequent distillation to separate components
g. have a clear methology to assess the treatment of waste, considering the physico-chemical properties of the individual waste and the specifications for the treated waste
h. report if there is any advice on preferable waste treatment (e.g related to waste treatment hierarchy) pursuant to the type of waste to be treated (e.g. EWL).

Achieved environmental benefits

The selection of a suitable treatment for a certain waste is vital to ensure that environmental emissions are reduced and that the waste is properly treated.

Operational data
Frequently, several procedures must be used for the correct treatment of waste. The procedure followed, or rather the combination (types of procedures, sequence of their application, applied controls, etc.) will be specified by typically a company/installation coordination procedure. In such a procedure, the laboratory results on the basis of the composition of the waste and its reaction behaviour have some impact on the type of waste treatment to be selected.

Driving force for implementation
The selection of a treatment is not only a function of the type of waste, but other issues such as local constraints (e.g. waste strategy), logistic considerations and what type of treatments are available in the region are also important issues to consider.

Sometimes and wherever possible, waste material is required to be processed by chemical, physical or biological treatment if it contains unacceptable quantities of environmentally hazardous substances or compounds which can be separated, converted, or immobilised, and thus rendered less harmful.

Example plants
Technique applied to all WT facilities.

Reference literature
[53, LaGrega, et al., 1994], [55, UK EA, 2001], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [131, UBA, 2003], [150, TWG, 2004]

4.1.2.2 Guaranteed supply of waste

Description
Waste can be seen as the ‘raw’ material used by WT facilities. In some cases the waste can be used as a reagent to treat other wastes. In any case, the guarantee to have the waste/material will be available at the right time for the continuing and proper performance of the installation is important.

Achieved environmental benefits
If the waste is to be used as a reagent in a treatment process, not having such a waste available may delay the treatment process for the waste type to be treated. This delay may incur associated environmental problems.

Applicability
For example, the guarantee of long term performance of anaerobic systems is a key issue for their economical feasibility (see Section 4.2.4)

Example plants
The main area of concern in anaerobic digestion is the guarantee of the long term performance of a plant which is key to its economical feasibility. This risk can be reduced through technological developments but the associated costs may affect the economics in the short term. Another example is the guarantee of having a sufficient supply of waste bases available in physico-chemical plants in order to neutralise acidic materials in the case that those are used as neutralisation processes.

The bunker or the equipment to feed the process should allow a constant feeding to abate overloads of machines.

Reference literature
[55, UK EA, 2001], [86, TWG, 2003], [126, Pretz, et al., 2003]

4.1.2.3 Techniques to increase the traceability of waste

Description

Any tracking or traceability system to be adopted needs to be capable of reporting all of the following:

- total quantity of waste present on site at any one time, in appropriate units, for example, 205 litre drum equivalents
- breakdown of waste quantities being stored pending on-site treatment, classified by treatment route
- breakdown of waste quantities on site for storage only, that is, awaiting onward transfer
- breakdown of waste quantities by hazard classification
- indicate where the waste is located on site relative to a site plan
- compare the quantity on site against total permitted
- compare the time the waste has been on site against the permitted time limit.

Some techniques which can be applied to increase the traceability of a waste in a waste treatment installation are:

a. to record and reference the information on waste characteristics and the source of the waste stream, so that it is available at all times. A reference number needs to be given to the waste and needs to be obtainable at any time in the process for the operator to identify where a specific waste is in the installation, the length of time it has been there and the proposed or actual treatment route. This is an important component in the management of the installation
b. to regularly review and keep up-to-date waste stream information, i.e. updating information with any changes
c. to put in place an internal tracking system and stock control procedure for all wastes, cross-referenced to the unique reference number raised at the pre-acceptance stage (see Section 4.1.1.2)
d. to apply a tracking system to hold all the information generated during pre-acceptance, acceptance, storage, treatment and/or removal off site. Records can be made and kept up-to-date on an ongoing basis to reflect deliveries, on-site treatment and dispatches. Documentation provided by the driver, written results of acceptance analyses, and details of off-loading points or off-site transfer locations need to be added to the tracking system documentation. All records relating to pre-acceptance need to be maintained at the installation for cross-referencing and verification at the waste acceptance stage. Records typically need to be held for two to six months after the waste has been treated or removed off site
e. to give each waste stream a unique reference number and to ‘follow’ the waste during its acceptance, storage, treatment or removal off site. If the waste is a regular arising waste, then the document should be unique to that waste batch
f. to have documentary systems or a computer database/series of databases, which are regularly backed up. The tracking system operates as a waste inventory/stock control system and includes: date of arrival on site, waste producer details, details on all previous holders, an unique identifier, pre-acceptance and acceptance analysis results, package type and size, intended treatment/disposal route, an accurate record of the nature and quantity of wastes held on site, including all hazards, where the waste is physically located in relation to a site plan, at what point in the designated disposal route the waste is currently at, etc.
g. to maintain the account for the treatment or disposal route method to which a particular type of waste is to be subjected
h. to maintain records to ensure sufficient knowledge is available as to what wastes have entered a particular vessel/tank. For example, once a waste has entered bulk storage or a treatment process, the tracking of individual wastes will not be feasible. However, the tracking of residues/compounds that will be building up within a vessel between desludging events can be carried out in order to avoid any incompatibility with incoming wastes

i. for bulk liquid wastes, to maintain a stock control record of the route through the process; whereas drummed waste control needs to utilise the individual labelling of each drum to record the location and duration of storage
j. to have a good quality packaging and labelling system for incoming containers.

Achieved environmental benefits
The system provides documentary evidence of the treatment given to a certain waste, detailing when the waste has entered the site, where it has come from, with which other compounds has it been mixed and stored and where and when it has been shipped. These techniques enable the waste treatment operator to:

- take advantage of any synergies between wastes
- prevent unwanted or unexpected reactions
- ensure that emissions are either prevented or reduced
- manage the throughput of wastes.

Cross-media effects
Not identified.

Operational data
Typically, computer databases are required. Implementation of an effective system also requires additional administrative work. Traceability systems need to question what exactly has to be traced and when.

Applicability
Widely applied in the WT sector. In the case of small WT plants, the adaptation of some traceability systems (e.g paper to computer based) may be difficult.

The application of some of the techniques mentioned above, may not be possible when installations operate on a continuous or semi-continuous basis. Some examples are when waste liquids from different batches are put together into the storage tank, when solid wastes are put into the bunker and mixed with other waste or when the physico-chemical properties of the waste change. Traceability systems for small volumes or quantities is more difficult to apply.

Driving force for implementation
To help the operator manage the installation.

It is commonly demanded by the waste authorities of the waste producer, to report that the waste is treated according to all relevant legislation and technical rules. This system helps as well to track how and when the treatment has been carried out.

Example plants
Commonly used in WT installations. Fundamentally important for the waste transfer installations.

Reference literature
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [150, TWG, 2004], [152, TWG, 2004], [153, TWG, 2005]

4.1.2.4 Improvement of the efficiency of waste treatments

Description

Waste treatment efficiency in this section relates to the improvement of the usefulness of the outputs, raw material consumption and material flow analysis. The techniques related to energy efficiency are included in Section 4.1.3.4. Some techniques which can be applied to increase the efficiency of waste treatment are:

a. to provide an assessment of the efficiency of the treatment process in relation to pollutants, i.e. in terms of the removal or partition of substances within the process, for example:
  - the precipitation of metals from solution for removal in the filter cake
  - the degree of transfer between the incoming waste and the emissions (to air, solid waste to land and liquid effluent to sewer, for example pesticides or solvents)
  - the utilisation of heat vapour used to preheat waste oil

b. to analyse efficiency parameters using the following steps:
  - process mapping – identifying the pathways within the process for the specific substance or substances
  - mass balance

c. to analyse the effect variability of the waste composition may have on the performance of WT units

d. to monitor efficiency. Operational efficiency monitoring may be carried out by instrumentation, direct operator observation, and chemical analysis. Any monitoring programme will typically involve extensive record keeping, using a combination of computers, chart recorders, and manually completed paper logs

e. to have in place procedures for waste material separation, and in such a way that the recyclability of the separated materials will not be impaired.

Some of these techniques are sometimes part of ISO 9000 and ISO 14001.

Achieved environmental benefits

A facility must monitor operations carefully to assure that its performance achieves the desired results. Optimisation of the waste treatment installations typically helps to achieve lower emissions and lower consumptions.

Operational data

It is recognised that to be commercially viable, waste treatment facilities need to deal with variable waste streams, but that it may not always be desirable or effective to overcomplicate the design and operation of a waste treatment process by trying to accommodate every component of the varied waste stream. Therefore, monitoring the waste and applying suitable separation can help to achieve a higher efficiency and economy of operation.

Some waste treatments have to deal with a wide and variable range of wastes. This requires the plant and equipment to be versatile and usable for a number of wastes. This contrasts with treatment techniques used for ‘in-house’ treatment on waste producer premises, where the number of waste streams is limited and well characterised. This characteristics of in-house treatments may lend themselves to the development of dedicated single stream treatment techniques.

Applicability

Even where the site weighs all the input wastes and outgoing waste streams and products, it is not always easy to perform a sensible mass balance on the system. Mass balances and material flow analysis for each single material fractions or ingredient are difficult and sometimes the results are questionable. The main reason is the inherent variations in the waste IN.

Examples of recyclable materials in Ph-c plants are principally oil, grease, organic solvent, metal, metal salts.

Driving force for implementation

Typically undertaken indirectly to reduce the operational cost of the installation or the disposal cost of the waste.

Example plants

There are still a large number of sites that do not have a weighbridge, or do not use the weighbridge for each load.

Reference literature

[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004], [153, TWG, 2005]

4.1.2.5 Management techniques

Description

Some techniques are:

a. operational control of the treatment process
b. provision and maintenance of suitable infrastructure (good housekeeping)
c. management of effluents (developed in Section 4.7.1)
d. control of the plant based on laboratory-determined analyses, which also determine treatment programmes, the required controls and documentation
e. to have the plant operation carried out exclusively by specialised and expert personnel (e.g. management level: with university qualification, relevant degree and/or working specialism; operative level: skilled worker, laboratory assistant). Personnel qualifications can be assured by a mix of a relevant time of studying, a continuing education measures; with the requisite specialist technical personnel knowledge being determined and controlled within the context of plant certification. Related with techniques described in Section 4.1.2.10
f. to have all the necessary peripheral structures required for a correctly functioning enterprise. This includes, for example, property boundaries, signs designating the location of parking places and storage facilities, lighting, scales, a workshop, etc.

Achieved environmental benefits

General improvement of the environmental awareness of the installation.

Applicability

Regular training is common in the waste treatment sector.

Reference literature

[50, Scori, 2002], [55, UK EA, 2001], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

4.1.2.6 Identification of economies of scale and synergies

Description

Where there are a number of separate installations (particularly where there are different operators), there may be a possibility to identify some installation wide issues and opportunities for interactions between the installations, whereby the overall performance of each installation may be improved. In particular by sharing or combining information or activities and enhancing co-operation. Some examples of this include:

a. improving communication procedures between the various permit holders; in particular those needed to ensure that the risk of environmental incidents is minimised
b. utilising benefits from the economies of scale to justify the installation of a shared CHP plant (see energy sections within Section 4.1.3)
c. combining combustible wastes to justify a combined waste-to-energy (see energy sections within Section 4.1.3)
d. utilising the waste from one activity possibly as a feedstock for another
e. utilising the treated effluent from one activity, if it is of an adequate quality, as the raw water feed for another activity
f. combining effluents to justify a combined or upgraded effluent treatment plant
g. avoiding accidents from one activity which may have a detrimental knock-on effect on a neighbouring activity
h. avoiding land contamination from one activity affecting another – or possible problems that one operator may own the land on which the other is situated.

Achieved environmental benefits

Can increase the energy efficiency, reduce waste generation, reduce water consumption and reduce water emissions from the overall complex.

Cross-media effects

Some of these communications may be difficult if related with legal issues concerning competition.

Applicability

Applicable where synergies are identified and where more than one activity is carried out.

Economics

Typically decreases the overall cost of the waste treatments.

Driving force for implementation

Typically increases the economic viability of the waste treatments.

Example plants

Many examples exist in the sector.

Reference literature

[55, UK EA, 2001], [86, TWG, 2003]

4.1.2.7 Provision of full details on the activities to be carried out

Description

The provision of adequate process descriptions of the activities and of the applied abatement and control equipment is important, to enable the regulator to gain a good understanding of the applied process. Appropriate items that can help to build up a good picture of the plant include:

a. a description of the waste treatment methods and procedures in place in the installation
b. providing pipe and instrumentation flow diagrams of the installation (e.g. R-/I-Fliesbilder)
c. diagrams of the main plant items where they have some environmental relevance, and also process flow diagrams (schematics). For example, plant design diagrams of the storage, tanks, and the treatment and abatement facilities, although in isolation these will typically not be enough to enable the proper environmental evaluation
d. details of chemical reactions and their reaction kinetics/energy balance
e. an equipment inventory, detailing plant type and design parameters, for example, flashpoints
f. details on the waste types to be subjected to the process
g. a control system philosophy and how the control system incorporates the environmental monitoring information
h. details of the venting and emergency relief provisions
i. operating and maintenance procedures
j. details on how protection is provided during abnormal operating conditions such as momentary stoppages, start-up, and shutdowns.

Furthermore, with regard to information, it is important for operators:

k. to have access to all the necessary regulations relating to operational safety and order and a schedule of work rules before the initial operation of the plan
l. to have an instruction manual. The instruction manual contains all the measures needed to ensure proper and safe disposal of wastes occurring during normal operation, maintenance operations, and during operational disturbances. All processes should be harmonised with alarm and emergency schedules. The instruction manual also details the duties and responsibilities of operating staff, the working instructions, the arrangements for maintenance and inspection, as well as reporting, documentation and storage requirements. This manual needs to be updated as necessary and should be available before the initial operation of the plant
m. to have an operational diary, to detail operating conditions and as evidence of the proper running of the plant. The operational diary will contain all the relevant information related to the day-to-day operation of the waste management facility plant, and will in particular:
    - record all waste treated in the plant, and any other materials that are recycled or disposed of in some other manner outside the plant
    - act as a register of the accepted waste
    - act as a register of any material recycled or disposed of in some other manner outside the plant
    - provide documented evidence in disputes, e.g. in cases where the delivery of waste material does not correspond to the details contained in the pre-acceptance documentation. In this case, the diary will detail all the measures taken
    - record special incidents, and in particular the details of any operational disturbances, including details on the possible causes and the corrective measures taken
    - record running times and downtimes of the plant
    - record the results of investigations and self-checking measurements
    - record the nature and scope of all maintenance measures
    - record the results of the function controls
n. to keep the operational diary up to date. All additional supporting statements required by the appropriate authority also need to be documented in the operational diary. In one system, the operational diary might involve collecting single sheets filled out by persons from the

different assets areas. The operational diary could also be managed using electronic data processing. Regardless of whether it is kept in electronic or paper format, it should always be kept in safe custody and protected from unauthorised access

o. to keep the operational diary for a period of five years
p. to report any incidents which lead to a significant deviation from normal operation immediately to the appropriate authority, in particular those bringing the plant to a standstill
q. to prepare an annual survey of the activities carried out and the wastes treated. The annual survey can also contain a quarterly balance sheet of the waste and residue streams, including the auxiliary materials used, for each site. The annual survey should be submitted to the appropriate authority within a period of three months after the end of the year.

Achieved environmental benefits
Helps assess operators proposals and in particular the opportunities for further improvements.

Cross-media effects
Not known.

Operational data
Management operation.

Applicability
Fully applicable in all WT installations. However, technique d (see description above) is sometimes seen as difficult to be applied to some installations due to the complex mixtures that represent some wastes as well as the variability in composition of the waste.

Driving force for implementation
This is typically a part of the operation permit.

Example plants
Common technique.

Reference literature
[55, UK EA, 2001], [86, TWG, 2003], [131, UBA, 2003], [150, TWG, 2004], [153, TWG, 2005]

4.1.2.8 Environmental management tools

Description
The best environmental performance is usually achieved by the installation of the best technology and its operation in the most effective and efficient manner. This is recognised by the IPPC Directive definition of 'techniques' as *'both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned'*.

For IPPC installations an Environmental Management System (EMS) is a tool that operators can use to address these design, construction, maintenance, operation and decommissioning issues in a systematic, demonstrable way. An EMS includes the organisational structure, responsibilities, practices, procedures, processes and resources for developing, implementing, maintaining, reviewing and monitoring the environmental policy. Environmental Management Systems are most effective and efficient where they form an inherent part of the overall management and operation of an installation.

Within the European Union, many organisations have decided on a voluntary basis to implement environmental management systems based on EN ISO 14001:1996 or the EU Eco-management and audit scheme EMAS. EMAS includes the management system requirements of EN ISO 14001, but places additional emphasis on legal compliance, environmental performance and employee involvement; it also requires external verification of the management system and validation of a public environmental statement (in EN ISO 14001 self-declaration is an alternative to external verification). There are also many organisations that have decided to put in place non-standardised EMSs.

While both standardised systems (EN ISO 14001:1996 and EMAS) and non-standardised ('customised') systems in principle take the *organisation* as the entity, this document takes a more narrow approach, not including all activities of the organisation e.g. with regard to their products and services, due to the fact that the regulated entity under the IPPC Directive is the *installation* (as defined in Article 2).

An environmental management system (EMS) for an IPPC installation can contain the following components:

- definition of an environmental policy
- planning and establishing objectives and targets
- implementation and operation of procedures
- checking and corrective action
- management review
- preparation of a regular environmental statement
- validation by certification body or external EMS verifier
- design considerations for end-of-life plant decommissioning
- development of cleaner technologies
- benchmarking.

These features are explained in somewhat greater detail below. For detailed information on components (a) to (g), which are all included in EMAS, the reader is referred to the reference literature indicated below.

a. definition of an environmental policy
   Top management are responsible for defining an environmental policy for an installation and ensuring that it:
   - is appropriate to the nature, scale and environmental impacts of the activities
   - includes a commitment to pollution prevention and control
   - includes a commitment to comply with all relevant applicable environmental legislation and regulations, and with other requirements to which the organisation subscribes
   - provides the framework for setting and reviewing environmental objectives and targets
   - is documented and communicated to all employees
   - is available to the public and all interested parties
b. planning, i.e.:
   - procedures to identify the environmental aspects of the installation, in order to determine those activities which have or can have significant impacts on the environment, and to keep this information up-to-date
   - procedures to identify and have access to legal and other requirements to which the organisation subscribes and that are applicable to the environmental aspects of its activities
   - establishing and reviewing documented environmental objectives and targets, taking into consideration the legal and other requirements and the views of interested parties
   - establishing and regularly updating an environmental management programme, including designation of responsibility for achieving objectives and targets at each relevant function and level as well as the means and timeframe by which they are to be achieved

c. implementation and operation of procedures

It is important to have systems in place to ensure that procedures are known, understood and complied with, therefore effective environmental management includes:

- structure and responsibility
  - defining, documenting and communicating roles, responsibilities and authorities, which includes appointing one specific management representative
  - providing resources essential to the implementation and control of the environmental management system, including human resources and specialised skills, technology and financial resources
- training, awareness and competence
  - identifying training needs to ensure that all personnel whose work may significantly affect the environmental impacts of the activity have received appropriate training.
- communication
  - establishing and maintaining procedures for internal communication between the various levels and functions of the installation, as well as procedures that foster a dialogue with external interested parties and procedures for receiving, documenting and, where reasonable, responding to relevant communication from external interested parties
- employee involvement
  - involving employees in the process aimed at achieving a high level of environmental performance by applying appropriate forms of participation such as the suggestion-book system or project-based group works or environmental committees.
- documentation
  - establishing and maintaining up-to-date information, in paper or electronic form, to describe the core elements of the management system and their interaction and to provide direction to related documentation.
- efficient process control
  - adequate control of processes under all modes of operation, i.e. preparation, start-up, routine operation, shutdown and abnormal conditions
  - identifying the key performance indicators and methods for measuring and controlling these parameters (e.g. flow, pressure, temperature, composition and quantity)
  - documenting and analysing abnormal operating conditions to identify the root causes and then addressing these to ensure that events do not recur (this can be facilitated by a ‘no-blame’ culture where the identification of causes is more important than apportioning blame to individuals)
- maintenance programme
  - establishing a structured programme for maintenance based on technical descriptions of the equipment, norms etc. as well as any equipment failures and consequences
  - supporting the maintenance programme by appropriate record keeping systems and diagnostic testing
  - clearly allocating responsibility for the planning and execution of maintenance.
- emergency preparedness and response
  - establishing and maintaining procedures to identify the potential for and response to accidents and emergency situations, and for preventing and mitigating the environmental impacts that may be associated with them

d. checking and corrective action, i.e.:
  - monitoring and measurement
    - establishing and maintaining documented procedures to monitor and measure, on a regular basis, the key characteristics of operations and activities that can have a significant impact on the environment, including the recording of information for tracking performance, relevant operational controls and conformance with the installation's environmental objectives and targets (see also the Reference document on Monitoring of Emissions) [68, EIPPCB, 2003]
    - establishing and maintaining a documented procedure for periodically evaluating compliance with relevant environmental legislation and regulations.
  - corrective and preventive action
    - establishing and maintaining procedures for defining responsibility and authority for handling and investigating non-conformance with permit conditions, other legal requirements as well as objectives and targets, taking action to mitigate any impacts caused and for initiating and completing corrective and preventive action that are appropriate to the magnitude of the problem and commensurate with the environmental impact encountered
  - records
    - establishing and maintaining procedures for the identification, maintenance and disposition of legible, identifiable and traceable environmental records, including training records and the results of audits and reviews
  - audit
    - establishing and maintaining (a) programme(s) and procedures for periodic environmental management system audits that include discussions with personnel, inspection of operating conditions and equipment and reviewing of records and documentation and that results in a written report, to be carried out impartially and objectively by employees (internal audits) or external parties (external audits), covering the audit scope, frequency and methodologies, as well as the responsibilities and requirements for conducting audits and reporting results, in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained
    - completing the audit or audit cycle, as appropriate, at intervals of no longer than three years, depending on the nature, scale and complexity of the activities, the significance of associated environmental impacts, the importance and urgency of the problems detected by previous audits and the history of environmental problems – more complex activities with a more significant environmental impact are audited more frequently
    - having appropriate mechanisms in place to ensure that the audit results are followed up
  - periodic evaluation of legal compliance
    - reviewing compliance with the applicable environmental legislation and the conditions of the environmental permit(s) held by the installation
    - documentation of the evaluation

e. management review, i.e.:
  - reviewing, by top management, at intervals that it determines, the environmental management system, to ensure its continuing suitability, adequacy and effectiveness
  - ensuring that the necessary information is collected to allow management to carry out this evaluation
  - documentation of the review

f. preparation of a regular environmental statement:
    - preparing an environmental statement that pays particular attention to the results achieved by the installation against its environmental objectives and targets. It is regularly produced – from once a year to less frequently depending on the significance of emissions, waste generation etc. It considers the information needs of relevant interested parties and it is publicly available (e.g. in electronic publications, libraries etc.)
    - when producing a statement, the operator may use relevant existing environmental performance indicators, making sure that the indicators chosen:
        - give an accurate appraisal of the installation's performance
        - are understandable and unambiguous
        - allow for year on year comparison to assess the development of the environmental performance of the installation
        - allow for comparison with sector, national or regional benchmarks as appropriate
        - allow for comparison with regulatory requirements as appropriate

g. validation by certification body or external EMS verifier:
    - having the management system, audit procedure and environmental statement examined and validated by an accredited certification body or an external EMS verifier can, if carried out properly, enhance the credibility of the system.

h. design considerations for end-of-life plant decommissioning
    - giving consideration to the environmental impact from the eventual decommissioning of the unit at the stage of designing a new plant, as forethought makes decommissioning easier, cleaner and cheaper
    - decommissioning poses environmental risks for the contamination of land (and groundwater) and generates large quantities of solid waste. Preventive techniques are process-specific but general considerations may include:
        - avoiding underground structures
        - incorporating features that facilitate dismantling
        - choosing surface finishes that are easily decontaminated
        - using an equipment configuration that minimises trapped chemicals and facilitates drain-down or washing
        - designing flexible, self-contained units that enable phased closure
        - using biodegradable and recyclable materials where possible

i. development of cleaner technologies:
    - environmental protection should be an inherent feature of any process design activities carried out by the operator, since techniques incorporated at the earliest possible design stage are both more effective and cheaper. Giving consideration to the development of cleaner technologies can for instance occur through R&D activities or studies. As an alternative to internal activities, arrangements can be made to keep abreast with – and where appropriate – commission work by other operators or research institutes active in the relevant field

j. benchmarking, i.e.:
    - carrying out systematic and regular comparisons with sector, national or regional benchmarks, including for energy efficiency and energy conservation activities, choice of input materials, emissions to air and discharges to water (using for example the European Pollutant Emission Register, EPER), consumption of water and generation of waste.

Standardised and non-standardised EMSs

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 14001:1996 can give higher credibility to the EMS, especially when subject to a properly performed external verification. EMAS provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

Achieved environmental benefits

Implementation of and adherence to an EMS focuses the attention of the operator on the environmental performance of the installation. In particular, the maintenance of and compliance with clear operating procedures for both normal and abnormal situations and the associated lines of responsibility should ensure that the installation's permit conditions and other environmental targets and objectives are met at all times.

Environmental management systems typically ensure the continuous improvement of the environmental performance of the installation. The poorer the starting point is, the more significant short-term improvements can be expected. If the installation already has a good overall environmental performance, the system helps the operator to maintain the high performance level.

Cross-media effects

Environmental management techniques are designed to address the overall environmental impact, which is consistent with the integrated approach of the IPPC Directive.

Operational data

No specific information reported.

Applicability

The components described above can typically be applied to all IPPC installations. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) 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. A number of studies are presented below. However, these are just examples and their results are not entirely coherent. They might not be representative for all sectors across the EU and should thus be treated with caution.

A Swedish study carried out in 1999 surveyed all 360 ISO-certified and EMAS-registered companies in Sweden. With a response rate of 50 %, it concluded among other things that:

- the expenses for introducing and operating EMS are high but not unreasonably so, save in the case of very small companies. Expenses are expected to decrease in the future
- a higher degree of co-ordination and integration of EMS with other management systems is seen as a possible way to decrease costs
- half of all the environmental objectives and targets give payback within one year through cost savings and/or increased revenue
- the largest cost savings were made through decreased expenditure on energy, waste treatment and raw materials
- most of the companies think that their position on the market has been strengthened through the EMS. One-third of the companies report increasing revenue due to EMS.

In some Member States reduced supervision fees are charged if the installation has a certification.

A number of studies ([77, Klemisch and Holger, 2002], [78, Clausen, et al., 2002]) show that there is an inverse relationship between company size and the cost of implementing an EMS. A similar inverse relationship exists for the payback period of invested capital. Both elements imply a less favourable cost-benefit relationship for implementing an EMS in SMEs compared to larger companies.

According to a Swiss study, the average cost for building and operating ISO 14001 can vary:

- for a company with between 1 and 49 employees: (CHF 64000) EUR 44000 for building the EMS and (CHF 16000) EUR 11000 per year for operating it
- for an industrial site with more than 250 employees: (CHF 367000) EUR 252000 for building the EMS and (CHF 155000) EUR 106000 per year for operating it.

These average figures do not necessarily represent the actual cost for a given industrial site because this cost is also highly dependent on the number of significant items (pollutants, energy consumption, etc.) and on the complexity of the problems to be studied.

A recent German study [69, Schaltegger and Wagner, 2002] shows the following costs (see Table 4.7) for EMAS for different branches. It can be noted that these figures are much lower than those of the Swiss study quoted above. This is a confirmation of the difficulty to determine the costs of an EMS.

Costs for building (EUR):	Costs for validation (EUR):
range: 18750 – 75000	range: 5000 – 12500
average: 50000	average: 6000

Table 4.7: Cost of application of EMAS

A study by the German Institute of Entrepreneurs [70, UNI/ASU, 1997] gives information about the average savings achieved for EMAS per year and the average payback time. For example, for implementation costs of EUR 80000 they found average savings of EUR 50000 per year, corresponding to a payback time of about one and a half years.

External costs relating to verification of the system can be estimated from guidance issued by the International Accreditation Forum [71, IAF, 2003].

Driving forces for implementation

Environmental management systems can provide a number of advantages, for example:

- improved insight into the environmental aspects of the company
- improved basis for decision-making
- improved motivation of personnel
- additional opportunities for operational cost reduction and product quality improvement
- improved environmental performance
- improved company image
- reduced liability, insurance and non-compliance costs
- increased attractiveness for employees, customers and investors
- increased trust of regulators, which could lead to reduced regulatory oversight
- improved relationship with environmental groups.

Example plants

The features described under (a) to (e) above are elements of EN ISO 14001:1996 and the European Community Eco-Management and Audit Scheme (EMAS), whereas the features (f) and (g) are specific to EMAS. These two standardised systems are reported to be applied in seven WT installations. Examples reported are in installation for the treatment of waste oils, waste solvents, preparation of waste fuel from hazardous waste and from non-hazardous waste.

Reference literature

[66, TWG, 2003], [72, EC, 2001], [73, ISO, 1996], [150, TWG, 2004]

4.1.2.9 Promote good collaboration between waste producer and holder

Description
Generally it can be said that options taken early in the chain can have the most benefits and that prevention is better than treatment. Thus, actions taken by the waste producer and holder can have a big effect on the waste. This technique thus focuses on trying to influence the waste producer and holder and if there are problems trying to change the bad waste management habits of the producer and holder.

Achieved environmental benefits
Waste treatment plants significantly rely on the linkages with the preceding logistics, actions and companies especially if it can help to avoid the need to use very expensive solutions for the treatment of waste.

Applicability
Sometimes it is very difficult to to persuade waste producers and holders to change their habits. Moreover, the control of the waste producer is carried out by the authorities.

Economics
Normally, this decreases the cost of the waste treatment.

Driving force for implementation
To try to decrease the cost of the treatment. This technique is related to Article 3(c) obligations of waste producers in sectors subject to IPPC and for producers not subject to IPPC, Article 2 of Directive on hazardous waste (91/689/EEC).

Example plants
Physico-chemical treatment plants of waste waters. The waste water arising during the treatment of waste in a Ph-c plant contains inadmissibly high levels of organic materials, depicted as AOX. Technically expensive and, in part, energy intensive procedures such as adsorption or oxidation must be used to separate these organic materials from, or to convert into, waste water.

A process-independent solution to this task is the separate collection of the organic materials – depicted as AOX – directly at the point where these arise, so that they are then not mixed with the waste to be treated and cannot contaminate the waste water produced in the course of the waste treatment. This, therefore, eliminates the need to apply the above-mentioned procedures to reduce the proportion of organic materials, depicted as AOX.

AOX cannot be separated by adsorption with activated carbon. It becomes clear that a separate collection of the materials shown in the AOX is certainly more effective. In practice, these types of substance are kept strictly separate.

The distillation operation should work together logistically in order to accomplish the separate collection of the materials to be prepared according to the distillation criteria. This co-operation is implemented in practice and has proved its worth.

Reference literature
[121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

4.1.2.10 Utilisation of qualified personnel in the facility

Description

Some examples are:

a. general provisions: at all times the operator of a WT plant needs to have sufficient staff available and on duty with the requisite qualifications. All personnel need to undergo specific job training and further education
b. supervisory staff: the supervisory staff and all heads of sections in the waste management facility plant need to be reliable and technically qualified and they need to have appropriate practical experience. Technical qualifications may have been obtained from a successfully completed course at a state or state-approved technical university, university of applied science or school of engineering. Technical expertise will also be recognised on the basis of comparable training or on many years of practical experience
c. other staff: other staff must be reliable and technically skilled. This technical skill may be based, for example, on formal qualifications in such areas as community services and waste disposal, on many years of practical experience, or on comparable training.

Achieved environmental benefits

Improves and prevents the environmental performance of the facility. Qualified people and training are essential in WT operations, both for the waste producers (sorting, collecting, etc.) and for the WT operator. Health, safety, security and environmental protection all depend on good management of the installation and as a result of workers qualifications.

Cross-media effects

Not known.

Operational data

This is a management tool.

Applicability

Fully applicable to the whole WT sector.

Economics

Qualified people typically are more expensive. Putting in place training programmes (either in house or externally subcontracted) will incur some extra costs for the operator.

Example plants

There are many examples in the sector**.** It might happen that delivered wastes might cause problems, so it is advantageous if the staff in charge are alert on problematic wastes. However, staff should be aware of all materials which might cause problems during processing. Depending on the applied machines these might be large bulky parts or other components like metals. If these staff are highly alert, an almost continuous processing with a small range of quality fluctuations might be guaranteed.

Reference literature

[126, Pretz, et al., 2003], [131, UBA, 2003], [150, TWG, 2004]

4.1.3 Utilities and raw material management

4.1.3.1 Provision of a breakdown of the energy consumption and generation by source

Description

In order to improve, the energy system from an environmental point of view, the system needs to be well understood and fully reported. Below are some techniques that may be used:

a. reporting energy consumption information in terms of delivered energy. For electricity, this may be converted to primary energy consumption using national/regional factors (e.g. in the UK for the public electricity supply, a conversion factor of 2.6 is typically used). An example format of how the information may be presented is given in Table 4.8 below:

Energy source	**Energy consumption**		
	Delivered (MWh)	**Primary (MWh)**	**% of total**
Electricity*			
Gas			
Liquid fuels			
Waste			
Other (operator to specify)			
* specify source			

Table 4.8: Energy consumption reporting
Based on [55, UK EA, 2001]

b. reporting the energy exported from the installation
c. providing energy flow information (for example, diagrams or energy balances) showing how the energy is used throughout the process. This information may allow operators to define or calculate the specific energy consumption of the installation.

Achieved environmental benefits

Evaluating the reduction of emissions from the energy system can only be carried out with a proper accounting of the actual emissions generated. The breakdown between generation and consumption can help to optimise the match between them and hence to optimise the use of energy resources.

Cross-media effects

In some cases, the environmental benefit of this technique is limited. The reason is that the possibility to decrease the consumption in an existing plant may be rather limited, and possible efforts to decrease consumption need to be balanced against possible higher emissions from the treatment.

Applicability

Fully applicable throughout the WT sector. However, in certain circumstances (e.g. historical development of the installation/site, management of the installation), it may be difficult to relate consumptions to each single process/treatment carried out within the overall WT process. These reports are typically carried out every year or every half a year. Higher frequencies may be applied in the case of a higher variation in the types of waste treated.

Economics

The requirements are basic and low cost.

Driving force for implementation

To reduce energy costs.

Reference literature

[55, UK EA, 2001], [116, Irish EPA, 2003], [150, TWG, 2004], [153, TWG, 2005]

4.1.3.2 Use of cleaner fuels

Description

The use of cleaner fuels has a direct impact on emissions from the combustion of those fuels. Fuels with less carbon, sulphur or particulate content per unit of energy will cause fewer emissions. For example, consider using electric or LPG powered vehicles. The use of cleaner fuels may conflict when energy is recovered from waste (e.g. the use of waste as fuel in the next Section 4.1.3.3), since they may also generate higher emissions in certain circumstances. Such an issue needs to be analysed case by case.

Achieved environmental benefits

Reduction mainly in the emissions of carbon, sulphur and nitrogen oxides and particulates.

Economics

Typically, cleaner fuels are more expensive.

Reference literature

[86, TWG, 2003], [116, Irish EPA, 2003], [150, TWG, 2004]

4.1.3.3 Use of waste as fuel

Description

Waste can be used as fuel in some waste treatment installations. Majority of these installations are covered by the WID and by WI BREF, and are not covered here. However, the use of fuel gases from waste installations (e.g. landfill and biogas) and certain types of hazardous waste (e.g. certain fractions of waste oils) are not covered in these documents. When using these type of fuels, some techniques that can be considered are:

a. certifying burners, i.e. certify that they burn at the level that it is required
b. rules concerning acceptable conditions for burning could include:
    - correct maintenance and operation of burners to ensure maximum combustion
    - controls on both the size of the burner and the volume of oil burned
c. using pollution control equipment attached to burners, and monitoring of emissions and ash disposal (see Section 4.6).

Achieved environmental benefits

Uses of a resource typically available on site. Due to the higher standards required by the WID, the incineration of waste typically generates lower emissions.

Cross-media effects

In some installations with low control, the incineration of waste may generate higher emissions of some substances.

Economics
Typically, waste fuels are cheaper than conventional fuels. For example, the likely control for small used oil burners would be a specified maximum contaminant emission from burners. This would require those burning used oil to test their air emissions to ensure they do not exceed stated levels. This is likely to be less effective and more expensive than installing input controls. In the case of small amounts of waste oils being used as fuels, testing air emissions is more difficult and more expensive than testing an input of oil, and if emissions do exceed stated levels, some damage may already have been done before the burner can be stopped. For smaller burners, the cost of output controls may likely negate the financial benefit of burning used oil over other fuels. Output controls for ash disposal would seek to direct how, and possibly where, ash could be disposed of safely.

Driving force for implementation
Waste incineration is covered by the Directive 2000/76/EC.

Example plants
For example, waste oil re-refining facilities use light ends from waste oil distillations as fuel. Combustion flue-gas scrubbing with caustic soda may be required to reduce acid gas emissions from a waste oil treatment plant. Then, stripping of process water is carried out for H_2S removal with the off-gases being routed to the process heaters for thermal destruction and then to the air via the flue-gas scrubbing system.

Large volume burners of any fuel are already required to have pollution control equipment in place, and many also have to monitor their emissions, as the potential effects, if something goes wrong, are deemed to be high.

Reference literature
[14, Ministry for the Environment, 2000], [42, UK, 1995], [116, Irish EPA, 2003], [150, TWG, 2004]

4.1.3.4 Measures to improve energy efficiency

Description
Some techniques applicable to increase the energy efficiency of WT installations are:

a. developing an energy efficiency plan which appraises the costs and benefits of different energy options
b. including energy management techniques as part of the whole environmental management system (EMS), including the monitoring of energy flows and the targeting of areas for reductions
c. using combined heat and power (CHP)
d. applying operating, maintenance and housekeeping measures to the most relevant energy consumption installations, 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)
    - steam distribution systems (leaks, traps, insulation)
    - room heating and hot water systems
    - lubrication to avoid high friction losses (e.g. mist lubrication)
    - boiler maintenance, for example, optimising excess air
    - other maintenance relevant to the activities within the installation
    - reviewing equipment requirements on a regular basis
    - minimising spillages and leaks by the use of drip trays. Most fuel spills will be washed to the main site interceptors

e. 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, techniques covering:
   - building insulation
   - use of energy efficient site lighting
   - vehicle maintenance
   - efficient plant layout to reduce pumping distances
   - phase optimisation of electronic motors
   - heat recovery
   - ensuring equipment is switched off, if safe to do so, when not in use
   - ensuring on-site vehicle movements are minimised and engines are switched off when not in use

f. 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)

g. applying energy efficiency techniques to building services

h. setting the time of operation of the high energy equipment to off-peak periods

i. defining and calculating the specific energy consumption of the activity (or activities), setting key performance indicators on an annual basis (e.g. MWh/tonne of waste processed). For example, based on primary energy consumption for the products or raw material inputs which most closely match the main purpose or production capacity of the installation

j. minimising the emissions of diesel engines

k. using landfill gas to produce electricity and heat

l. making an energy survey to identify the opportunities of further energy savings

m. using heat of the furnaces and engines for vaporisation processing, drying and for preheating activities

n. selectingthe appropriate waste to be treated in the installation. Typically, installations not designed to treat a certain type of waste consumes more energy when treating such waste.

Achieved environmental benefits

An energy efficiency plan could be summarised in a format similar to the example below in Table 4.8, together with supporting information from any appraisal procedure carried out. The plan is required to ensure that the operator has considered all relevant techniques.

Energy efficiency option	**CO_2 savings (tonnes)**	
	Annual	*Lifetime*
7MW CHP plant	13500	135000
High efficiency motor	2	14
Compressed air	5	n.a.

Table 4.9: CO_2 saving from the integration of different improvement energy efficiency techniques
[55, UK EA, 2001]

Utilising an energy efficiency plan and switching to cleaner fuels can reduce the energy consumption and the environmental emissions from that energy use. An increase in the energy efficiency of the boilers and heaters reduces the emissions of VOCs, due to the more complete combustion and the minimisation of fuel losses.

Operational data

The place within the existing WT installation where the improvement is applied typically dependent on the existing installation.

Applicability

Fully applicable. However, in installations where several WT activities are performed, the energy consumption may be difficult to allocate to each activity due to the integrated approach typically used by the energy system.

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 make 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 can constitute more than 5 % of the total energy consumption.

Economics

Typically energy efficient systems have higher investment costs. However, their operation costs are typically lower (or the revenues higher). Costs are typically higher for existing installations than for new installations. Some examples are shown in Table 4.10.

Energy efficiency option	**NPV EUR'000**	**NPV/CO_2 saved EUR/tonne**
7MW CHP plant	2058	15
High efficiency motor	0.75	52.5
Compressed air	n.a.	n.a.
Indicative only, based on cost/benefit appraisal.		

Table 4.10: Economics of the integration of different improvement energy efficiency techniques [55, UK EA, 2001]

The improvement of the energy efficiency needs to be balanced with the cost to achieve this. WT consume some sort of energy (electricity, steam etc.) and the possibility to decrease the consumption in an existing plant may be rather limited in some cases. In such cases, the efforts required may not be economically or environmentally justified.

Reference literature

[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [66, TWG, 2003], [116, Irish EPA, 2003], [132, UBA, 2003], [150, TWG, 2004], [153, TWG, 2005]

4.1.3.5 Raw material selection

Description

This section deals with the selection and substitution of the raw materials used. Some techniques are to:

a. identify the raw and auxiliary materials, other substances and water that have been proposed for use. This involves gathering a list together of the materials used (including, i.e. generic information about materials; note that grouping together those of a similar type is normally adequate rather than listing every commercial alternative used) which have the potential for significant environmental impact, including:
   - the chemical composition of the materials where relevant
   - the quantities used
   - the fate of the material (that is, approximate percentages going to each media and to the product)
   - the environmental impact where known (for example degradability, bioaccumulation potential, toxicity to relevant species)
   - any reasonably practicable alternative raw materials which may have a lower environmental impact (i.e. applying the substitution principle)

b. justify (for example, on the basis of emissions, product quality and economic reasons), the continued use of any substance for which there is a less hazardous alternative

c. maintain a detailed inventory of the raw materials used on site

d. implement procedures for the regular review of new developments in raw materials and the regular implementation of any suitable materials that are less hazardous

e. have quality assurance procedures in place for the control of the content of raw materials

f. re-use the spent lime from incinerator lime injection acid gas abatement systems

g. re-use waste strong acids in those treatments where acid is needed.

Achieved environmental benefits

These measures can:

- reduce the use of chemicals and other materials
- substitute less harmful materials for those which can be more readily abated, and when abated can lead to substances which, in themselves, are more readily dealt with
- help to develop an understanding of the fate of by-products and contaminants and their environmental impact
- be seen as a preferred option for some acid wastes, but depends on the volume and contamination of the waste.

Cross-media effects

Possible, for example in the re-use of spent lime, attention should be given to the level of metal and organic contamination that may be present.

Operational data

Due to the nature of the WT processes, the consumption of raw material is influenced by the variation of the waste IN. Moreover, there are cases where substitution of raw materials by waste is not possible. For example, raw lime has a much higher alkalinity than spent lime, and consequently larger volumes of the spent lime are required. This places a limitation in relation to the size of reactor vessel. This requires a similar scale up with mixing tanks to produce the lime solution.

Applicability

The scope to minimise the potential environmental impact of the use of raw materials is sometime limited in terms of the quantity used (waste minimisation) or of their nature (for example, presence of contaminants, use of less harmful alternatives).

Driving force for implementation

Economic and environmental reasons. For concentrated acids (>70 w/w-%) there is a market for blended or reconcentrated acids. It has become viable to use 50 w/w-% acids, although this requires a greater energy input. It is anticipated that the growth area for this market may be in the 20 – 30 % acids range.

Annex IV of the IPPC Directive states that considerations to be taken into account generally, and in specific cases when determining BAT, are the use of low waste technology and less hazardous substances, the recycling of substances generated and of waste, where appropriate.

Example plants

The following raw material substitutions are considered for application in the UK:

Raw material	Possible substitute
Sodium hydroxide	Only 'mercury free' NaOH should be used[1]
Demulsifiers	Only fully biodegradable products with known, safe degradation products should be used
[1] Industry producers of NaOH consider that mercury free NaOH should contain less than 50 µg/kg	

Table 4.11: Examples of raw material substitution
[55, UK EA, 2001], [86, TWG, 2003]

Ph-c plants are planned in such a manner that a maximum amount of recyclable materials can be separated and a minimum amount of auxiliary materials must be used. The consumption of auxiliary materials is minimised by as much as possible if the waste which is to be disposed of can be used (i.e. treatment of waste with waste) instead of manufactured materials.

Reference literature

[55, UK EA, 2001], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

4.1.3.6 Techniques to reduce water use and prevent water contamination

Description

Water use should be minimised within the BAT criteria for the prevention or reduction of emissions and should be commensurate with the prudent use of water as a natural resource. Some general information about those issues have been analysed in the 'Common Waste water and waste gas treatment' BREF. Some techniques to consider for the WT sector are:

a. performing regular water audits, with the aim of reducing water consumption and preventing water contamination. A good water audit requires the following:
    - the production of flow diagrams and water mass balances for all activities using water
    - the establishment of water efficiency objectives by comparison with sector guidance or, where this is not available, national benchmarks
    - the use of water pinch techniques or other water optimisation techniques
    - the use of the above information to identify and assess opportunities for a reduction in water use and so that an action plan can be prepared for the implementation of improvements, set against a given time-scale
b. using water-efficient techniques at source

c. recycling water within the process. Possible options where this may be possible are:
    - to recycle water within the process from which it arises, by treating it first if necessary. Where this is not practicable, it can be recycled to another part of the process which has a lower water quality requirement
    - to identify the scope for substituting water from recycled sources, identifying the water quality requirements associated with each use. Less contaminated water streams, for example, cooling waters, need to be kept separate if there is some scope for its re-use, possibly even after some form of treatment

d. separately discharging uncontaminated roof and surface water, which cannot be used

e. ultimately carrying out some form of treatment on the waste water. However, in many applications, the best conventional effluent treatment produces a good water quality which may be usable in the process directly or when mixed with fresh water. While treated effluent quality can vary, it can be recycled selectively when the quality is adequate, and still reverting to discharge when the quality falls below that which the system can tolerate. The WT operator can identify where treated water from the effluent treatment plant could be used and justify where it cannot. In particular, the cost of membrane technology continues to come down in price, so much so that now this can be applied to individual process streams or to the final effluent from the effluent treatment plant

f. replacing the effluent treatment plant, leading to a much lower effluent volume. However, a concentrated effluent stream will remain but, where this is sufficiently small, and particularly where waste heat is available for further treatment by evaporation, a zero effluent system could be produced

g. minimising the water used in cleaning and washing down (subject to the impact on dust emissions) by:
    - vacuuming, scraping or mopping in preference to hosing down
    - evaluating the scope for re-using wash-water
    - using trigger controls on all hoses, hand lances and washing equipment

h. discharging rainwater to interceptors

i. undercovering some parts of the site to avoid contamination of rainwater (e.g. in the main waste treatment plant)

j. protecting systems to avoid liquid and solid spills being discharged directly to watercourses or to sewer

k. identifying, and where possible, quantifying significant fugitive emissions to water from all relevant sources, including estimating the proportion of total fugitive emissions for each substance

l. applying the following techniques to subsurface structures
    - establishing and recording the routing of all installation drains and subsurface pipework
    - identifying all subsurface sumps and storage vessels
    - applying engineering systems to ensure leakages (e.g. from pipes) are minimised and where these occur, can be readily detected, particularly where hazardous substances are involved
    - providing, in particular, secondary containment and/or leakage detection for such subsurface pipework, sumps and storage vessels
    - establishing an inspection and maintenance programme for all subsurface structures, for example, pressure tests, leak tests, material thickness checks

m. applying the following techniques to surfacing structures:
   - describing in detail the design (relevant information may include as appropriate: capacities; thicknesses; distances; material; permeability; strength/reinforcement; resistance to chemical attack; inspection and maintenance procedures; and construction quality assurance procedures), and conditions of the surfaces of all operational areas
   - having in place an inspection and maintenance programme of impervious surfaces and containment kerbs
   - justifying where operational areas have not been equipped with:
     - an impervious surface
     - spill containment kerbs
     - sealed construction joints
     - connection to a sealed drainage system

n. applying the techniques to bunds mentioned in Section 4.1.4.4.

Achieved environmental benefits

Reducing the water use may be a valid environmental (or economic) aim in itself. In addition, from the point of view of reducing polluting emissions, any water passing through an industrial process is degraded by the addition of pollutants, and therefore there are distinct benefits to be gained from reducing the water used, in particular:

- associated benefits within the process such as a reduction in energy requirements for heating and pumping the water
- reduction of water use reduces dissolution of pollutants into the water leading in turn to reduced sludge generation in the effluent treatment plant
- a mass balance calculation carried out in the water can typically reveal where consumption reductions can be made.

Applicability

Typically this is a part of an integral EMS (Section 4.1.2.8) in the installation. Some of these techniques are only applied to complex WT plants, to identify the opportunities for maximising the re-use, and for minimising the use of water.

The techniques mentioned above may have some applicability restrictions in the case that water releases are continuous or batch and in the case that the WWTP is installed on-site or off-site.

Economics

Some economic incentives to apply this technique can be to:

- reduce the necessary size of (a new) waste water treatment plant
- reduce costs where water is re-used in-house or purchased from, or disposed of to, another party.

Driving force for implementation

Economic incentives to reduce waste water generation and water consumption. In some EU countries, there are incentive systems in place which have the aim of encouraging a reduction in water consumption.

Example plants

Flow diagrams and water mass balances are commonly used. Some sites have sub surface interceptors, storage tanks, mixing tanks and pipe runs and it may be difficult to see how the integrity of these could be determined. There may be emissions to the underlying ground from all of these installations that would generally be treated as a notifiable release. Some installations have reported that it is possible to reduce up to 90 % of the water consumption.

Reference literature

[54, Vrancken, et al., 2001], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [150, TWG, 2004]

4.1.4 Storage and handling

This section covers techniques to consider in the determination of BAT for storage and handling activities in a WT installation. However, it needs to be pointed out that a horizontal BREF entitled 'Emissions from Storage' is available and provides more information on the issue.

4.1.4.1 Generic techniques applied to waste storage

Description
Some general techniques are:

a. specifying storage procedures for circumstances where vehicles carrying waste are to be parked on site overnight or on public holidays, when the site may be unsupervised over these periods
b. locating storage areas away from watercourses and sensitive perimeters and in such a way so as to eliminate or minimise the double handling of wastes within the installation
c. clearly marking and signposting storage areas with regard to the quantity and hazardous characteristics of the wastes stored therein
d. clearly and unambiguously stating in writing the total maximum storage capacity of the site needs which should be together with details of the method used to calculate the volumes held against this maximum. The stated maximum capacity of storage areas should not be exceeded
e. ensuring that the storage area drainage infrastructure can contain all possible contaminated run-off and that drainage from incompatible wastes cannot come into contact with each other
f. maintaining at all times clear vehicular (for example, forklift and pedestrian) access to the whole of the storage area, so that the transfer of containers is not reliant on the removal of others which may be blocking access, other than drums in the same row
g. using a dedicated area/store for sorting and repackaging laboratory smalls. Once the wastes have been sorted according to their hazard classification, with due consideration for any potential incompatibility problems, and repackaged then these drums do need not to be stored within their dedicated laboratory smalls area but can be and indeed need to be removed to the appropriate storage area
h. carefully considering the tank and vessel optimum design, in each case taking into account the waste type, storage time, the overall tank design and mixing system in order to prevent sludge accumulation and ease of desludging. Storage and treatment vessels need to be regularly desludged
i. ensuring that all connections between vessels are capable of being closed via suitable valves. Overflow pipes need to be directed to a contained drainage system, which may be the relevant bunded area or to another vessel provided suitable control measures are in place
j. equipping tanks and vessels with suitable abatement systems, together with level meters with audible and visual high level alarms. These systems need to be sufficiently robust and regularly maintained to prevent foaming and sludge build-up affecting the reliability of the gauges
k. ensuring that storage vessels holding flammable or highly flammable wastes meet special requirements
l. preferably routing pipework above ground, although if it is underground the pipework needs to be contained within suitable inspection channels
m. replacing underground or partially underground vessels without secondary containment, for example, double skinned with leakage detection, by aboveground structures
n. equipping silos with abatement systems, level monitors and high level alarms
o. ensuring that incorporate storage bunkers extraction systems for particulate abatement or spray damping

p. locating bulk storage vessels on an impervious surface which is resistant to the material being stored. The vessels need to have sealed construction joints within a bunded area with a certain capacity. Some examples on capacity volumes applied are: at least 110 % (others 100 %) of the largest vessel or 25 % (others 50 %) of the total tank volume within the bund
q. ensuring that the vessels supporting structures, pipes, hoses and connections are resistant to the substances (and mix of substances) being stored
r. not using vessels beyond the specified design life, unless the vessels are inspected at regular intervals with written records kept to prove they remain fit for the purpose and that their intensity remain intact
s. connecting, where oil treatment is a pretreatment process within a chemical treatment plant, the head space above the oil settlement tank to the overall site exhaust and scrubber units. Some sites have local exhaust ventilation systems to balance air displacement when loading/unloading tankers
t. storing organic waste liquid (e.g. with a flashpoint of less than 21 °C) under a nitrogen atmosphere to keep it inertised. Each storage tank is put in a waterproof retention area and equipped with a level indicator. Gas effluent from events are collected and treated.
u. using polymer sheeting to cover open solids storage facilities that may generate particulates
v. having an appropriate number of tanks for the different kinds of incoming and outgoing streams
w. equipping some or all of the tanks with outlets on different heights of the tank to be able to take out certain layers of the content
x. dealing with waste streams containing VOCs separately and using plants dedicated to these waste streams
y. having measures available to prevent the build up of sludges higher than a certain level and the emergence of foams that may affect such measures in liquid tanks, e.g. by regularly controlling the tanks, sucking out the sludges for appropriate further treatment and using anti-foaming agents
z. equipping tanks and vessels with suitable abatement systems when volatile emissions may be generated, together with level meters and alarms. These systems need to be sufficiently robust (e.g. able to work if sludge and foam is present) and regularly maintained

Some generic techniques in the reduction of odour related to storage are:

aa. optimising the controlling time lapse and temperature in the settling processes
bb. controlling the decanting of settled layers by visual assessment of samples from different levels
cc. handling odorous compounds in fully enclosed, suitably abated vessels
dd. storing drums and containers of odorous materials in enclosed buildings
ee. storing acid and alkali wastes that may be used in the odour treatment in a series of silos and then used to create an optimum balance of acid and alkali in jumbo tanks (or smaller units).

Achieved environmental benefits

The appropriate and safe storage of wastes helps to reduce fugitive emissions (e.g. VOC, odours, dust) and the risks of leakages. Segregated storage is necessary to prevent incidents from incompatible substances reacting and as a means of preventing escalation should an incident occur.

Some justification of technique p (see descripton above) for a volume of 110 % is that takes into account the build-up of rainfall with the bund.

Example plants

Sites storing organic wastes with a solvent content tend to have a carbon filter system to control discharges to air and to undertake some monitoring of the exit gas. Some VOCs can be returned to solution through aqueous scrubbers or mineral oil scrubbers, whilst other VOCs can be trapped in activated carbon filters. Roofed tanks are common when storing materials containing products with high vapour pressure. Special equipment is required when storing highly flammable products. Special care is typically taken in order to avoid leaks and spillages to the ground which would pollute the soil and groundwater or allow material to enter surface water. Some sites have balancing systems (with nitrogen gas) to reduce the air displacement when filling the tanks. Blanketing and balancing of all storage tanks used in a re-refining process is carried out. The amount of displacement to vent during transfer of contents is minimised in some cases by connected vent pipes. See an example in the Figure 4.1 below.

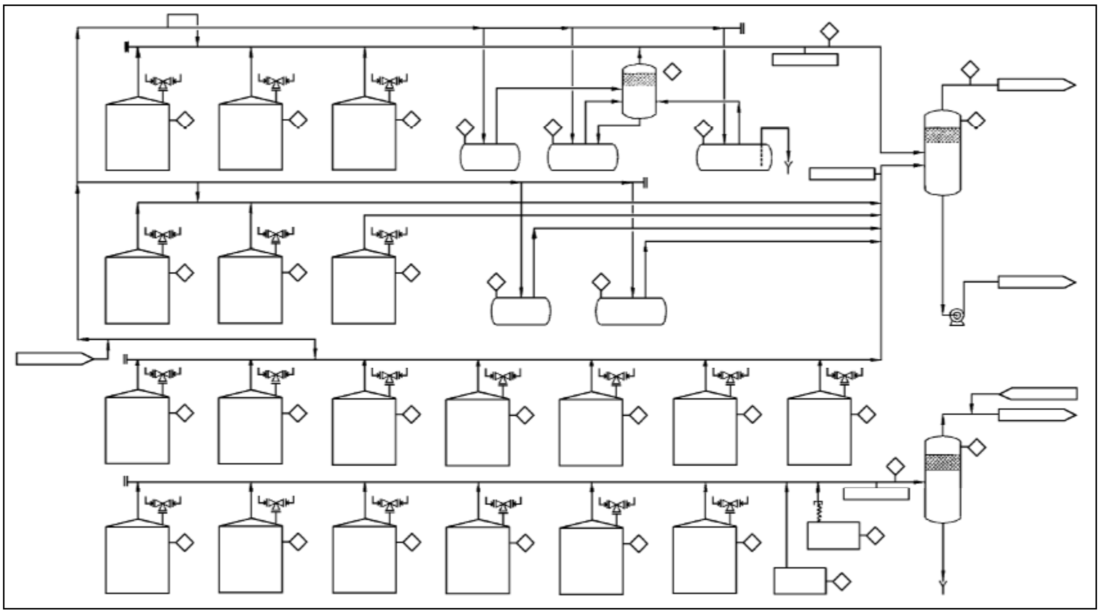


Figure 4.1: Blanketing system in a storage system used in a waste oil re-refining facility [36, Viscolube, 2002]

One EU installation has blanketed all the storage tanks of the input and intermediate materials of the process. The only tanks that are not blanketed are for gasoil (different kinds) and water. Another EU installation has blanketed all the storage tanks of output and intermediate materials of the process. Traps of VOCs and odours in storage tanks are common in many waste oil refineries. This type of installation is also common in the preparation of waste fuel from liquid organic wastes.

Reference literature

[30, Eklund, et al., 1997], [36, Viscolube, 2002], [50, Scori, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [116, Irish EPA, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [128, Ribi, 2003], [150, TWG, 2004], [153, TWG, 2005]

4.1.4.2 Techniques for the storage of drums and other containerised wastes

Description

Some techniques are:

a. storing containerised wastes under cover. This can also be applied to any container that is held in storage pending sampling and the emptying of containers. Covered areas need to have adequate provision for ventilation. The air is treated before it is released depending on the type of contamination if any (see Section 4.6)
b. storing containers with well fitting lids, caps and/or with valves secure and in place
c. maintaining the availablity and access to storage areas for containers holding substances that are known to be sensitive to heat and light under cover and protected from heat and direct sunlight
d. strictly following regulations related to the storage areas for containers holding flammable or highly flammable wastes, as these areas are highly regulated
e. only processing containers following written instructions. These instructions need to include which batch is to be processed and the type of container required to hold any residues
f. applying positive ventilation or keeping the storage area below atmospheric pressure
g. utilising open sided roofed areas
h. utilising flameproof lighting
i. not storing drums more than two high and always ensuring that there is access space for inspection on all sides. That is, four 205 litre drums on a pallet, stacked no more than two 205 litre drums high in rows
j. storing containers in such a way that leaks and spillages could not escape over bunds or the edge of the sealed drainage area
k. having a small bulking unit that is designed to allow laboratory smalls to be decanted into a lime slurry in 205 litre drums prior to disposal at the treatment plant. This will utilise a hood placed over the drum which is connected to an exhaust system and activated carbon filter. The system is not air-tight, since the operator has to be able to empty the bottles into the container, but it might provide a simple system for making an estimate of the discharges to the air during the decanting of solvents at minimum cost
l. producing and following written procedures for the segregation and packing of laboratory smalls
m. avoiding storing incompatible substances within the same drum/container (e.g. laboratory smalls)
n. using a dedicated area/store for sorting and repackaging laboratory smalls
o. once the wastes have been sorted according to hazard classification, with due consideration for any potential incompatibility problems, and repackaged, ensuring that these drums are not stored within the dedicated laboratory smalls area but are removed to the appropriate storage area
p. where laboratory smalls are decanted into larger containers, carrying out this in a closed building with a ventilation system and exhaust air treatment and a bunding system without drainage
q. storing drums and containers including hazardous waste in basins which are impermeable and have a double construction
r. storing completely closed containers like IBC and bigger, that may be stored outside halls, over a surface protected ground.

Achieved environmental benefits

The storage under cover of drummed waste has the advantage of reducing the amount of potentially contaminated water that may be produced in the event of any spillage and of extending the useful life of the container. Some of the techniques presented also prevent the emissions which could be caused by storing incompatible substances together which might then react together. Other benefits are related to avoiding soil contamination.

Cross-media effects

Related with technique a (see description above), the provision for ventilation by means of wall or roof vents or by the actual construction of the area, for example, open barn is seen to be a dilution of emission to the air.

Operational data

Handling is usually more complicated in covered areas than in uncovered ones. It may be physically impossible to store some large containers under cover. Covered installations also need also to consider the access requirements for fire fighting.

Applicability

Related with technique a, it is not necessary to store all containerised waste under cover. Typically, the waste and containers that are not sensitive to light, heat light, extreme ambient temperatures or water ingress are excluded. Under such circumstances, adequate bunding of storage areas and containment/treatment of water run-off is typically enough to ensure an effective environmental protection.

Reference literature

[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [150, TWG, 2004], [152, TWG, 2004], [153, TWG, 2005]

4.1.4.3 Techniques to improve the maintenance of storage

Description

Some techniques are:

a. putting in place procedures for the regular inspection and maintenance of storage areas including drums, vessels, pavements and bunds. Inspections need to pay particular attention to any signs of damage, deterioration and leakage. Records need to be kept detailing action taken. Faults should be repaired as soon as practicable. If the containment capacity or the capability of bund, sump or pavement is compromised then the waste needs to be removed until the repair is completed
b. carrying out daily inspection of the condition of containers and pallets and keeping written records of these inspections. If a container is found to be damaged, leaking, or in a state of deterioration, provision needs to be made to either over-drum or transfer the contents to another container. Pallets damaged to the extent that the stability of the containers is or may become compromised need to be replaced. ‘Plastic shrink wrap’ needs to only be used to provide secondary stability to drum/container storage, in addition to the use of pallets of an appropriate condition
c. having in place and following a routine programmed inspection of tanks, and mixing and reaction vessels, including periodic thickness testing. In the event of damage or deterioration being detected, the contents need to be transferred to an appropriate alternative storage. These inspections need to preferably be carried out by independent expert staff and written records need to be maintained of the inspection and of any remedial action taken.

Achieved environmental benefits

Reduces storage problems and avoids fugitive emissions.

Example plants

Many examples exist in the sector.

Reference literature

[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [150, TWG, 2004]

4.1.4.4 Bunds for liquid storage

Description
All tanks containing liquids whose spillage could be harmful to the environment need to be bunded. Some issues to consider for these bunds are that they need to:

a. be impermeable and resistant to the stored materials
b. have no outlet (that is, no drains or taps), but should drain to a collection point for treatment
c. have the pipework routed within bunded areas with no penetration into contained surfaces
d. be designed to catch leaks from tanks or fittings
e. have a sufficient bund capacity. See point p in Section 4.1.4.1
f. be subject to regular visual inspections and any contents pumped out or otherwise removed under manual control should be checked first for contamination. Where not frequently inspected, the bunds should be fitted with a high level probe and an alarm as appropriate. There needs to be a routine programmed inspection of bunds (normally visual but extending to water testing where structural integrity is in doubt)
g. have fill points within the bund.

Note, the working areas for liquid decanting and storage areas need to be separately bunded.

Achieved environmental benefits
Reduces contamination of soil and water from major spillages or incidents, involving a loss of containment.
Applicability
Storage of liquids.

Driving force for implementation
These issues are typically regulated in the different EU countries.

Reference literature
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [150, TWG, 2004]

4.1.4.5 Restricting the use of open topped tanks, vessels or pits

Description
Some techniques are:

a. not allowing direct venting or discharges to the air by linking all vents to suitable abatement systems
b. keeping the waste or raw materials under cover in waterproof packaging.

Achieved environmental benefits
Reduces fugitive emissions (e.g. VOC, particulates) and spillages.

Operational data
During accidental events discharges to the air may be permited to avoid more severe damage.
Applicability
Typically applied to the storage of waste that may cause fugitive emissions (e.g. VOC, particulates).

Reference literature
[55, UK EA, 2001], [86, TWG, 2003], [150, TWG, 2004]

4.1.4.6 Generic techniques applied to waste handling

Description
Some general techniques are:

a. having in place systems and procedures to ensure that wastes are transferred to the appropriate storage safely
b. continuing the waste tracking system that began at the pre-acceptance stage, linked with acceptance, throughout the duration the waste is kept at the site (see Section 4.1.2.3)
c. having in place a management system for the loading and unloading of waste in the installation, also taking into consideration any risks that these activities may incur (for example, in the transfer of bulk liquid waste from tanker to storage vessels). This might involve:
   - having in place systems to prevent 'tanker drive off', i.e. a vehicle pulling away whilst still coupled
   - assuring that these processes are only carried out by people trained to do so and with an appropriate amount of time so as not cause pressure to work more quickly than deemed acceptable
   - having in place measures to ensure that the couplings are a correct fit; this will prevent the coupling loosening or becoming detached. Issues related to coupling include:
     - an installation providing and maintaining hoses can help to guarantee the integrity and fitness of the couplings
     - ensuring that special care is taken so that the coupling is able to withstand the maximum shut valve pressure of the transfer pump, otherwise a serious event could occur
     - protecting of the transfer hose may not be necessary where a gravity feed system is in place. It will however still be important to maintain a sound coupling at each end of the transfer hose
     - controlling potential leaks due to coupling devices by fairly simple systems such as drip trays, or by designated areas within the bund system. Rainwater falling over the rest of the bund area falls to a sump and, if uncontaminated, can be pumped to the site interceptor and discharge points. The bund areas are inspected, maintained and cleaned. Pollution of water discharges can occur, but are minimised by design and management
     - good housekeeping practices requiring constant attention and cleaning
   - providing of routine maintenance, so that a more acute accident situation does not arise due to the failure of plant or equipment. This may include the failure of a pump seal or the blockage of a filter pot commonly used at transfer points
   - having an emergency storage for leaking vehicles, to minimise an acute incident associated with the failure of the seal on the road tanker
   - back balancing the vapour system when loading road tankers
   - having measures in place to ensure that the correct waste is discharged to the correct transfer point and that the waste is then transferred to the correct storage point. In order to prevent an unauthorised discharge, a lockable isolating valve needs to be fitted to the loading connection. This needs to be kept locked during periods when there is no supervision of the unloading points
d. recording in the site diary any small spills during decanting. Spills need to be retained within the bunded areas and then collected using adsorbents. If this is not done, the spillage will exit the site through the rainwater collection systems or may generate fugitive emissions (e.g. VOC)
e. having a qualified chemist/person attend the site of the waste producer/holder to check the laboratory smalls, classifying the substances accordingly and packaging the containers into specific containers. In some cases, the individual packages are prevented from mechanical damage in the drum by the use of vermiculite. Some operators only deal with laboratory smalls if the customers use their packing service

f. packing containers of chemicals into separate drums based on their hazard classification. Chemicals which are incompatible (e.g. oxidisers and flammable liquids) should not be stored in the same drum
g. having in place a system to ensure that the correct discharge point or storage area is used. Some options for this include ticket systems, supervision by site staff, keys or colour-coded points/hoses or fittings of a specific size
h. utilising an impervious surface with self-contained drainage, to prevent any spillage entering the storage systems or escaping off site in the offloading and quarantine points
i. ensuring that damaged hoses, valves and connections are not used. Hoses, valves and connections need to designed and maintained to be sure that they are suitable for the purpose to be used and that they are chemically stable towards what they are intended for
j. using rotary type pumps equipped with a pressure control system and safety valve
k. collecting the exhaust gas from vessels and tanks when handling liquid waste that may generate fugitive emissions
l. selecting the adequate packaging material considering what material/waste is intended to be contained (e.g. dangerous material)
m. having in place systems and procedures to ensure that waste subjected to be transferred is packaged and transported in accordance with legislation concerning the safe carriage of dangerous goods.

Achieved environmental benefits
An appropriate and safe storage of wastes helps to reduce fugitive emissions, the risks of leakages and prevention of accidents. Segregated storage is necessary to prevent incidents from incompatible substances and as a means of preventing escalation should an incident occur. A transfer of damaged pallets may lead to other pallets being stored on top, resulting in further damage and possible collapse of the stack.

Applicability
Common abatement systems can be connected to the venting systems for tanks, to reduce solvent losses to the air due to displacement when filling tanks and tankers. Sites handling dusty wastes may have specific hoods, filters, and extraction systems.

Most sites have a full concrete base, with falls to internal site drainage systems leading to storage tanks or to interceptors that collect rainwater and any spillage. Interceptors with overflows to sewers usually have automatic monitoring systems, such as a check on pH, which can shut down the overflow.

Driving force for implementation
There is legislation concerning the safe carriage of dangerous goods.

Example plants
The larger solvent transfer stations reduce displacement losses from loading and unloading tankers and drums with balancing systems or VOC recovery systems. Many chemical treatment plants and solvent storage sites have pollution abatement equipment to minimise acidic and VOC emissions.

Sites storing organic wastes with a solvent content tend to utilise a carbon filter system to control discharges to air and to undertake some monitoring of the exit gas.
Many of the waste transfer stations storing and pumping larger quantities of VOCs have abatement equipment or balancing equipment to minimise losses to the air due to displacement or thermal effects.

Reference literature
[50, Scori, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [116, Irish EPA, 2003], [122, Eucopro, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.1.4.7 Handling of solid waste

Description
Some techniques are:

a. ensuring the bulking of different batches only takes place with compatibility testing
b. not adding liquid wastes to solid wastes other than in purpose designed and built reaction vessels, and only after the appropriate compatibility tests
c. using local exhaust ventilation to control odour and dust
d. unloading solid and sludge in a closed and depressurised building
e. balancing of air between tanks and different areas
f. using pumping of sludges instead of open movement.

Achieved environmental benefits
Avoids accidents and fugitive emissions.

Cross-media effects
When pumping sludges or liquids from one container to another, some emissions may be generated in the area where the material is pumped due to the displacement of the air.
Applicability
Techniques noted as c) and d) of the description section above are typically applicable to wastes that may generate fugitive emissions.

Example plants
Preparation of waste fuel.

Reference literature
[29, UK Environment Agency, 1996], [55, UK EA, 2001], [86, TWG, 2003], [122, Eucopro, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.1.4.8 Handling activities related to transfers into or from drums and containers

Description
This section includes drum, tank, tanker or small container transfers into or from drums. Some techniques are:

a. ensuring that bulking/mixing only takes place under instruction from, and under the direct supervision of a suitable manager/chemist and under local exhaust ventilation when appropriate
b. bulking up odorous materials only under controlled conditions (e.g. not in the open air) to avoid odour emissions
c. keeping the container lidded/sealed as much as possible
d. transferring wastes in containers into storage vessels using a dip pipe
e. during bulking to tankers, using vapour balance lines connected to appropriate abatement equipment
f. ensuring that the transfer from a tanker to a drum or viceversa uses a minimum of two people to check the pipes and valves at all times
g. manipulating drums using mechanical means, for example a fork-lift truck with rotating drum handling fitting
h. ensuring that transfers/discharges only take place after compatibility testing has been completed (see Section 4.1.4.13) and then only with the sanction of an appropriate manager. The approval should specify which batch/load of material is to be transferred; the receiving storage vessel; the equipment required, including spillage control and recovery equipment; and any special provisions relevant to that batch/load
i. ensuring that tankers are not used as reaction vessels as this is not their designed purpose

j. blending by bulking into tankers needs to only take place once suitable verification and compatibility testing has been carried out
k. decanting larger individual containers of waste into IBCs or 205 litre drums and generally bunding these areas to protect site drainage
l. taking suitable precautions against the hazards of static electricity when handling flammable liquids
m. securing together the drums by shrink-wrap
n. training fork-lift drivers in the handling of palletised goods, to minimise fork-lift truck damage to the integrity of drums
o. using sound and undamaged pallets
p. replacing any damaged pallets on arrival and not transferring them into storage
q. providing adequate space needs within drum storage areas
r. only moving drums and other mobile containers between different locations (or loaded for removal off site) under instructions from the appropriate manager; also then ensuring that the waste tracking system is amended to record these changes.

Achieved environmental benefits
Avoids fugitive emissions, e.g. by minimising splash, fume and odour, health and safety problems; and prevents unexpected releases or reactions.
Applicability
Technique r (see description above) is typically applied to locations within the installation.

Reference literature
[55, UK EA, 2001], [86, TWG, 2003], [150, TWG, 2004], [153, TWG, 2005]

4.1.4.9 Automatic unloading of drums

Description
The unloading station includes (from upstream to downstream):

a. a drum supply station driven by pneumatic motorisation. The drums, transported by means of a fork-lift, are placed onto a set of conveyors with motorised rollers, ensuring that the containers are then directed to the grip station
b. a grip station for the drums equipped by a hydraulic clamp. A hydraulic clamp equipped with three lugs distributed along the circumference of the drums, permits the latter to be directed, travelling in a translocatory motion, to the different terminals of the station
c. a station for the cutting, scraping, washing and ejection of the drum bottom. The disposal of the pasty waste is assured by two parallel vertical H-bars, one of the sharp flanges of which rubs against the inside casing of the drum, causing friction. The shape of the upper part of the bars is one that is adapted to the penetration of thick matter. The washing of the drums, in line with the high pressure/low flowrate principle, permitting a reduced consumption of water, is assured by nozzles placed inside metal sheaths
d. a station for the disposal, scraping, and high-pressure cleaning of the shell of the drum. After disposal and cleaning, the drums are pressed by two rams in the direction of their largest dimension. Appropriate casings are provided so as to retain the spatters and strappings of the drums. The pressed drums are then directed to a collection container by a roller conveyor
e. a station for the pressing and removal of the cleaned drums
f. a control cabin.
g. VOC emissions prevention. The volatile organic compounds emitted by the cutting, disposal and washing stations are collected by hoods connected to a ventilation device and are treated in an incineration unit.

Achieved environmental benefits

Reduces the length of time that the conditioned waste remains on site and optimises the process of cleaning the containers. The purpose of such a system is to unload waste from drums without human intervention avoiding accidents.

Applicability

The station is designed to accept standard drums of 120 and 200 litre capacities capable of being fully opened and closed. Its disposal capacity is 250 drums/day.

Driving force for implementation

The automated station for the unloading of conditioned waste shall meet the following dual objective:

- to improve the working conditions of the operatives
- to reduce the length of time that the conditioned waste remains on site and to optimise the process of cleaning the containers.

Example plants

Applied to the preparation of fuel from hazardous waste.

Reference literature

[91, Syke, 2003], [122, Eucopro, 2003], [150, TWG, 2004]

4.1.4.10 Techniques to improve stock control in storage

Description

Some issues to consider are:

a. for bulk liquid wastes, stock control involves maintaining a record of the route through the entire process. For drummed waste, the control needs to utilise the individual labelling of each drum to record the location and duration of storage
b. the provision of emergency storage capacity. This would be relevant in a situation where it would be necessary to transfer a waste from a vehicle, due to a defect or potential failure of the vehicle containment. These events are infrequent and available capacity within the installation may be a limiting factor
c. all containers need to be clearly labelled with the date of arrival, relevant hazard code(s) and a unique reference number or code enabling identification through the stock control and by cross-reference to pre-acceptance and acceptance records. All labelling needs to be resilient enough to stay attached and legible throughout the whole storage time at the installation
d. use of over-drumming as an emergency measure. All appropriate information needs to be transferred onto the label of the new container. Moving large quantities of wastes in over-drums need to be avoided by re-drumming once the incident leading to the over-drumming has been dealt with
e. automatic monitoring of the storage and treatment tanks levels with the tank level indicators
f. the control of, e.g. with existing flow balancing systems or simple activated carbon filters, some of the emissions from the tanks when they are agitated or treated when mixed, as well as generally from chemical treatment tanks or sludge mixing tanks
g. limiting the reception storage area to a maximum of one week only (see Section 4.1.1.5)
h. taking measures (e.g acceptance planning, identifiying the maximum capacity limit for that waste, and ensuring storage capacity is not exceeded) to avoid problems that may be generated from the storage/accumulation of waste. This is important as waste characteristics can change during storage/accumulation, e.g. they can compact and harden, or, as a result of mixing reactions can occur producing reaction products and waste water. In some cases homogenisation of the waste will only be possible with the aid of heating, or the addition of accessory agents, etc. and by also having knowledge of the reaction behaviour of the waste. Applying some simple preventive efforts can generally help mitigate these disadvantages.

Achieved environmental benefits
Prevents emissions during storage activities.

Operational data
A management system is required as the above techniques relate to a quality management system (QMS).

Example plants
Many examples exist in the sector.

Reference literature
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [150, TWG, 2004]

4.1.4.11 Computer controlled high rack storage area for hazardous wastes

Description
The logistic centre in the compound of different treatment facilities is a computer controlled high rack storage area for hazardous wastes. Here, all substances are identified, weighed, photographed and sampled before storage.

Of special importance is the in-house laboratory, where samples of the individual waste substances are analysed before disposal or recovery in order to identify the exact substance properties and to determine the appropriate treatment process. The laboratory also produces concepts for clean-up in cooperation with the other departments.

In order to prevent fires in the high rack area, the vessels are subject to inerting with nitrogen. An installed nitrogen accumulation plant produces nitrogen with a 2 % oxygen residue content, which is then discharged into the vessels. This process is continuously controlled and registered. In order to reduce gaseous emissions, the inert gas from the vessels is circulated by ventilators and filtrated by activated carbon.

Achieved environmental benefits
It separates different types of hazardous wastes and ensures its appropriate treatment process.

Operational data
Before storage of the containers in the high rack area, administrative and technical controls take place (e.g. sampling and photographic documentation). Storage of the containers is then carried out by means of a programmed stock control system. Transport of the container within the high rack area is carried out by computer-controlled shelf access equipment. Programming ensures that all transport processes of the container are planned in advance and thus predefined, and that all associated information (e.g. documents and sampling results) and executed transport processes of the container are registered, which allows for comprehensive control. In order to enable reception and storage of wastes in varying containers, every container is put on a standardised pallet. This pallet is designed as a collecting tray that collects spill-overs, e.g. from sampling.

Applicability
This technique is applicable to waste treatment facilities receiving hazardous wastes.

Example plants
An example waste disposal plant in Germany.

Reference literature
[157, UBA, 2004]

4.1.4.12 Tank and process pipework labelling

Description

Some issues to consider related to labelling requirements are:

a. all vessels need to be clearly labelled with regard to their contents and capacity, and need to have an unique identifier. Tanks need to be appropriately labelled depending on their use and contents, for example:

Content	Example label
Solvent	Highly flammable
Effluent	Waste water

b. the label should differentiate between waste water and process water, combustible liquid and combustible vapour and the direction of flow (i.e. in or out-flow)
c. written records need to be kept for all tanks, detailing the unique identifier; capacity, its construction, including materials; maintenance schedules and inspection results; fittings, and the waste types which may be stored/treated in the vessel, including flashpoint limit
d. use of a suitable pipework coding system, for example, CEN European Standard Colour Coding, e.g.

Colour	Coding	Content
Green	6010	Water
Brown	8001	Combustible liquid/vapour
Red	3001	Fire fighting water
Blue	5012	Compressed air

e. tagging all valves with an unique identifier and showing this on the process and instrumentation diagrams
f. correctly sizing and maintaining all connections in an undamaged state.

Achieved environmental benefits

The systems make it easier for the operator to maintain a good knowledge of the whole process and help to reduce accidents and control emissions.

Applicability

Tagging all valves with an identifier which is then shown on the process and instrumentation diagram is not common practice, even in the chemical industry.

Reference literature

[55, UK EA, 2001], [86, TWG, 2003]

4.1.4.13 Carrying out a compatibility test prior to transfer

Description
A good compatibility test should cover the following elements:

a. a sample from the receiving tank/vessel/container is mixed in a proportional ratio with a sample from incoming waste stream, which is proposed to be added to the tank/vessel/container
b. the two samples need to cover the 'worst case' scenario of likely constituents
c. any evolved gases and the cause of possible odour need to be identified
d. if any adverse reaction is observed, an alternative discharge or disposal route needs to be found
e. due considerations need to be taken of the implications of scale-up from laboratory compatibility testing to bulk transfer
f. the particular compatibility test parameters will be driven by the wastes being bulked. As a minimum, records of testing need to be kept, including any reactions giving rise to safety parameters (increase in temperature, evolution of gases or raising of pressure), operating parameters (viscosity change and separation or precipitation of solids) and other parameters such as an evolution of odours.

Table 4.12 presents an example of a compatibility chart and indicates that careful planning must be given to chemical storage. For example, 'acids, minerals, non-oxidising' (number 1) can generate heat and violent polymerisation reactions when mixed/blend with aldehydes (number 5).

No.	Name of reactivity group																							
1	Acids, minerals, non-oxidising	1																						
2	Acids, minerals, oxidising		2																					
3	Acids, organic		G H	3																				
4	Alcohols, glycols	H	H F	H P	4																			
5	Aldehydes	H P	H F	H P		5																		
6	Amides	H	H GT				6																	
7	Amines, aliphatic, aromatic	H	H GT	H		H		7																
8	Azo compounds, diazo comp., hydrazines	H G	H GT	H G	H				8															
9	Carbamates	H G	H GT						H G	9														
10	Caustics	H	H	H		H				H G	10													
11	Cyanides	GT GF	GT GF	GT GF					G			11												
12	Dithiocarbamates	H GF F	H GF F	H GF GT		GF GT		U	H G				12											
13	Esters	H	H F						H G		H			13										
14	Ethers	H	H F												14									
15	Flourides, inorganic	GT	GT	GT												15								
16	Hydrocarbons, aromatic		H F														16							
17	Halogenated organics	H GT	H F GT					H GT	H G		H GF	H						17						
18	Isocyanates	H G	H F GT	H G	H P			H P	H G		H P G	H G	U						18					
19	Ketones	H	H F						H G		H	H								19				
20	Mercaptans, other organic sulphides	GT GF	H F GT						H G									H	H	H	20			
21	Metals, alkali, alkaline earth, elemental	GF H F	GF H F	GF H F	GF H F	GF H F	GF H	GF H	GF H	GF H	GF H	GF H	GF GT H	GF H				H E	GF H	GF H	GF H	21		
22	Metals, other elemental and alloys as powders, vapours or sponges	GF H F	GF H F	GF					E F GT	U	GF H							H E	GF H		GF H F		22	
23	Metals, other elemental and alloys as sheets, rods, drops, modings, etc.	GF H F	GF H F						H F G									H F						23

No.	Name of reactivity group																																									
24	Metals and metal compounds, toxic	S	S	S			S	S			S														24																	
25	Nitrides	GF H F	H F E	H GF	GF H E	GF H			U	H G	U	GF H	GF H	GF H				GF H	U	GF H	GF H	E				25																
26	Nitrites	H GT F	H F GT						U													H P			S	GF H	26															
27	Nitro compounds, organic		H F GT			H			H E													H GF E				H GF E		27														
28	Hydrocarbons, aliphatic, unsaturated	H	H F			H																	H E						28													
29	Hydrocarbons, aliphatic, saturated		H F																											29												
30	Peroxides and hydroperoxides, organic	H G	H E		H F	H G		H GT	H F E	H F GT		H E GT	H E GT					H E	H	E	H F GT	H E	P G		H G	H GF E	H P GT		H P		30											
31	Phenols and cresols	H	H F						H G										H P			GF H				GF H					H	31										
32	Organophosphates, phosphoyhioates, phosphodithioates	H GT	H GT						U		H E											H									U		32									
33	Sulphides, inorganic	GT GF	HF GT	GT		H			E										H												H GT			33								
34	Epoxides	H P	H P	H P	H P	U		H P	H P		H P	H P	U								H P	H P	H P		H P	H P					H P	H P	U	H P	34							
101	Combustible and flammable materials, misc.	H G	H F GT																			H G F				H GF F					H F GT					101						
102	Explosives	H E	H E	H E					H E		H E			H E								H E	H E	H E	E	E					H E	H E		H E	H E	H E	102					
103	Polymerisable compounds	P H	P H	P H					P H		P H	P H	U									P H	P H	P H	P H	P H					P H	P H		P H			H E	103				
104	Oxidising agents, strong	H GT		H GT	H F	H F	H F GT	H F GT	H E	H G GT		H F GT	H F GT	H F	H F		H F	H GT	H F GT	H F	H F GT	H F E	H F E	H F		H F E	H F GT	H E	H F	H F	H G	H F	H F GT	H F GT	H F G	H F G	H E	H F GT	104			
105	Reducing agentes, strong	H GF	H F GT	H GF	H GF F	GF H F	GF H	H GF	H G				H GT	H F				H E	GF H	GF H	GF H						H GF	H E			H E	GF H	GT GF H		H	GF H	H E	H P GF	H F E	105		
106	Water and mixtures containing water	H	H						G										H G			GF H	GF H		S	GF H								GT GF						GF GT	106	
107	Water reactive substances									Extremely reactive! Do not mix with any chemical or waste material!																																107
	No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	101	102	103	104	105	106	107

Note key: Reactivity code (capital letter): consequences of mixing/blending
H: Heat generation **F: Fire** **G: Innocuous and non-flammable gas generation** **GT: Toxic gas generation**
GF: Flammable gas generation **E: Explosion** **P: Violent polymerisation** **S: Solubilisation of toxic substances** **U: May be hazardous but unknown**

Table 4.12: Example of a compatibility chart for the storage of hazardous waste
[53, LaGrega, et al., 1994]

Achieved environmental benefits
Prevents any adverse or unexpected reactions and releases before transfer to storage tanks.

Applicability
Testing is necessary prior to transfer. This needs to cover:

- tanker discharges to bulk storage
- tank to tank transfers
- transfers from a container to a bulk tank
- bulking into drums/IBCs
- bulking of solid waste into drums or skips.

Reference literature
[53, LaGrega, et al., 1994], [55, UK EA, 2001], [86, TWG, 2003]

4.1.4.14 Segregation of storage

Description
A key issue in providing safe storage is compatibility. This has two independent considerations:

- the compatibility of the waste with the material used to construct the container, tank, or liner in contact with the waste (e.g. certain solvents should not be stored in plastic containers)
- the compatibility of the waste with other wastes stored together (e.g. containers of cyanide waste should not be located near acid waste).

After wastes have been checked on arrival, they are split into different groups based on the chemical content and the size of the containers. Some techniques are:

a. consideration of any chemical incompatibilities to guide the segregation criteria (e.g. avoid placing acids with cyanides). The Seveso Directive and Chemical law provide guides for this segregation. The storage BREF also provides some guidances
b. not to mix waste oils with waste solvents. Some commonly used automotive products such as degreasing solvents, aerosol brake cleaners and aerosol carburetor cleaners may contain halogen compounds containing chlorine, bromine and iodine. If mixed with waste oil the entire mixture can become more difficult to treat
c. differentiation of storage according to the hazardness of the waste (e.g. flashpoint limit at 55 °C)
d. to have fire protection walls between storage sectors or a security distance large enough to avoid fire propagation.

Achieved environmental benefits
Segregated storage is necessary to prevent incidents from incompatible substances reacting together and as a means of preventing escalation should an incident occur. Another possible secondary benefit may be related to the fact that mixing wastes may make overall waste management more difficult.

Cross-media effects
Typically more space is necessary for segregated storage.

Applicability
The storage of oxidisers and flammable liquid containers is carried out separately so that they cannot come into contact with one another as a result of leakage.

Driving force for implementation

To prevent incidents due to incompatible reactions occurring. Some legislation and guidances are available on this issue in some Member States (e.g. UK).

Reference literature

[15, Pennsylvania Department of Environmental Protection, 2001], [53, LaGrega, et al., 1994], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [150, TWG, 2004], [151, EIPPCB, 2003]

4.1.5 Segregation and compatibility testing

Description

A primary aid for source reduction is to avoid mixing wastes. The principle is that a mixture of a small amount of hazardous waste with a larger amount of non-hazardous waste creates a large amount of material that must be treated as a hazardous waste. More information can be found in Section 2.1.5. Some techniques and principles to consider are:

a. not making the waste a liquid if it is dry
b. having proper labelling of all lines and containers. This will greatly increase the likelihood that plant personnel will follow any change in practices intended to enhance segregation of wastes
c. only allowing the mixing of polluted wastes of different pollution strengths if the mixed waste is treated according to the more polluted waste
d. keeping the cooling water separate from the waste streams (e.g. from waste waters)
e. considering and when appropriate applying segregation when storing materials (see Section 4.1.4.14)
f. having rules restricting the types of wastes that can be mixed together. Some purposes of such rules are to reduce the environmental risk, for safety reasons or to prevent dilution.

Achieved environmental benefits

Keeping wastes segregated greatly facilitates any required treatment. A lot of problems could be prevented, when an appropriate separation at the source (at production site of the waste) is executed. The key is to segregate incompatible wastes by placing them in separate areas constructed of suitable materials. In some cases if stored together, incidents such as leaks could result in a mixing of incompatible wastes. Different chemical reactions could then occur, with some reactions potentially producing excessive pressure and/or heat, thus posing fire or explosion hazards. Others could produce toxic fumes or gases.

For example, unsegregated used oils typically have a lower value than fuel oil. Contaminated waste oils have the potential to cause pollution when used in combustion processes. Segregated used lubricants can have a higher recovery value as fuel.

The feeding process in the preparation of solid waste fuels from MSW is very important because it has a great influence on the waste OUT qualities. An effectual homogenisation has to be guaranteed and highly contaminated loads should be barred from solid waste fuel processing because they might downgrade the product qualities.

Cross-media effects

In some cases, mixing waste may present a higher risk (due to the potential chemical incompatibility of some components) and may discard the opportunities for recycling.

Applicability

Some techniques mentioned in the description section are applied to waste IN, others to the waste OUT and others are used during the management of the installation (e.g handing and storage of waste). The major impediments to waste segregation programmes are those materials that go to plant trash that do not belong there. Examples to note include laboratory samples, which must be disposed of as hazardous wastes. Other materials include solvents and pigments, for which special receptacles must be provided.

Some plants have separated bunkers for different kinds of waste, e.g. household wastes, commercial wastes similar to household wastes and production specific commercial wastes.

Technique a (see description above) sometimes is considered not applicable for reasons of safety.

Application of the basic principles of mixing an blending as described in Section 2.1.5 (risk prevention, substandard processing and prevention of diffuse dispersal) is different for each treatment route. Wastes may be treated in routes and may end up as a fuel, as a building material, as a fertiliser, as an animal feed, as a feedstock for new products, etc. Given the strongly varying character of the numerous processes, this elaboration will lead to very different results for each route. The choice of the treatment that is made will evidently affect the possibilities for the mixing of wastes. For each waste treatment route, the type and concentrations of environmentally hazardous substances differ and the operational criteria for assessment of the mixing activity will, therefore, also differ.

Before mixing wastes, there is a general assumption that some types of wastes are not suitable for recycling or re-use at all. This may concern wastes from several cleaning processes, for example FGT residues, fly ash, hardening salts, filter cakes containing bearing metals from detoxification-neutralisation-dewatering, blast furnace gas dust, etc. Mixing of these wastes and residues from cleaning processes, which contain high cumulative concentrations of environmentally hazardous substances, is not permitted in any processing route for recovery. These are wastes that must be disposed of and whose environmental risks must be rendered harmless prior to disposal through immobilisation or particle separation techniques. The issues about waste treatment selection are covered in Section 4.1.2.1.

Economics

Some solid waste streams can be segregated effectively through minor changes in equipment. Typically, the disposal of a mixed waste will be more expensive than the treatment of a stream composed of a single type of waste.

Driving force for implementation

Hazardous waste Directive (91/689/EEC) and waste Directive (75/442/EEC) provide the EC legislation framework for the mixing and blending of waste. Some countries define national rules (e.g. in some countries it is absolutely forbidden to mix slag/bottom ash from different sources).

Mixing and blending rules on an operational level are within the boundaries of the permit and other (legal and voluntary) obligations and are written and applied under the responsibility of the waste treatment operator. They take into account risk and safety approaches in order to:

- avoid accidents, which may cause risks to human health and adverse effects on the environment
- prevent technical and mechanical incidents which can cause damage to installations.

So, blending and mixing rules on an operational level are generally linked with:

- regulations in the permit (non-authorised wastes, obligations to keep wastes separated)
- regulations dedicated to safety
- internal and operational procedures (for example, quality control, ISO 14000 certification)
- pre-acceptance and acceptance procedures
- prescription of compatibility tests (during pre-acceptance and acceptance procedures).

Example plants

Some examples of compatibility test typically applied in the waste sector are:

- compatibility tests for storage (see Section 4.1.4.14)
- simulation of the effects associated with the neutralisation in a laboratory experiment
- selection and dosage of the correct precipitation and flocculation agents must be determined in any event through experimentation
- experimental laboratory tests are necessary to determine which chemicals are best suited for oxidation/reduction and what the reaction is like
- laboratory tests carried out to identify the quantity of activated carbon necessary for cleaning the waste water. The most important results are the charge value, e.g. g TOC/g activated carbon, and the necessary contact time
- since the dosing point is particularly important when using organic splitting agents, controls by the laboratory during the process are required
- examination of the following parameters (see Table 4.13) when evaporation/distillation systems need to be applied.

Ingredients	Remarks	Evaporator type
Undissolved solids	Already present or occurring due to precipitation	Evaporators without incrustation and with mechanical equipment for the removal of solids
Volatile substances forming incrustations or gumming	During thermal dissolution	Evaporators with short holding periods and/or small temperature differences between heating and boiling phase
Water vapour-volatile ingredients	With high concentration in the initial solution	Evaporators with special vapour treatment
Boundary-surface active materials	Foam-forming	Evaporators with special separation design and/or addition of anti-foaming agents

Table 4.13: Ingredients affecting evaporation
[121, Schmidt and Institute for environmental and waste management, 2002]

The laboratory is equipped with equipment (e.g. turbo-agitators used only briefly for mixing, slow agitators for floc formation), which roughly simulates the plant conditions.

Segregation of waste oils in order to produce a material with a higher value than fuel oil is a common practice.

Some examples of mixing and blending rules applied to certain types of processes and wastes are reported below.

Thermal processes

In most cases, it is pointless to treat some wastes (some examples in the Applicability section above) by thermal processes. However, if the organic matter content in the original waste is more than 10 %, a thermal treatment may be needed. One criterion for assessing the effectiveness of incineration is, for example, to measure the ‘loss due to burning’ after the thermal treatment. If the ‘loss due to burning’ amounts to less than 5 % of the dry weight of the newly created residue, the treatment is effective. An alternative criterion for the effectiveness of incineration is a level of organic carbon below 3 % in the residue.

Treatment of wastes contaminated with POPs

Mixing and blending of wastes for recovery could be allowed if the concentration of POPs does not exceed the low POP content as defined in the Basel and Stockholm Treaties. This is reflected in the technical guidelines for the environmentally sound management of wastes consisting of, containing, or contaminated with, POPs and with PCBs that were recently adopted by the 7th Conference of the Parties to the Basel Convention. In Table 4.14 the low POP contents are presented. However mixing wastes for other treatment routes such as soil cleaning, preparing animal feed, preparing fertilisers, etc. can be prohibited even if the low POP content is not exceeded.

Compound	Low POP content
Dioxins/furans	0.015 TEQ mg/kg
PCB	50 mg/kg
Other POPs	50 mg/kg

Table 4.14: Maximum concentrations allowed for mixing wastes for recovery [156, VROM, 2004]

Heavy metals - Cd, Hg, Tl

When the three basic principles on mixing and blending and their elaboration are taken into account, competent authorities may allow the following maximum concentrations in wastes for mixing for co-firing or co-incineration, as presented in Table 4.15. Emissions of the heavy metals mercury, cadmium and thallium into the air will occur when waste containing such components are used in cement kilns and power stations. Diverting anything above the maximum concentration levels is, therefore, not allowed. Competent authorities can divert from these maximum concentrations by prescribing a lower level in the permit for mixing and blending, if the acceptance criteria of the receiving plant make this necessary. In this respect, it is relevant to note, that a distinction has to be made in concentrations allowed for mixing and in concentrations to determine the allowable air emission limits.

Metals	Maximum concentration (mg/kg dry matter)
Mercury	10
Cadmium	100
Thallium	100

Table 4.15: Maximum concentrations allowed for mixing for co-firing or co-incineration [156, VROM, 2004]

Waste containing contaminants, other than those mentioned above, may be mixed in order to meet the acceptance criteria for the processing plant. Naturally this does not apply to the previously mentioned residual substances and residues from processing, which contain high concentrations of contaminants.

Reference literature

[53, LaGrega, et al., 1994], [86, TWG, 2003], [89, Germany, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [126, Pretz, et al., 2003], [150, TWG, 2004], [152, TWG, 2004], [156, VROM, 2004]

4.1.6 Techniques for the environmental improvement of other common techniques

4.1.6.1 Techniques to reduce emissions from drum crushing and shredding activities

Description
Several techniques which can be applied to reduce emissions from drum crushing and shredding activities are:

a. making the drum crushing and shredding plant fully enclosed and fitting it with an extractive vent system linked to abatement equipment, e.g. an oil scrubber and activated carbon filter. The abatement system can be interlocked with the plant operation, so that the plant cannot operate unless the abatement system is working
b. keeping skips for the storage of crushed/cut drums covered
c. using sealed system, e.g. chutes, for the containment of residues
d. using sealed drainage
e. avoiding crushing drums that contain (or which have contained) flammable and highly flammable wastes or volatile substances, unless the residues have first been removed and the drum then cleaned.

In a shredding facility, the following techniques can also be applied:

f. providing a hall for conditioning hazardous waste before treatment; the entire treatment hall is kept permanently under negative pressure by the exhaust air treatment installation. Therefore, no emissions are released
g. storing of acids, bases, photographic chemicals, chemicals from households, pesticides and lab chemicals
h. storage for flammable liquids like waste solvents, with a flashpoint of <21 ºC
i. decomposition of the aerosol cans into the following components: propellants, liquid ingredients, metals and plastics
j. suction cleaning of all emissions; an automatic control for the suction of the exhaust air from different processes can be applied and this suction can be reduced during the operation-free time to avoid consuming energy
k. treating the exhaust air with a dust filter and/or a regenerative post-combustion for a residue-free combustion. An upstream pre-coat filter (activated carbon and lime mixture) to collect the adhesive components can also be used.

When treating hazardous wastes in a shredding facility, the following techniques can also be applied:

l. pressure-surge-proof channel of 12 m high against damages
m. the facility is pressure resistant up to 10 bar
n. batch-wise operating of the shredder for minimising the exposure
o. using fire alarm systems and sprinkler installations; furthermore, boxes are equipped with a sprinkler installation for the reduction of dust
p. having an online connection to the rescue service; in case of a fire, the fire department is immediately notified
q. using explosion-proof switches, aggregates and machines in the entire hall
r. using overpressurised cabins with activated carbon filters in all machines, for the safety of the workers
s. fire water of 50 m^3 in a subsurface basin
t. permanent nitrogen flooding of the work space inside the shredder, therefore under oxygen exclusion no reactions will take place (nitrogen purge device).

Finally, to protect the soil in a shredding facility, the following techniques can be applied:

u. using a vacuum monitored laminated base for the identification of leaks; the base of the hall is bowl shaped so that liquid material cannot flow out
v. retaining fire water of 450 m^3; this is possible through the bowl shaped base with a pump sump for pumping the fire water.

Achieved environmental benefits
Reduces VOC emissions to air and reduces contamination to water streams and to soil. Drum crushing/shredding units may vent directly to the air. One technique to reduce VOC emissions is to avoid venting directly to the air unless the emissions/vents have been washed and fully purged of their former contents. Some techniques, for example technique t (see description above), are carried out to prevent ignition.

Operational data
Inert atmospheres to avoid ignition can be generated by the use of inert gases, for example nitrogen or carbon dioxide.

In an aerosol can shredder, suction cleaning of 30000 m^3 hall air per hour over the dust filter is applied. Two separate exhaust air collecting and treatment systems are used. Alternately, controllable source suction in the boxes, shredder and aerosol can shredder with a maximal of 12000 m^3/h may be implemented. The exhaust combustion facility is used at more than 800 ºC for a complete destruction of the harmful substances.

Applicability
Such treatments of some wastes containing e.g. VOCs may create flammable atmospheres which can be a problem as there may also a possibility of static discharges with some types and mixes of wastes and reagents. In some specific cases, some drums containing volatile substances (see technique e in the description section above) may be crushed if the crusher incorporates a system that avoids flammable or explosion problems. When wastes handled do not generate emissions to air (e.g. odours, dust, VOCs) then extractive systems are typically not applied.

Economics
An example bin shredding installation in Germany. The capacity of the facility is 5000 Mg/a. The quantity of hazardous waste treated is 1000 t/yr. The investment needed for the treatment plant is EUR 325000.

An example aerosol can shredding installation in Germany. The capacity of the treatment facility is 500 t/yr. The investment needed for the treatment plant is EUR 500000.

Example plants
An example plant consists of a fume-extracted enclosure mounted on a raised platform and contains a hydraulically operated remotely controlled crushing head. Residues expelled from the drums during crushing are passed via an enclosed chute into a drum placed underneath the elevated platform. Vapours are extracted through an oil scrubber and two activated carbon filters in series, before discharge to the air. Interlocks prevent operation of the crusher when either the crusher door is open or the abatement system is not operating.

Reference literature
[55, UK EA, 2001], [86, TWG, 2003], [150, TWG, 2004], [152, TWG, 2004], [157, UBA, 2004]

4.1.6.2 Techniques to reduce emissions from washing processes

Description
Some techniques include:

a. identifying the components that may be present in the items to be washed (e.g. solvents)
b. transferring washed waste to appropriate storage and then treating this in the same way as the waste from which it was derived
c. using treated waste water from the WT plant; the resultant waste water can be recycled in the WWTP or back to the installation in the case of Ph-c treatment plants. In the latter case, the waste water is treated exactly the same way as waste which has been transported and delivered in the cleaned construction/receptacle/container.

Achieved environmental benefits
Allows the identification and treatment of washing residues.

Applicability
The washing of drums and IBCs is usually only carried out where there is an adjacent treatment plant to accept the wash-waters or when there are other possibilities available to treat the washing water properly.

Washing and cleaning procedures are generally carried out using treated waste water. The resultant washing and cleaning waste water is returned to the process or to the WWTP plant for retreatment. In some cases, the WWTP is installed outside the WT installation.

Reference literature
[55, UK EA, 2001], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

4.1.7 Techniques to prevent accidents and their consequences

Description
IPPC requires, as a general principle, that necessary measures should be taken to prevent accidents which may have environmental consequences, and to limit those consequences. Some techniques include:

a. producing a structured accident management plan within a time-scale, which includes:
    - identifying the hazards to the environment posed by the installation. Particular areas to consider may include waste types, overfilling of vessels, failure of plant and/or equipment (for example, over-pressure of vessels and pipework, blocked drains), failure of containment (for example, bund and/or overfilling of drainage sumps), failure to contain fire-waters, making the wrong connections in drains or other systems, preventing incompatible substances coming into contact, unwanted reactions and/or runaway reactions, emission of an effluent before adequate checking of its composition has taken place, vandalism/arson, extreme weather conditions e.g. flooding, very high winds
    - assessing all risks (hazard x probability) of accidents and their possible consequences. Having identified the hazards, the process of assessing the risks can be viewed as addressing six basic questions:
        - what is the estimated probability of their occurrence? (source, frequency)
        - what may be emitted and how much? (risk evaluation of the event)
        - where does it go to? (predictions for the emission – what are the pathways and receptors?)
        - what are the consequences? (consequence assessment – the effects on the receptors)
        - what are the overall risks? (determination of the overall risk and its significance to the environment)
        - what can be done to prevent or reduce the risk? (risk management – measures to prevent accidents and/or reduce their environmental consequences)

The depth and type of assessment will depend on the characteristics of the installation and its location. The main factors which should be taken into account are:

  - the scale and nature of the accident hazard presented by the installation and the activities
  - the risks to areas of population and the environment (receptors)
  - the nature of the installation and complexity or otherwise of the activities and the relative difficulty in deciding and justifying the adequacy of the risk control techniques

b. having a documented system which can be used to identify, assess and minimise the environmental risks and hazards of accidents and their consequences
c. ensuring that the waste acceptance system of pre-acceptance sampling and analysis, followed by verification upon arrival at the installation forms a crucial role in accident prevention (see Section 4.1.1)
d. maintaining an inventory of substances, present or likely to be present, which could have environmental consequences if they escape. It should not be forgotten that many apparently innocuous substances can be environmentally damaging if they escape (for example, a tanker of milk spilled into a watercourse could destroy its ecosystem). (The inventory is also related with traceability, see Section 4.1.2.3)
e. having procedures in place for checking raw materials and wastes to ensure compatibility with other substances with which they may accidentally come into contact (see compatibility Section 4.1.4.13)
f. keeping apart incompatible wastes and substances according to their hazard potential. Incompatible waste types need to be segregated by bays or stored in dedicated buildings. The minimum requirement involves a curbed perimeter and separate drainage collection. Measures also need to be in place to prevent containers falling over into other storage areas
g. providing adequate storage arrangements for raw materials, products and wastes
h. utilising an automatic system based on microprocessor control, passing valve control or tank level readings. Some examples are: ultrasonic gauges, high level warnings and process interlocks
i. ensuring that control is maintained in emergency situations, considering the utilisation of process design alarms, trips and other control aspects, e.g. automatic systems based on microprocessor control and passing valve control or tank level readings, such as ultrasonic gauges, high level warnings, process interlocks and process parameters
j. documenting the control measures in place, including the evaluation of these measures and a decision about their adequacy
k. putting in place appropriate control techniques to limit the consequences of an accident, such as oil spillage equipment, isolation of drains, alerting of relevant authorities and evacuation procedures
l. applying, as appropriate, preventative techniques, such as suitable barriers, to prevent damage to equipment from the movement of vehicles (see Section 4.1.4.6)
m. providing appropriate containment, e.g. bunds and catchpots, building containment (see Section 4.1.4.4)
n. implementing techniques and procedures to prevent the overfilling of storage tanks (liquid or powder), e.g. level measurements, independent high level alarms, high level cut-off, and batch metering (see Section 4.1.4.1)
o. keeping an up-to-date installation log/diary to record all incidents, near-misses, changes to procedures, abnormal events, and the findings of maintenance inspections. Leaks, spills and accidents can be recorded in the site diary. The incident and response is then available to estimate notifiable releases for the annual report
p. establishing procedures to identify, respond to and learn from such incidents
q. identifying the roles and responsibilities of personnel involved in accident management. Together with this, clear guidance needs to be available on how each accident scenario needs to be managed, for example, containment or dispersion, to extinguish fires or to let them burn
r. putting in place procedures to avoid incidents occurring as a result of poor communication among operation staff during shift changes and following maintenance or other engineering work

s. identifying and providing personnel training requirements as required
t. systems already applied for the prevention of fugitive emissions are generally relevant in addition to drainage systems (see also Section 4.1.3.6):
    - procedures need to be in place to ensure that the composition of the contents of a bund sump, or sump connected to a drainage system, are checked before treatment or disposal
    - drainage sumps need to be equipped with a high level alarm or sensor with a pump to suitable storage (not to discharge);
    - there needs to be a system in place to ensure that the sump levels are kept to a minimum at all times
    - high level alarms, etc. should not be routinely used as the primary method of level control
u. ensuring that process waters, site drainage waters, emergency fire-water, chemically contaminated waters and spillages of chemicals are, where appropriate, contained and where necessary, routed to the effluent system, with a provision to contain surges and storm-water flows, and treated before emission to controlled waters or sewer. Sufficient storage needs to be provided to ensure that this can be achieved. Spill contingency procedures also need to be put in place to minimise the risk of an accidental emission of raw materials, products and waste materials and to prevent their entry into water. Any emergency fire-water collection system needs to also take account of the additional fire-water flows or fire-fighting foams. Emergency storage lagoons may be needed to prevent contaminated fire-water reaching controlled waters (see also Section 4.1.3.6):
v. applying maintenance and testing to the same standards as the main plant or stand-by plants
w. considering and, therefore if appropriate, planning for the possibility of containment or abatement for accidental emissions from vents and safety relief valves/bursting discs. Where this may be inadvisable on safety grounds, attention needs to be focused on reducing the probability of the emission
x. applying suitable procedures and provisions for, e.g. the storage of certain types of hazardous waste which may require automatic alarms and possibly sprinklers. The facility must provide adequate water supply for extinguishing fires plus the capability to collect and store fire-water run-off. The storage or treatment of any water-reactive waste will necessitate an alternative type of fire protection system
y. putting in place safe shutdown procedures
z. establishing communication routes with relevant authorities and emergency services both before and in the event of an accident. Post-accident procedures need to include an assessment of the harm that can be caused and steps need to be developed to redress this
aa. having in place sufficient security measures, including personnel, to prevent vandals and inadvertent intruders who could become exposed from contact with waste, or from damaging the equipment, or illicit dumping. Most facilities use a combination of security guards, total enclosure (usually with fences), controlled entry points, adequate lighting, proper warning signs, and 24 hour surveillance. Typically, the guards also operate the gatehouse where they prevent entry of unscheduled trucks and monitor the entry of visitors
bb. having in place and following an inspection system containing a list of items to be inspected, a schedule, and the typical problems that may be encountered. The inspection should examine process equipment, storage areas, emergency equipment, monitoring equipment, and security devices. Basically, the inspection should check for equipment malfunctions, structural deterioration, operator errors, and discharges that could lead to the release of hazardous waste constituents
cc. appointing one facility employee as an emergency coordinator to take leadership responsibility for implementing the plan. It is important that the facility offers training to its employees to perform their duties effectively and safely so that staff know how to respond to an emergency
dd. having in place a fire protection and explosion protection system, containing prevention and detection equipment, and extinction equipment.

Achieved environmental benefits

The most significant environmental risks associated with waste treatment operations are from the storage of hazardous wastes, from emissions resulting from wastes reacting together either from leaks or spillages, or from treatment processes going out of control.

Combinations of inappropriate equipment and poor inspection and maintenance procedures can also increase the accident risks through, for example, tank overfill situations where level indicators may not be working or have not been correctly calibrated.

Leaks, spills and accidents will occur at any site. One transfer station suggests that there is likely to be an accidental break of a drum every quarter. Technique o (see description section above) helps operators to understand operational problems so that they can put in place measures which will prevent or minimise their occurrences in the future.

Cross-media effects

Not known.

Operational data

Technique o (see Description section above) typically is a computer-based system.

Applicability

Some of the techniques are WT sector specific but others are very general. Some are only relevant for hazardous waste treatments.

Driving force for implementation

Mainly for health and safety reasons (reducing accidents). Technique bb) in the description section above is a basic requirement of EC Directive 75/442 Article 9.

Example plants

These techniques are standard procedures applied in all types of WT plants. However waste treatment plants, typically utilise a manually operated system.

Reference literature

[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [116, Irish EPA, 2003], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004], [152, TWG, 2004]

4.1.8 Techniques to reduce noise and vibrations

Description

A noise management plan is typically part of the environmental management system (EMS in Section 4.1.2.8). Such a plan normally:

a. describes the main sources of noise and vibration (including infrequent sources); and the nearest noise-sensitive locations. This description covers the following information for each main source of noise and vibration within the installation:
   - the source and its location on a scaled plan of the site
   - whether the noise or vibration is continuous/intermittent, fixed or mobile
   - the hours of operation
   - a description of the noise or vibration, e.g. clatter, whine, hiss, screech, hum, bangs, clicks, thumps or has tonal elements
   - its contribution to the overall site noise emission, e.g. categorised as high, medium or low unless supporting data are available

b. provides the above information also for the operation of infrequent sources of noise and vibration (such as infrequently operated/seasonal operations, cleaning/maintenance activities, on-site deliveries/collections/transport or out-of-hours activities, emergency generators or pumps and alarm testing)

c. details the appropriate noise surveys, measurements, investigations (which can involve detailed assessments of sound power levels for individual plant items) or modelling may be necessary for either new or existing installations taking into consideration the potential for noise problems.

Sticking to the ‘noise and vibration’ plan encourages operators to:

d. adequately maintain any parts of the plant or equipment whose deterioration may give rise to increases in noise (e.g. to carry out maintenance of bearings, air handling plant and the building fabric, as well as specific noise attenuation measures associated with plant, equipment or machinery)

e. enclose noisy areas/activities inside buildings.

Achieved environmental benefits

Reduces noise levels generated by the installation.

Applicability

A common sense approach needs to be adopted in determining which sources to include. The ones which need to be considered are those which may have an environmental nuisance impact; for example, a small unit could cause an occupational noise issue in an enclosed space but would be unlikely to cause an environmental issue. Conversely a large unit or a number of smaller units enclosed within a building could, for example, cause a nuisance only if the doors are left open. It also needs to be remembered that some noise, which is not particularly noticeable during the day, may become more noticeable at night.

Driving force for implementation

A reduction of noise and vibrations.

Reference literature

[55, UK EA, 2001], [150, TWG, 2004]

4.1.9 Techniques for de-commissioning

Description

To minimise de-commissioning problems and any associated environmental impacts, some techniques include:

a. considering the de-commissioning at the design stage, thereby making suitable plans to minimise risks during later de-commissioning
b. for existing installations where potential problems are identified, putting in place a programme of design improvements. These designs improvements need to ensure that:
    - underground tanks and pipework are avoided. If it is economically not possible to replace, then operators should protect them by secondary containment or a suitable monitoring programme
    - there is provision for the draining and clean-out of vessels and pipework prior to dismantling
    - lagoons and landfills are designed with a view to their eventual clean-up
    - insulation is provided which is readily dismantled without dust or hazard
    - any materials used are recyclable (having regard for operational or other environmental objectives)
c. maintaining a site closure plan to demonstrate that, in its current state, the installation can be decommissioned to avoid any pollution risk and to return the site of operation to a satisfactory state. The plan should be kept updated as material changes occur. However, even at an early stage, the closure plan can include details on:
    - either the removal or the flushing out of pipelines and vessels where appropriate and their complete emptying of any potentially harmful contents
    - plans covering all the underground pipes and vessels
    - the method and resource necessary for the clearing of lagoons
    - the method of closure of any on-site landfills
    - the removal of asbestos or other potentially harmful materials, unless it has been agreed that it is reasonable to leave such liabilities to future owners
    - methods of dismantling buildings and other structures, for the protection of surface- and groundwater at construction and demolition sites
    - the required testing of the soil needed to ascertain the degree of any pollution caused by the site activities and information on what is needed for any remediation to return the site to a satisfactory state as defined by the initial site report
d. describing the measures proposed, upon definitive cessation of activities, to avoid any pollution risk and to return the site of operation to a satisfactory state (including, where appropriate, measures relating to the design and construction of the installation)
e. describing plans for the clearing of deposited residues, waste and any contamination resulting from the waste treatment activities
f. ensuring that plant and equipment taken out of use are decontaminated and removed from the site.

Achieved environmental benefits

Prevents environmental issues during de-commissioning.

Applicability

The techniques mentioned here are applicable to the installation operation lifetime, the design and build stage of the activities and the site closure.

Driving force for implementation

Technique e (see description section above) is mandatory for current EU regulation on waste.

Example plants

The decomissioning of whole plants or parts of them occur frequently in the sector.

Reference literature

[55, UK EA, 2001], [116, Irish EPA, 2003], [150, TWG, 2004]

4.2 Techniques to consider in biological treatments

This section contains techniques considered to have a good environmental operating performance (e.g use of a good energy system) or that can help lead to a good environmental performance (e.g. environmental management systems). These techniques are applied with biological treatments typically used as part of a whole waste treatment. Biological treatments of waste waters are covered in Section 4.7.

4.2.1 Selection of the appropriate biological treatment

Description

A key technical factor for selecting the appropriate system is its capability to provide proper contact between the organic constituents of the waste and the microbial population. This capability depends primarily on the state of the waste and its concentration. An approximate schematic of the system offering the most capability as a function of these two variables is shown in Figure 4.2.

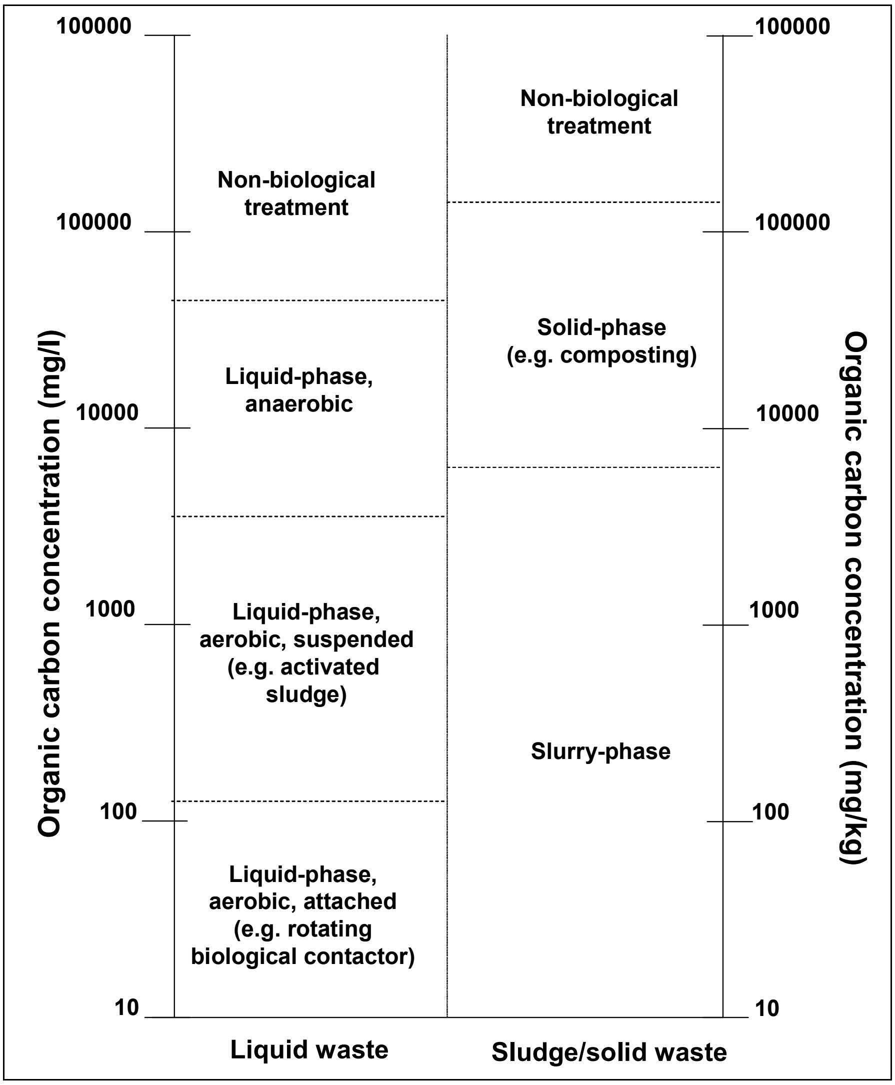


Figure 4.2: Selection of an appropriate biological treatment system as a function of concentration and the form of waste
[53, LaGrega, et al., 1994]

In addition, fully enclosed or encapsulated bioreactors help to better control the biological treatment and avoidance of fugitive emissions (e.g. VOC, odours, dust).

Achieved environmental benefits

Selecting the appropriate biological treatment for the waste to be treated helps to avoid operational problems as well as to extract the major benefit from the waste (e.g. use as fuel).

Operational data

Important features, for consideration, of the selected biological system are the uniform distribution of the nutrients and moisture of the waste to be treated (homogeneity) as well as the availability of treatment selected.

Driving force for implementation

Waste hierarchy may give some guidance on what type of treatments can be used. However, it may be that when applying the waste hierarchy without a good underlying analysis, a good result may not be achieved. It has been reported that in the case of sewage sludge treatment, because of the low energy content of biologically treated sewage sludge in relation to thermally dried sewage sludge, a good option may be to either select anaerobic digestion and thermic drying and/or incineration for different wastes.

Reference literature

[53, LaGrega, et al., 1994], [150, TWG, 2004]

4.2.2 Specific storage and handling techniques for biological treatments

Description

Some techniques related to storage and handling techniques in biological waste treatment include:

a. having reception pits or equalisation tanks
b. housing and equipping the waste treatment installation (including acceptance area and bunker), mechanical treatment, storage facilities and all biological treatment steps) with an exhaust air collection device (containing dust, TOC, ammonia, odours, germs), and where applicable, a removal facility. Air exchanges three or four times per hour are common
c. purifying the exhaust air or re-using it, e.g. as supply air for biological degradation
d. keeping the pollution of the exhaust air low by:
   - avoiding traffic routes through the delivery area
   - using surfaces and work equipment that are easy to clean
   - minimising the storage time of wastes in the delivery area
   - cleaning the floor of the hall regularly with an appropriate sweep-suction cleaner or industrial vacuum cleaner
   - cleaning sunshades, conveyor bands and other equipment at least once per week
e. using a combination of automated and rapid action doors with so-called air curtain installations, which in practice could also act as a lock, with the opening times of the doors being kept to a minimun. This can be helped by the insertion of sensor-controlled rolling shutter gates or flap gates and by sufficient dimensioning of the manoeuvring area in front of the hall. It needs to be recognised that the discipline of the hall and vehicle fleet staff is at least equally important to actually realise the short opening times. It also needs to be ensured that sufficient maintenance of the doors is carried out as required and stick to the appropriate operation. Installing an air curtain creates a curtain of surrounding air in the open door that prevents the ingress of air from the hall. For an underground bunker, which the vehicles approach backwards and then tip over their load, the installation of a curtain with the vehicle outline behind the actual door may be a way to minimise air exchange during unloading as far as possible
f. closing feed bunkers constructed with a vehicle sluice; in open warehouses and during unloading of waste vehicles, the bunker waste gas is removed by suction and fed into a waste gas treatment facility.

In addition during storage and handling, the following measures are suitable for dust minimisation:

g. depositing dust through defogging systems, although this is not mandatory
h. using suction to extraction point sources and hall air, with subsequent dedusting
i. applying coverage of the belt conveyor
j. preventing or minimising large falling heights at interband transmissions
k. using slowly running comminution aggregates
l. regularly cleaning aggregate areas, hall floors and traffic routes
m. using a tyre washing plant to prevent dispersion of waste by the vehicles into the outer areas of the plant.

Also anaerobic decomposition in the storage of waste materials from a civic amenity site/transfer station comprising high levels of grass mowings during warm wet periods should be actively avoided. Typically grass has a high moisture content, and mats together to prevent ingress of oxygen. If the waste has been piled up in a transfer station for a day or so, then bulked into a container and stored in a pile in wet weather, anaerobic conditions will set in. Another possibility for moisture ingress is through unprotected windrows after prolonged wet weather causing aerobic decomposition to cease, so these should be suitably protected or covered.

Achieved environmental benefits
It is important in liquid waste biotreatment systems that the flow of substrate is relatively constant to maintain correct operation, otherwise unexpected emissions can be caused. Some techniques are focused on preventing emissions into the air. For example, temperature rises in waste heaps containing organic matter due to increased biological activity, may occur within short periods of time and may result in air emissions (total C, odour).

Due to the higher temperatures inside the hall, in winter an airflow profile develops at the hall gates, with warm air leaving the hall in the upper part of the opening and cool air entering at the bottom.

Residual wastes may contain large amounts of small-grained particles. Therefore, in the bunker considerable dust emissions can be expected due to the tipping and loading processes with mobile tools, which should be retrieved or deposited as close to the source as possible.

Operational data
The storage areas are usually filled from road tankers or from a pipe to the source.

Applicability
Due to the wide range of biological treatment procedures covered here as well as types of wastes (e.g. containing volatile components, odour), there are some techniques that may be not be applicable to some biological treatments (e.g. activated sludge, aerated lagoons, MBT, in-situ bioremediation, oil contaminated soil und sludge, production of biogas to be used as fuel,...). Some applicability exceptions identified in the techniques below which can be found in the description section above are the following:

- technique b for the last steps of biological treatment or after treatment
- technique e is typically applied to waste no so odours are emitted
- technique f is typically applied to high odour waste.

Driving force for implementation
Related to technique b from the description section above, three or four air exchanges where operators work is applicable by Italian regional law. In areas where operators do not work, two exchanges per hour are typically applied. Technique f comes from a special requirement of TA Luft for fermentation plants and a general provision of the 30 BlmSchV german regulation. Technique m is also a general provision of the 30 BlmSchV German regulation.

Reference literature

[56, Babtie Group Ltd, 2002], [132, UBA, 2003], [150, TWG, 2004]

4.2.3 Selection of feedstock for biological systems

Description

Some issues to consider are:

a. the presence of substances which are not subject to beneficial treatment such as, toxic metals need to be limited for entering into the biological processes. For example, some mechanical treatment may help to accomplish such limitations
b. adding sewage to the organic fraction of municipal solid waste increases the nutrient level as well as adding moisture content. Other wastes that can also have benefits are organic industrial wastes, food processing wastes and agricultural wastes
c. whilst the process itself is an important aspect, the quality of the feedstock probably has the biggest effect and so it is vital to maximise its quality. Both admissible waste types and separation processes are important here. Some techniques include:
    - the right balance of the nutrient content (e.g. nitrogen vs. carbon content)
    - minimising the presence of toxic and unwanted materials (including heavy metals, pathogens and inert materials)
    - recognising that any non-biodegradable components of waste which are fed into an anaerobic digester, and will not be affected by the process, simply take up unnecessary space. To maximise the benefit of using the technique (both environmental and economic) and to minimise the cost, it is important to minimise the presence of these components in the anaerobic digestion feedstock
d. not mixing different types of waste if not proved to be appropriate. This is related with Section 4.1.5
e. continuous learning about the influence of the waste characteristics on the operational settings as aggregates, mass flow, volumes, biological degradation variables (e.g. temperature, CO_2) as well as measured (gaseous) emissions (e.g. use of continuously acquired emission data (raw gas and/or clean gas), VOC, methane, for the adjustment of settings, i.e. automatic control of biological processes)

Achieved environmental benefits

Avoids toxic compounds entering the biological systems, i.e. toxic in terms of reducing biological activity. A good balance of the nutrient content avoids emissions, for example of nitrogen compounds.

If non-biological active parts of the feedstock are separated from the feedstock, such streams can be easily re-used or recycled (e.g. glass, metals)

Cross-media effects

The addition of sewage sludge to the organic fraction of MSW may have bad effects on the biological treatment itself, the exhaust gas quality that is generated during the biological treatment or the quality of the waste OUT.

Operational data

In the case of technique c (see description section above) an integral biological drying of municipal waste is undertaken, as typically the presence of plastics and other non-biodegradable materials can represent an advantage for aeration, preventing anaerobic zones, which leads to lower emissions.

Reference literature

[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [150, TWG, 2004], [153, TWG, 2005]

4.2.4 Generic techniques for anaerobic digestion

Description

Some techniques include:

a. having a close integration between waste management and water management. This would be helpful for further developments and for management to make improvements and gather data
b. recycling the maximum amount of waste water to the reactor, to facilitate any dissolved organic material being converted to biogas
c. operating the system under thermophilic digestion conditions, in order to increase the pathogen destruction, biogas production rate (hence higher energy recovery) and the retention time
d. measuring TOC, COD, N, P and Cl levels in inlet and outlet flows, in order to balance feeds and to ensure good methane production
e. controlling relevant parameters in digestion water, digestion residue and waste water in regular intervals in order to ensure good operation of the installation
f. having closed feed bunkers constructed with a vehicle sluice. In open warehouses and during unloading of waste vehicles, the bunker waste gas is to be removed by suction and fed into a waste gas treatment facility
g. having adequate space particularly for the storage area on the basis of the estimated monthly utilisation
h. designing, constructing and operating the facility in order to prevent soil contamination due to sewage water
i. re-using the condensed water vapours arising from ventilation of the windrows (maturing process) and the accumulated water only in the case of open aerobic digestion treatments in order to humidify the solid waste and in the case that olfactory nuisances may be avoided.

Although anaerobic systems can be operated in stages to reduce overall COD in the effluent, they are generally operated for efficient methane production and the liquid effluent tends to be more concentrated than effluent from aerobic systems, and requires an aerobic final treatment stage. This could be via a discharge to sewer, or though a second stage on site process.

Achieved environmental benefits

Increases the efficiency of anaerobic digestion and allows better use of their products. Minimising the quantity of potentially toxic materials is also an important consideration for the quality of the end-product. Anaerobic systems are effective at breaking down ring compounds (for example, phenols) and generate methane that can be utilised as a fuel. However, not all compounds derived by the anaerobic breakdown of aromatic rings (e.g. xenobiotica) can be mineralised under anaerobic conditions. Anaerobic treatment steps therefore need to be followed by a subsequent aerobic degradation step in order to lead organic material to a full mineralisation.

Odour emissions of 500 – 1000 GE/m^{3}from anaerobic treatment can be reached by using an appropriate combination of biofilter and scrubber if the NH_3 content is higher than 30 mg/Nm^3.

Cross-media effects

The use of sludge in anaerobic digestion needs to be decided on a case-by-case basis, since the heavy metal concentration in sludge may present difficulties for the operator to meet the tight limit values for quality composted products which exist in some EU countries.

Operational data

The high degree of flexibility associated with anaerobic digestion is claimed to be one of the most important advantages of the method, since it can treat several types of waste, ranging from wet to dry and from clean organics to grey waste. The suitability of the method for very wet materials, for instance, has been addressed as an important feature in those scenarios where source separated food waste cannot be mixed up with enough quantities of bulking agents such as yard waste (namely, waste from many metropolitan districts).

Anaerobic biological systems are sensitive to chlorinated and sulphur compounds, pH and to temperature fluctuations and may require a pre-acidification stage.

Recycling of waste water (technique b in the description section above) may result in a increase of the concentration of of toxic/inhibiting compounds that may cause negative effects on the biological treatment.

Thermophilic digestion conditions (technique c in the description section above) may not be useful or possible for all applications (e.g. adaptations of micro-organisms communities for the degradation of chlorinated aromatic compounds or dechlorination of specific xenobiotica cannot be achieved under thermophilic conditions, no thermophilic microbial population can be adapted to the compounds to be treated).

In certain circumstances, it is necessary to control relevant parameters in digestion water, digestion residue and waste water, at regular intervals in order to ensure a good operational mode of the installation (technique d in the description section above). In these cases the parameters mentioned are not sufficient for process control. According to the aim of the treatment (landfilling, fertilisers), parameters for the control of the output have to be fixed according to further use.

Applicability
The main area of concern in anaerobic digestion is the guarantee of the long term performance of a plant, which is of course key to its economic feasibility. This risk can be reduced through technological developments but the associated costs of these can affect the economics in the short term. The building of more plants in the future will further operating knowledge and this may increase confidence (see Section 4.1.2.2). Technique e in the description section above is appropriate to reduce odour emissions.

Economics
Specific investment costs are generally much higher than with aerobic digestion. Having a close integration between waste management and water management would be helpful for further development. This would reduce the extra costs related to the discharge of excess waters from anaerobic digestion to a waste water treatment plant. However, in reality this occurs only rarely across Europe, most often where water utilities are involved in the process.

Driving force for implementation
Better management of the process and requirements of the Landfill Directive. Techniques from e to h in the description section above are requirements under the German TA Luft regulations and technique e is necessary for odour reduction.

Example plants
This treatment method is relatively rare at present (it is only part of waste management strategies in four countries, Germany, Austria, Belgium and Denmark, although some applications are also found on mixed or residual wastes in France, Spain and Italy, and a small-scale plant is also known to be in operation in the UK). Recent developments in source separation schemes in Italy and Spain suggest an optimistic view for the future availability of quality feedstock.

It is also worth mentioning that anaerobic digestion is experiencing the fastest growth take-up across Europe in Spain, thanks to public funding of facilities through EU programmes. Such funding reduces the overall management costs, since depreciation is one of main cost factors.

Reference literature
[33, ETSU, 1998], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [114, Hogg, 2001], [150, TWG, 2004], [153, TWG, 2005]

4.2.5 Increase the retention time in the anaerobic digestion processes

Description
Involves allowing the digestate to spend more time under degradation conditions.

Achieved environmental benefits
A higher retention time will enable more extensive biodegradation and subsequently a better quality digestate and thus can increase the biogas production. Having a high enough temperature and a long enough retention time will ensure that the material is mature, free from pathogenic bacteria and seeds and generate lower odour emissions.

Cross-media effects
The achieved benefits have to be balanced against a lower possible loading rate, which reduces the throughput and thus increases the economic cost per tonne treated.

Applicability
An increase in the biogas production typically has an effect on the quality of the digestate and biogas. Then, an optimisation of the amount of biogas, biogas quality and quality of digestate needs to be carried out.

Reference literature
[59, Hogg, et al., 2002], [150, TWG, 2004]

4.2.6 Techniques for the reduction of emissions when biogas is used as fuel

Description
The biogas from the fermenter is dehumidified and solid particles are removed before it is used as fuel by either an external user or for internal use. Biogas can be used in gas motors, e.g. block unit heating power plants, gas boilers, vehicles or for other uses such as fuel for VOC thermal abatement techniques. Two types of emission techniques can be followed. The first type relates to the cleaning of the biogas before using it, in order to reduce the emissions after its combustion, and the other relates with the abatement of emissions after the combustion of the biogas. Both types of techniques are covered here, some specific measures include:

a. reducing hydrogen sulphide emissions by scrubbing the biogas using iron salts, adding those iron salts into the digester or biological oxidation by a controlled addition of oxygen
b. using selective catalytic reduction (SCR) (Section 4.6.21) to reduce reduce NO_x
c. using a thermal oxidation unit to reduce CO and hydrocarbons
d. using activated carbon filtration
e. equipping those plants with biogas storage and an emergency flare.

Note that when flaring any biogas that cannot be used on-site or upgraded to natural gas quality, the outlet temperature of the flue-gas should be at least 900 °C and the residence time 0.3 sec. The maximum aimed concentration of sulphur compounds in biogas is 50 ppm, or a removal efficiency of at least 98 %.

Among the abatement procedures that may take place in a separate treatment step are: biological scrubbing processes (biological oxidation of the sulphide to sulphur or sulphuric acid), gas scrubbing with water or organic solvents, dry filters composed e.g. of lake iron ore, and adsorption, e.g. to activate carbon.

Some guidance for large combustion plants using biogas have been referenced in the LCP BREF.

Achieved environmental benefits

Parameter	Biogas	Exhaust gas
AOX	<150	
CO		100 – 650[1]
Dust		<10 – 50
NO_x		100 – 500 [2]
H_2S		<5
HCl		<10 – 30
HF		<2 – 5
Hydrocarbons		<50 – 150
SO_2		<50 – 500
Data in mg/Nm^3 at 5 % O_2 [1] when using spark ignition engines with low heat capacity (e.g. <3 MW_{th}) the value of 650 may be difficult to achieve. In those cases, 1000 can be seen as more achievable. [2] when using pilot injection engines with a low firing capacity (e.g. <3 MW) the achieved values are 1000. The lower end of the range can only be achieved with abatement		

Table 4.16: Achieved emission values with the use of good engines and abatement techniques [54, Vrancken, et al., 2001], [117, DG Env, 2001], [132, UBA, 2003], [150, TWG, 2004]

Cross-media effects

Addition of substances as iron salts or oxygen into the anaerobic reactor may be counterproductive to the fermentation process.

Operational data

The utilisation of oxidation catalysts (technique a from the Description section above) is typically used as a short term tool due to corrosion problems that may generate.

Applicability

Cleaning of biogas (except dewatering and removal of solids) before power/heat generation in gas motor and flue-gas cleaning are not usually necessary, according to some information, to reach many of the values given in Table 4.16. Those emission values are typically met by motor adjustments alone. The only expection highlighted is the co-fermentation of pig manure. The biogas generated typically requires desulphurisation because of the high sulphur content, especially in order to prevent corrosion of the unit using the biogas.

Economics

Secondary measures to reduce emissions from flue-gas when biogas is used as fuel. It is considered not economically viable nor environmentally justified for small power/heat installations. In order to reflect such an issue, for example in Germany, installations smaller than 3 MW_{th} have higher emission limit values.

Driving force for implementation

At least three MS have legislation regulating the emissions when using biogas as fuel.

Reference literature

[54, Vrancken, et al., 2001], [117, DG Env, 2001], [132, UBA, 2003], [150, TWG, 2004]

4.2.7 Increasing the energy efficiency of the electricity generators and anaerobic digestion systems

Description
Some issues to consider are:

a. for good energy efficiency, a biogas with an energy content of between 20 and 25 MJ/Nm^3 is preferable
b. electrical conversion efficiencies will vary according to the combustion plant. Practical experience with small scale combustion engines with a rated capacity of less than 200 kW indicate an electrical conversion efficiency of around 25 %, larger plants (up to 17000 kW) can have a higher conversion efficiency of around 36 %. If there is also the added possibility of heating water from the engine's exhaust, this can increase the overall conversion efficiency to 65 – 85 %
c. installing biogas engines with efficiencies higher than 30 % is essential for achieving good overall energy efficiency.

Achieved environmental benefits
Increases the energy efficiency of anaerobic digestion processes. Some data on the energy production are presented in the following two tables (Table 4.16 and Table 4.17). Ranges in these tables are wide, and probably reflect not only the differences in performance across plants, but also across the feedstocks input.

	Net energy production (kWh/tonne of waste)		
Source	**Minimum**[1]	**Average**[1]	**Maximum**[1]
1		100	
2		102	
3		110	
4	80	110	140
5	75	113	150
6	100	115	130
7	105	131	157
8	120	145	170
9	100	150	200
10		154	
11	254	273	292
[1]If only one figure is quoted, the reference in question did not provide a range			

Table 4.17: Net energy production figures that can be achieved under optimum operation of anaerobic digestion processes
[59, Hogg, et al., 2002]

Parameter	**Low value (kWh/t waste)**	**High value (kWh/t waste)**
Biogas yield	70 Nm^3/t waste	140 Nm^3/t waste
Percentage methane	55 %	60 %
Calorific value of biogas	385	840
Electricity generated (30 % efficiency)	116	252
Electricity for export (70 % of electricity generated)	81	176
Heat recovered for CHP option (70 %)	189	412
Heat exported for CHP option (80 % of that recovered)	151	329

Table 4.18: Electricity and heat generated from anaerobic digestion
[59, Hogg, et al., 2002]

Example plants
Many examples of anaerobic digestion plants exist worldwide.

Reference literature
[59, Hogg, et al., 2002]

4.2.8 Techniques to improve mechanical biological treatments

Description
Some techniques include:

a. using filters on the exit air to minimise particulate emissions
b. reducing emissions of nitrogen compounds by optimising the C:N ratio and using acid scrubbers
c. avoiding anaerobic conditions in aerobic treatment installations (where the waste gets starved of oxygen, usually due to it being saturated) by:
    - introducing sufficient woody materials to the mixture (e.g. wood chips), and keeping the structure open. This also helps to reduce the impact of excess nitrogen
    - avoiding waste materials that have both a high water content and limited interstices between the waste materials for water to drain down through the waste under gravity
d. controlling the air supply using a stabilised air circuit. A good adjustment of the aeration can be carried out by controlling the CO_2 concentration per segment or by on line measurements of certain parameters (e.g. O_2, temperature, moisture, methane, VOC, CO_2) of the air supply/exhaust air. This guarantees a sufficient air supply, irrespective of the composition of the waste. The process air is collected from the halls, the exhaust system, etc.
e. using air circulation in order to increase the concentration of carbon compounds in the air. This makes thermal afterburning a feasible alternative for a biological filter. Under these conditions only, e.g. 2500 – 8000 Nm^3 of air per tonne waste need to be treated (related with Section 4.2.11)
f. fully establishing the feedstock specifications
g. carefully positioning the windrows to enable proper access for forming and turning
h. efficient balancing of water to minimise the production of leachates
i. providing impermeable hard standing over a sufficient area to allow machinery movements to turn windrows and also to provide space for leachate collection drainage
j. introducing a high permeability drainage layer, such as wood chips, in the windrow construction to allow leachate drainage and airflow into the windrows
k. making provisions for leachate collection with recirculation systems, in order to feed the leachate back into the windrows to maintain the optimum moisture content and also to facilitate the leachate treatment
l. treating the condensation water by buffer, bioreactors and ultrafiltration. The purified waste water (permeate) can then be used as process water in the cooling circuit that it is evaporated in the cooling tower
m. using as a solid fuel the filter cake generated on the dust filters of the air treatment system
n. thermally insulating the hall ceiling of the biological degradation hall in aerobic processes in order to minimise the generation of condensate
o. recycling process waters or muddy residues within the aerobic treatment process to completely avoid water emissions
p. installing and then operating the conveyor and storage systems, as well as internal treatment equipment for process waters and vapour condensates, in such a way that they do not give rise to relevant diffuse (fugitive) emissions
q. the pretreatment of the biological treatment feedstock to optimise the biological treatment. This may include mechanical techniques like: separating substances which are rather unsuitable for biological treatment, interfering substances and pollutants, as well as optimising the biological degradation of remaining wastes by increasing both availability and homogeneity

r. controling the air emissions of organic compounds, particulate matter, odour, ammonia, mercury, nitrous oxide (N_2O) and dioxins. Some techniques for this are mentioned in Section 4.6.

Achieved environmental benefits

MBT plants are very flexible. They can be built on a modular basis. Some of the above techniques avoid odour, nitrogen and methane emissions.

Optimised biological processes combine a reduction of emissions to water and air during treatment in the treatment plant. Furthermore, another environmental benefit is that mechanically biologically pretreated waste is characterised by a marked reduction in volume, water content and gas formation potential, as well as having a significant improvement in leaching and settlement behaviour in landfills. Another benefit is that a high calorific waste stream is separated which can be incinerated with energy recovery.

Mechanical and physical treatments used as a pretreatment to optimise the conditions for the subsequent biological treatment (e.g. mixing, homogenising, moistening) are adjusted to enhance the separation of valuable materials (e.g. ferrous materials), inhibiting materials or materials for which a biological treatment is not suitable. Sometimes the separation enhances more than one type of material mentioned above.

Related with technique c (see description section above), however, a controlled amount of anaerobic conditions obtained in well regulated processes may be of interest in aerobic treatment due to the production of methane, which can be used as an energy input for thermal-regenerative exhaust gas treatment (and if in addition the quality of the waste OUT still fulfils the requirements, the exhaust gas treatment is optimised, and security arrangements (prevention of explosion and security for employees) are sufficient.

Cross-media effects

VOC emissions from MBTs cannot be avoided because of VOC already in the waste IN and the VOC generated by the biological process. Thus, requirements like housing / fully enclosed bioreactors, collection of exhaust air and effective treatment of exhaust air (limit values for the emissions) reduce such emissions. Aerobic systems (MBT) are suitable for treating wastes containing VOCs. In addition, anaerobic systems may result in well pretreated wastes but still may have a high potential for emissions (ammonia and other compounds generated during anaerobic treatment) and a high biological reactivity (under subsequent aerobic conditions). Therefore, a combination of anaerobic (pretreatment) and aerobic treatment steps are typically required.

Concerning technique c from the description section above on introduction of sufficient woody materials, generally in MBTs there is enough structural material given by the feedstock (MSW). Input of woody materials can cause problems in meeting landfill criteria (e.g. TOC).

Related to e from description section above, when the recirculating air has high humidity, the treatment of the exhaust air may cause problems. In such a case, it is necessary to condense water vapour and thus the condensate water needs to be treated and cooling is necessary to condensate the water.

Related to technique o from the description section above, the aerobic treatment has to take into account that accumulation of recycled substances can result in undesired effects (salinisation --> inhibitory effects, recycling of N-compounds --> higher air emissions of N-compounds (e.g. ammonia, laughing gas).

Operational data

Aerobic biological systems are generally more robust than anaerobic systems, and are less sensitive to chlorinated and sulphur compounds, pH and temperature fluctuations and do not require a pre-acidification stage.

Good operational practice will determine whether or not the site remains aerobic. It is in the operator's best interest to maintain aerobic conditions, to avoid odour problems and to speed up aerobic digestion rates. Anaerobic conditions may lead to occasional problems, i.e. not a regular event, which still need to be recorded in the site diary.

When the relative humidity of the exhaust air is high (more than 90 %), the emission of particulates is low.

Applicability

MBT is widely used for the treatment of MSW, sludges and other types of waste. Aerobic systems may be unsuitable for treating wastes containing VOCs, which may be emitted to the air. Aerobic systems are less effective at breaking down ring compounds (for example, phenols) than anaerobic systems.

Driving force for implementation

The Landfill Directive's acceptance criteria for biodegradable waste. These criteria aim to decrease the biodegradable content of the waste, thereby leading to a significant reduction of gas and leachate emissions from landfill.

Example plants

Widely used throughout Europe. Aerobic systems are used to reduce the putrescible and moisture content of whole waste prior to landfill or for the production of waste derived fuels enclosed. This is a common practice prior to landfill in Europe.

Reference literature

[31, Greenpeace, 2001], [54, Vrancken, et al., 2001], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [114, Hogg, 2001], [116, Irish EPA, 2003], [132, UBA, 2003], [150, TWG, 2004], [153, TWG, 2005]

4.2.9 Aerobic digestion of slurries

Description

Biological treatment of slurries.

Achieved environmental benefits

An example process is a two-step batch process used to treat creosote waste. This involves suspending creosote waste with surfactants in a vessel for seven days at 20 % solids and then transferring the supernatant to a polishing reactor for 14 days of additional biological treatment. This produces the PAH reductions shown in Table 4.19 below:

Constituent	Initial concentration (ppm)	Final concentration (ppm)
Phenanthrene	13000	<100
Fluorene	7000	<100
Fluroanthrene	8000	<500
Pyrene	6000	<500
Benzo(a)pyrene	9000	<100
Benzo(b)fluoranthrene	13000	<500
Benzo(a)anthrarene	11000	<100

Table 4.19: Reported reduction in polycyclic aromatics
[53, LaGrega, et al., 1994]

Cross-media effects

The agitation not only homogenises the slurry but also promotes the volatilisation of contaminants.

Applicability

Wastes can be sludges or solids. It is applied in the treatment of wood preserving wastes, creosote waste, petroleum refining sludges and contaminated soil.

Reference literature

[53, LaGrega, et al., 1994]

4.2.10 Aeration control of biological degradation

Description

Some techniques include:

a. applying overpressure operation
  - this has the following advantages:
    - lower risk of wetting and compaction of the aeration floor
    - rectified flows of air and natural heat emission
    - low requirements for the construction of the aeration floor
  - however, there are also disadvantages:
    - mixing of heap air and hall air
    - intake of air saturated with water vapour into the hall
    - limited accessibility of the hall
    - high corrosion of the constructive elements and machines with increased abrasion and maintenance costs
    - it is not possible to determine the process parameters of the exhaust air
    - biological degradation can only be controlled through indirect measurements and experience
    - separate treatment and purification of heap and hall exhaust air is not possible

b. applying suction (under pressure) operation
  - suction operation by contrast to overpressure operation has the following advantages:
    - only minor pollution of the hall air with heap air
    - low corrosion of the constructive elements and machines
    - hall is accessible during heap aeration
    - possible to determine the process parameters in the heap exhaust air
    - separate collection and treatment of heap air possible
  - the disadvantages of suction operation are:
    - higher requirements for the construction of the aeration floor
    - danger of wetting the distance and diffuse air layer

c. having aeration floor with slitted plates and a basement cellar to ensure an even aeration of the complete moving/turning

d. adapting aeration to the biodegradation activity of the material by segmentation of the biological degradation area in separately controllable aeration fields. Also by regulating the air quantity per aeration field depending on the temperature and oxygen content, by frequency-controlled ventilators or by alternating the cyclic operation

e. ensuring that there is an even flow through the biodegraded material in tunnel system floors, by using embedded punched pipes and relatively high pressures

f. using heat-exchangers to lower the exhaust gas temperature and humidity, in order to ensure a heat discharge in circulating air systems.

Achieved environmental benefits

The aims of aeration are to:

- ensure a sufficient oxygen content in the heap
- prevent methane formation in anaerobic areas
- discharge any methane generated
- lead off the released reaction heat
- allow biogenic drying (in MBT plants with dry stabilisation).

Cross-media effects

The aims mentioned above have to be balanced against the competing aim of minimising the air quantity and evaporation losses.

Operational data

In static biological systems, there is no turnover. Generally the rule holds that the shorter the turnover intervals (with simultaneous watering), the greater is the danger of the heap running dry. Watering the heap without turning often only humidifies the layers near the surface.

Applicability

In encapsulated systems such as tunnel, box or container, aeration of the biologically degraded products occurs under pressure and by circulating air operation. In the housed hall systems both pressure and suction systems are used.

Economics

The construction investment costs of an aeration floor with slitted plates and basement cellar are 40 to 50 % higher than those of other available systems (e.g. aeration tubes or channels in the bottom of the hall).

Reference literature

[132, UBA, 2003]

4.2.11 Management of exhaust gas in MBTs

Description

A good exhaust gas/exhaust air management system contains the following elements:

a. separate collection of exhaust air partial flows
b. minimisation of the exhaust gas through multiple use/cascade-use, circular guidance
c. minimisation of the exhaust gas through anaerobic degradation of organic substances (fermentation with utilisation of biogas instead of aerobic digestion)
d. treatment of partial flows with a combination of biological, chemical, physical and thermal treatment components
e. reduction of specific exhaust air emissions to between 2500 and 8000 Nm^3 per tonne of waste by installing circular guidance across heat-exchangers and by discharging the excess heat as a precondition for an effective circular guidance
f. re-use of the exhausted air as far as possible. The remaining air needs to be treated before being disposed of to the air
g. treatment of the exhausted gas from the delivery area, such as low bunkers and underground bunkers with or without mechanical treatment of the delivered wastes or the recycling of the gas as the air supply (process air) for biological degradation
h. installation in closed rooms with locks or equivalent facilities of the unloading sites, feed bunkers and receiving bunkers or other equipment for delivery, transport and storage of the input substances. The aim of this measure is the minimisation of diffuse emissions. In locks this is achieved by suction of the airlock area so as to keep the ambient pressure below atmospheric pressure
i. for machines, apparatus or other equipment used for mechanical treatment or for physical separation of the waste, e.g. by crushing, classing, sorting, mixing, homogenising, dewatering, drying, pelletising or pressing, the management system needs to ensure that potential diffuse emissions are minimised through encapsulation or suction (focal point suction) of the individual aggregates
j. use of closed containers for the removal of goods emitting dust
k. used of encapsulated or housed systems for the conveyance and treatment of fermentation residues. The exhaust air from these systems is to be collected (hall and source suction), preferrably so it can be re-used within the process or for it to be treated

l. splitting of the total volume flow that is to be treated into heavily polluted exhaust gas and lightly polluted exhaust air. Therefore, the choice of a suitable system for the treatment of the lightly polluted but odour prone exhaust air plays a key role in MBT plants with long term biological degradation. However, the system is completed by further components, such as an acid scrubber (absorption of ammonia), a dust filter and an oxidation facility for the treatment of higher polluted streams mainly from the pre-biological degradation stage. The type of the oxidation facility (thermal, chemical, physical) and the exhaust gas quantity from the pre-biological degradation that has to be treated have to be adapted to the chosen process concept and fixed in each individual case
m. monitoring exhaust gas emissions on line and using data for the adjustment of biological processes
n. using of absorption/desorption and combustion systems in case the concentration of the carbon compounds is low.

Achieved environmental benefits
Reduces air utilisation and exhaust air emissions.

Operational data
The exhaust gas management affects both the construction and process engineering of the facility. The following factors play key roles in any exhaust gas management strategy:

- minimisation of hall volume
- segmentation of the operation units
- close-to-source measures for the active and passive minimisation of emissions.

Applicability
Mechanical biological treatments (MBT)

Reference literature
[132, UBA, 2003], [150, TWG, 2004]

4.2.12 Abatement techniques for biological treatments

Table 4.20 shows air abatement techniques reported to be applied in biological treatment plants. These are described in detail in Section 4.6.

Technique	Section number where it is covered
Generic prevention	Section 4.6.1
Adsorption	Section 4.6.7
Biofilters	Section 4.6.10
Chemical scrubbing	Section 4.6.12
Low-oxidative processes	Section 4.6.13
Incineration	Section 4.6.14
Catalytic combustion	Section 4.6.16
Regenerative thermal oxidiser	Section 4.6.18
Non-thermal plasma treatment	Section 4.6.20

Table 4.20: Air abatement techniques used in biological treatment plants

4.3 Techniques for physico-chemical treatments

This section contains techniques considered to have a good environmental operating performance (e.g use of a good energy system) or that can help lead to a good environmental performance (e.g. environmental management systems). Techniques in this section relate to physico-chemical treatments described in Section 2.3.

4.3.1 Techniques used in physico-chemical treatment plants of waste waters

4.3.1.1 Planning the operation of a Ph-c plant

Description
The following principles have to be followed:

a. all measurement and control installations have to be easily accessible and easy to maintain
b. control and testing system have to be established
c. the reception inspection need to be adapted to the information from the declaration analysis of the proof of waste disposal and to the process order provided for each particular treatment
d. the production of waste water should be prevented as far as possible by construction measures, e.g. roofing of the reception area
e. in order to prevent unwanted mixing, the reaction containers should also serve as storage containers
f. adequate storage capacity has to be provided, since the time of demand and delivery usually do not coincide
g. the plant concept should provide for potential modification or expansion
h. collection and transport of wastes as well as delivery (quantity, time) should be adjusted to the operation
i. producers and distributors should be addressed for all technical details and information (e.g. about containers, pipes, pumps, valves and filters),
j. planning and construction (especially legal matters) should be discussed early with the responsible authorities and with technical planning offices.

Achieved environmental benefits
Emissions are reduced as the correct treatment procedure is established in the Ph-c plant.

Operational data
The design of a Ph-c plant is set in a clear way which follows the material flow. For example, two fundamentally different cases need to be distinguished:

1. dimensioning of a plant which treats similar waste types
2. dimensioning of a plant which treats varying waste types.

In case (1), the plant can be developed by means of experiments that are specifically tailored to the waste requirements. The necessary process steps can be tested individually or in combination; the result is an optimal treatment solution. In case (2), different treatment processes have to be planned that lead to optimal treatment when applied in combination. In addition, while in case (1) continuously operated plants seem appropriate, in case (2), discontinuous operation should be recommended because of adjustment of the technology and operation mode to different reactive behaviour of the wastes.

Applicability
Applicable to new installations.

Reference literature
[157, UBA, 2004]

4.3.1.2 Techniques for Ph-c reactors

Description

Some techniques include:

a. clearly defining, the objectives and the expected reaction chemistry for each treatment process. There needs to be a defined end-point to the process so that the reaction can be monitored and controlled. The suitable inputs to the process need to be defined and the design needs to take into account the likely variables expected within the waste stream
b. assessing each new set of reactions and proposed mixes of wastes and reagents prior to treatment in a laboratory scale test mix of the wastes and reagents to be used. This needs to lead to all reactions that will occur in the full scale treatment and so the mixing of wastes needs to be done to a pre-determined batch 'recipe'. This needs to take into account the potential scale-up effects, for example, the increased heat of reaction with the increased reaction mass relative to the reactor volume, increased residence time within the reactor and modified reaction properties, etc.
c. specifically designing and operating the reactor vessel so that it is fit for its intended purpose. Such designs need to include considerations of the chemical process hazards, a hazard assessment of the chemical reactions, considerations of appropriate prevention and protection measures, together with consideration of the planned process management, that is, working instructions, staff training, plant maintenance, checks, audits and emergency procedures
d. enclosing all treatment/reaction vessels and ensuring that they are vented to the air via an appropriate scrubbing and abatement system
e. where appropriate, ensuring that the reactor vessels (or the mixing vessels where the treatment is carried out) are charged with premixed wastes and reagents. For example some reactor vessels may need to be 'pre-limed' or charged first with the reacting alkali to control the reaction, using for example calcium hydroxide solution made up prior to charging the reactor vessel
f. avoiding decanting the sacks or drums directly to the vessel. This practice can lead to:
    - concentration 'hotspots' at the surface of the reaction liquor
    - a loss of reaction control
    - the emission of fumes from the instantaneous reaction at the interface
    - the open hatch venting fumes and thus bypassing the appropriate abatement
g. monitoring the reaction to ensure that it is under control and proceeding towards the anticipated result. For this purpose, the vessels used for treatment need to be equipped with high level pH and temperature monitors. These need to be automatic and continuous and linked to a clear display in the control room or laboratory, together with an audible alarm. A risk assessment may require process monitors to be linked to cut-off devices. Monitoring of the reaction is necessary because the reaction characteristics in the reactor may vary from those found in the laboratory tests. Monitoring needs to provide an early indication of any deviation from the laboratory tests, and also needs to enable measures to be taken to halt or modify the reaction. There should, consequently, be a provision for the cooling and/or quenching of reactor vessels
h. ensuring that there is adequate mixing within a treatment vessel as this may determine the success of the reactor. The standard method for agitating the contents of a vessel is a rotating impeller. There is a geometric ratio between the size of the impeller and the clearance from the vessel (determined by type and size of vessel). This also depends on the agitation speed and characteristics of the waste. A seal is required where the impeller enters the vessel to prevent fugitive releases. A method of mixing should be provided
i. in order to track and control the process of change, keeping a written procedure for the proposal, consideration and approval of any changes or technical developments including all procedural or quality changes
j. ensuring that any VOCs that are emitted due to the high temperature rise in the reaction vessels are returned to the treatment system after condensation in the scrubbers
k. monitoring the reaction throughout the course of the reaction. It may be necessary to extract the exhaust air of the reactor

l. having a system, as is the case at most sites, to exchange the air above the reaction vessels and to pass it through some type of treatment system to remove gases such as ammonia, hydrogen chloride, sulphur dioxide. Typically aqueous liquors from scrubbers are returned to the treatment plant, and activated carbon systems are regenerated (e.g. by steam stripping) or in case this is not possible, the activated carbon is incinerated.

Achieved environmental benefits
Control of the reaction/treatment process is crucial to environmental protection and to preventing possible accidents. A yield of 96 % removal of metals can be attained.

Applicability
Physico-chemical plants undertake input waste screening to enable them to store wastes in the correct tanks and to balance the reactions.

Driving force for implementation
Some national effluent standards are available, e.g. the Surface Waters Pollution Act in the Netherlands.

Example plants
In general, neutralisation reaction tanks are fitted with alkaline scrubber units and most of the acid gases are returned to the process along with some of the VOCs and almost all of particulate matter/liquors. The capacities of the example plants vary from 200 to 40000 m^3/yr.

Reference literature
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004], [156, VROM, 2004]

4.3.1.3 Neutralisation

Description
The purpose and principle of operation of the neutralisation is shown in Section 2.3.2. Some issues to consider include:

a. preventing the mixing of acidic/basic waste with other streams to be neutralised when the mix contains metals and complexing agents at the same time. This prevents the formation of metal complexes that are difficult (from an economic point of view) to separate afterwards. Complexing ions to watch out for include, for example, EDTA, NTA and cyanides
b. making the necessary neutralisation equipment robust and easy to use can help the equipment stand up to the vigours of use in Ph-c plants dealing with acidic/basic wastes needing neutralisation
c. ensuring that the customary measurement methods, i.e. with the aid of glass electrodes or similar sensors, are used in Ph-c plant operation for the neutralisation of waste matter if the electrodes are constantly cleaned and properly calibrated. Determination of the pH value is also possible by the measurement of prepared samples or by measurement using litmus paper
d. separately storing the neutralised waste water in order to avoid negatively affecting the quality of the treated waste water due to secondary reactions occurring if they were stored together. Final inspection of the treated waste water needs to be performed after a sufficient storage time has elapsed.

Achieved environmental benefits
Improves the neutralisation process performance and avoids downstream problems (e.g. preventing the mixing of wastes or other streams in a way that further treatment of the waste water is no longer possible).

Operational data

If sulphuric acid (H_2SO_4) and milk of lime ($Ca(OH)_2$) are combined, gypsum ($CaSO_4 \cdot 2H_2O$) may be produced as a reaction product. The gypsum may lead to deposits and incrustation, causing serious operational disruption and necessitating extensive maintenance and repair measures. However, these problems can be minimised by adequate operation of the neutralisation process (using diluted H_2SO_4 and pre-neutralisation with lime) and vigorous mixing. If NaOH instead of lime is used for neutralisation, other problems may occur. According to some experiences, high sulphate concentrations in the waste water caused by NaOH neutralisation may attack sewers made of concrete and consequently lead to odour emissions.

Applicability

Neutralisation can be applied with all mixable liquid waste.

Example plants

In a dilute aqueous system, it should be possible to conduct neutralisation processes without either deliberately or inadvertently producing gases. In such system processes involving potentially hazardous substances, for example, acid neutralisation can normally be performed without creating substances that require continuous abatement, for example, SO_x, etc.

Reference literature

[55, UK EA, 2001], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

4.3.1.4 Precipitation of metals

Description

The objective of these techniques is to precipitate the metals contained within aqueous wastes. Some techniques include:

a. acidifying the waste to solubilise all the metals in a first step
b. adjusting the pH to the point of minimum solubility where the metals will precipitate
c. allowing the resulting treated waste to clarify by decantation when possible (for example, high concentrations of metals in water are very difficult to be clarified by decantation), and/or by the addition of other dewatering equipment (e.g. filter press or centrifuge equipment)
d. avoiding the input of complexing agents, chromates and cyanides (due to the danger of HCN formation from acidifying waste materials)
e. changing precipitation conditions, for example, if the target metal concentration of treated waste water is not achieved using hydroxide precipitation (e.g. because of the presence of complexing agents), sulphidic precipitation (e.g. with sodium sulphide or organic sulphides) can be used. This aims at the formation of metal sulphides which are difficult to dissolve in water. Hydrogen sulphide is used, and therefore operating conditions and emissions demand particular consideration. In practice, sulphide precipitation is used in treating waste water containing complexing agents
f. avoiding organic materials from entering the process, since they generally disrupt the precipitation reaction
g. organising the process according to the following steps:
    - experimental investigation by the laboratory; determination of a treatment programme
    - establishing process control values, e.g. pH value, temperature, metal concentration
    - determination of ancillary agents according to type, quantity, concentration
    - determination of dosage for the ancillary agents, e.g. l/h
    - determination of the sequence for the addition of the ancillary agents
    - functional testing of the equipment
    - execution of the precipitation/flocculation; documentation of process control.

Achieved environmental benefits

Substances such as chromium, zinc, nickel, lead are usually present dissolved in solution or absorbed onto particulate or colloidal matter. It is a relatively simple and robust technology and shows performances of up to 95 %.

Cross-media effects

Chromium (III), zinc and cadmium are amphoteric and solubility will rise at a pH above their mimimum solubility points. The production of sludge containing metals can be seen as a cross-media effect. The amount of filter cake can be reduced by replacing the lime by sodium hydroxide, however, in such a case, the fluorides are not precipitated.

The use of sulphide technique e (from the description section above) typically results in a high sulphide concentration of the waste water. Alternatively, wet oxidation or separation at source may be applied.

Operational data

Similarly to acid/alkali neutralisation, the process involves the addition of acid or alkali (which may be a waste) within a stirred reaction vessel. Typically lime is used as the hydroxide.

Related to technique b from the description section above, Table 3.48 (in Chapter 3) showed the pH range values for the precipitation of various metals as hydroxides. The pH value for minimum solubility depends on the metal, and then in the case of a mixture of metals, an optimum value needs to be found. For such an optimum pH, it may be that some metals do not precipitate at all. This is the reason why, in some cases, more than one pH step is used to maximise the removal of metals.

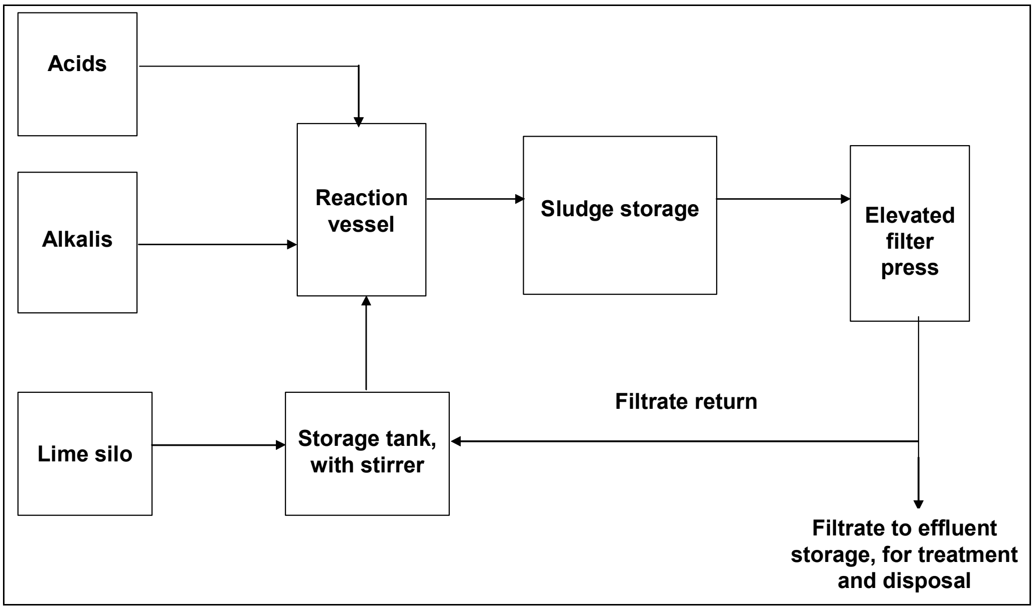


Figure 4.3: Representation of a precipitation/neutralisation process
[55, UK EA, 2001]

The advantages of batch operations in the treatment of waste with characteristics which vary very much from load to load are shown by the results of the operation and experience, for example:

- for a constant pH value, the metal concentration in the waste water can still decrease
- by repeated mixing of waste water and sedimentary sludge, additional co-precipitation effects can be achieved; a prerequisite for co-precipitation is gentle sludge circulation and transport.

Since in general metal corrosive materials are used, the plant (containers, pipelines, measuring technology) must be appropriately equipped and/or protected (use of synthetic materials, painting, etc.).

Applicability

Aqueous waste treatment processes treat a variety of compatible aqueous waste materials by precipitating soluble metals and acidic anions out of solution while increasing the particle size of suspended solids, thereby aiding later phase separation between solids and liquids by clarification and filtration. Typical wastes include interceptor wastes, paint spray booth wastes and process effluents, among others.

Driving force for implementation

In the Netherlands, this technique of concentrating metals in the sludge is applicable for waste waters containing metals (except for picking acid and except for waste waters containing precious metals) when the waste water contains a metal (As, Co, Cr, Cu, Fe, Mo, Ni, Pb, Sn, V and Zn) concentration of more than 200 mg/l of which 25 mg/l are present in the water fraction and / or the amount of Cd is bigger than 0.2 mg/l.

Example plants

In an example plant, galvanising/pickling acid is added to a reaction vessel, lowering the pH to 5. This allows the release of ferrous ions from the acid, to act as a reducing agent, reducing metals from high to low oxidation states, which can then be removed (as hydroxides) from solution by later increasing the pH to 9 by lime addition.

Reference literature

[55, UK EA, 2001], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004], [153, TWG, 2005]

4.3.1.5 Break-up of emulsions

Description

Some techniques include:

a. using waste acids and waste alkalis as materials to break up the emulsions
b. using evaporation, ultrafiltration or organic breaking up agents
c. testing for the presence of cyanides in the emulsions to be treated. If cyanides are present the emulsions need a special pretreatment first
d. setting up simulated laboratory tests first. The operator typically sets up a treatment programme, containing details about the type and quantity of the acids, caustic solutions and flocculation agents to be used. Laboratory tests on samples can help determine whether an adequate waste water quality can be achieved
e. carrying out the process with substantial precision and control of the process and organic splitting.

Achieved environmental benefits

The acid splitting of emulsions is of extraordinary importance for the disposal of waste and for the protection of water, because waste, such as spent acids and waste alkali, can be used for the treatment of the emulsions. During organic splitting, incomplete splitting is possible in the event of underdosing, and a new formation of emulsions is possible with overdosing.

Techniques mentioned in the description section above are important to be considered in the determination of the the most appropriate method for the break-up of each type of emulsion to avoid environmental and operational problems.

Cross-media effects
Further treatment of the waste water may possibly be necessary subsequent to the treatment of the emulsion, for example using an ion exchange, or activated carbon adsorption. If this is necessary it should be specified as an operating instruction in the treatment programme.

The use of waste acids and waste alkalis (see technique a in the description section above) typically produce a waste water with higher concentrations of salts and remaining oil. The oily sludge is typically more difficult to be landfilled and the oil cannot be recovered.

Operational data
The actual treatment of the emulsion, also referred to as splitting the emulsion, consists of two treatment phases:

- destabilisation (separation) of the emulsion, by mixing the emulsion with acids
- flocculation and precipitation of the dissolved metals present in the separated emulsion.

Reference literature
[121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

4.3.1.6 Oxidation/reduction

Description
Some techniques include:

a. abating the air emissions generated during oxidation/reduction
b. having in place safety measures and gas detectors (e.g. suitable for detecting HCN, H_2 S, NO_x).

Achieved environmental benefits
Reduces the emissions that may occur from the redox reactions.

Example plants
The collection of the exhaust air is ensured by suction with a fan and exhaust air filter. Here no measurements are made since the transported exhaust air rate is overdimensioned. The filter, which may involve acid or base scrubbers, is regularly controlled and if necessary regenerated.

Reference literature
[121, Schmidt and Institute for environmental and waste management, 2002]

4.3.1.7 Techniques for the treatment of wastes containing cyanides

Description
Cyanides can be destroyed by using different kinds of oxidising agents, such as hypochlorite, chlorine, ozone, peroxides and peroxides with UV radiation. Other techniques can be electrochemical oxidation or wet oxidation with air (medium to high pressure). High temperatures also destroy cyanides in solid waste. However, incineration techniques are not included in this document. Some issues to consider include:

a. cyanides can be destroyed in aqueous waste streams by oxidation with a basic oxidising agent at a pH not less than 10 and a chlorine concentration of less than 1 g/l. The reaction is very rapid
b. adding caustic soda in excess can prevent the pH from falling too low
c. the mixing of cyanide wastes with acidic compounds (e.g neutralisation, acid emulsion break-up) needs to be avoided

d. since the treatment of cyanide is by oxidation the destruction can be checked by the measurement of redox potentials (electropotentials). The addition of sodium hypochlorite to an effluent sump can therefore be controlled
e. the use of electrolysis to oxidise cyanide.

Achieved environmental benefits
The resulting cyanate cannot readily be reduced back to cyanide and any discharge of cyanate to a watercourse will not lead to free cyanide being generated. There are also less health risks. The pretreatment of waste waters containing cyanides is essential to avoid the formation of metal-cyanide complexes. With these techniques, concentrations of less than 0.1 mg/l of cyanide can be achieved.

Cross-media effects
Use of oxidant (e.g. hypochlorite, potassium permanganate) when required.

Using hypochlorite or chlorine increase the salt content of the waste water and can also increase the content of AOXs. Cyanogen chloride may also be generated during the treatment with chlorine oxidisers. When using chlorinated oxidisers, it is important that the pH of the system remains greater than 10. If the pH is too low, then cyanogen chloride and hydrogen cyanide can be formed. If there is excess hypochlorite present then chlorine gas can be released, and if there is a lack of hypochlorite then residual cyanide will present.

Using H_2O_2 or ozone as an oxidiser does not create any of the by-products as shown in the following reactions:

$$\mathrm{NaCN} \;+\; \mathrm{OCl} \quad > \; \mathrm{OCN} \;+\; \mathrm{NaCl} \quad \text{(hypochlorite method)}$$

$$\mathrm{CN} \;+\; \mathrm{H_2O_2} \quad > \; \mathrm{OCN} \;+ \mathrm{H_2O} \quad \text{(peroxide method)}$$

Operational data
Discharges of aqueous effluents to watercourses is monitored continuously for cyanide content, free chlorine and the pH level. The use of pure oxygen as an oxidiser is not as efficient as the other oxidants mentioned.

Applicability
Chemical and thermal treatment methods are most widely used for the destruction of waste streams containing cyanide.

Driving force for implementation
The destruction of cyanides.

Reference literature
[55, UK EA, 2001], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004], [156, VROM, 2004]

4.3.1.8 Techniques for the treatment of wastes containing chromium (VI) compounds

Description
Some techniques include:

a. the mixing chromium (VI) wastes with other wastes needs to be avoided
b. the conversion of Cr(VI) to less hazardous Cr(III) can be achieved by the addition of a reducing agent, for example, sodium metabisulphite, pickling acid, sodium dithionite. The trivalent metal can then be precipitated in the normal way (see Section 4.3.1.4).

Achieved environmental benefits
Chromium (VI) is the highest oxidation state of the metal, an example of this is chromic acid, or chromium oxide (CrO_3) which is acidic, toxic, water-soluble and used as an oxidising agent. With these treatments concentrations less than 0.1 mg/l of chromium (VI) are achievable.

Cross-media effects
There is a need for a reducing agent.

Driving force for implementation
Treatment by straightforward neutralisation of chromium (VI) compounds is ineffective so an initial step needs to be applied involving reduction to chromium (III), the trivalent state.

Reference literature
[55, UK EA, 2001], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004], [156, VROM, 2004]

4.3.1.9 Techniques when treating waste water contaminated with nitrites

Description
Some techniques include:

a. avoiding mixing nitrites wastes with other wastes
b. checking and avoiding nitrous fumes during the oxidation and acidification of nitrites
c. checking and avoiding nitrous fumes during the reduction of nitrites.

Achieved environmental benefits
Concentrations of less than 2.0 mg/l of nitrite can be achieved by good optimisation of the nitrites treatment process.

Cross-media effects
Use of an oxidiser agent is required in oxidation processes. Reducing agents used are urea or amidosulphuric acid.

Example plants
There are three plants operating such systems in Austria.

Reference literature
[121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

4.3.1.10 Treatments of phenolic solutions by oxidation

Description
It is possible to treat aqueous wastes containing phenol (3 – 5 w/w-%) by catalytic oxidation, using an oxidising agent and a metal catalyst or by a strong oxidising reagent (e.g. $KMnO_4$).

Achieved environmental benefits
Reduces the phenol content in aqueous wastes.

Cross-media effects
Use of oxidising agent and catalyst where necessary.

Operational data
The treatment procedure needs to take account of the exothermic nature of the reaction. Feedstocks can be diluted before treatment. The process temperature, pH and redox potential are continually monitored.

Example plants
An example plant in UK shows uses of this process on a three tonne batch basis in a stainless steel, double skinned vessel.

Reference literature
[55, UK EA, 2001], [150, TWG, 2004]

4.3.1.11 Techniques for wastes containing ammonia

Description
Some techniques include:

a. for waste with ammonia solutions up to 20 w/w-%, treating them using a dual column air stripping system with an acidic scrubber. A dual column process has been developed, where the initial column raises the temperature of the feedstock and maintains the pH between 10 – 11. The feedstock is then transferred to a second column where it is run countercurrently across a packed column against air
b. recovering the ammonia in the scrubbers and returning it to the process prior to the settlement stage
c. removing the ammonia removed in the gas phase by scrubbing the waste with sulphuric acid to produce ammonium sulphate.

Achieved environmental benefits
These techniques prevent a large emission of ammonia gas during the initial neutralisation process when the pH is changing rapidly, as the tanks are agitated and the temperature is rising.

Operational data
Solutions high in ammonia can also undergo pretreatment (e.g. air stripping) to reduce the concentration of ammonia before reaching the treatment plant.

Applicability
Such systems are applied to waste waters with a high ammonia content. There are other wastes containing ammonia / ammonium what, e.g. landfill leachate, for which the described stripping system is not adequate due to the transfer of other substances to the gas phase.

Economics
The solutions containing ammonia can also be used as a deNOx agent. This destination might be less expensive than collection/treatment as a hazardous waste.

Driving force for implementation
Ammonia contributes to acid rain and manure pollution.

Reference literature
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [150, TWG, 2004]

4.3.1.12 Filtration

Description
Some techniques include:

a. extending any air sampling for ammonia in exhaust stacks or filter press areas to cover VOCs
b. linking the air space above some presses to the main abatement system at the plant
c. improving the draining behaviour of mud by the addition of flocculation agents, for example lime, or synthetic flocculation agents. This conditioning of the mud take place in containers equipped with adjustable agitators. To mix the mud with the flocculation agents, an intensive mixture can be achieved in a short time by accelerating the agitator; the agitator usually moves slowly during the floc formation, so as not to impair flocculation.

Achieved environmental benefits
Improves the filtration process and reduces the fugitive emissions. Filter cake with high concentrations of metals, e.g. nickel and copper, can be used as a raw material in the metalurgical industry.
Cross-media effects
The need to clean the filter cloths is a disadvantage; applying high pressure cleaners with water or washing the cloths in special partly acid washing solutions have proven to be beneficial for this purpose.

The need to maintain the presses and to remove cake/sludge means that the system is opened on a regular basis, making it hard to avoid air emissions.

Operational data
Energy is required to run the process.

Reference literature
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

4.3.1.13 Flotation

Description
The dissolved air flotation (DAF) system generates a supersaturated solution of waste water and compressed air by raising the pressure of the waste water stream to that of the compressed air, then mixing the two in a retention tank. This supersaturated mixture of air and waste water flows to a large flotation tank where the pressure is released, thereby generating numerous small air bubbles. Through a combination of adsorption and entrapment, the flocculated particles rise to the surface of the reactor. The suspended solids float to the top of the liquid and form a foam that is then skimmed off. Some soluble colloidal substances are removed from the waste water by adding coagulation and flocculation chemicals to form precipitates with the solutes.

Achieved environmental benefits
DAF is widely used because of its effectiveness in removing a range of solids.

Cross-media effects
Emissions to the air are possible and a large amount of chemical sludge is produced (containing $FeCl_3$, $Al(OH)_3$, polyelectrolytes and enclosed particles), which need to be treated before disposal.

Operational data
Usually chemicals such as polymers, polyelectrolytes, aluminium salts (e.g. sulphates), or iron salts (e.g. ferric chloride) are used to enhance the adhesion of bubbles. The process requires energy to run.

Driving force for implementation
No need for a sedimentation vessel.

Example plants
DAF is widely used.

Reference literature
[55, UK EA, 2001], [86, TWG, 2003], [150, TWG, 2004]

4.3.1.14 Ion exchange processes

Description
Some techniques include:

a. using ion exchangers only for salt concentrations of less than 1500 mg/l. Otherwise the treatment is not economically viable
b. using pretreatments to reduce the salt concentration, e.g. precipitation
c. removing solid materials in solutions by sand filters or activated carbon adsorption before using ion exchange processes
d. using conductivity measurements to monitor and operate the ion exchanger plant (cation-anion combination). It is very sensitive and not likely to be susceptible to interference.

Further test parameters may be oils, emulsified materials (combustion loss), solid materials in the intake of the ion exchanger, the pH value, aromatic hydrocarbons, chlorinated hydrocarbons and organic acids.

Achieved environmental benefits
Improvement of the ion exchange processes.

Operational data
Ion exchangers can only work in ‘clean’ solutions, i.e. solutions, which primarily contain ions but no solid constituents.

Reference literature
[121, Schmidt and Institute for environmental and waste management, 2002]

4.3.1.15 Membrane filtration

Description
The requirement for resistance vis-a-vis cleaning, long life as well as low manufacturing costs of the membranes, applies to all membrane procedures. The selection of the suitable membrane is of central importance for the treatment of waste. Some techniques in the selection and use of a suitable membrane include:

a. examining in the laboratory which membrane is suitable for the waste to be treated
b. submitting the permeate and concentrate resulting from ultrafiltration to subsequent treatment. In the case of the permeate, this may be detoxification, neutralisation, precipitation or evaporation. In the case of the concentrate, this may need to be disposed of
c. monitoring the following parameters in micro and/or ultrafiltration systems:
    - pH value
    - throughput
    - electrical conductivity
    - pressure, temperature
    - oil content
    - permeate efficiency and/or quality (e.g. clouding value, hydrocarbons)
    - cyanide, nitrite, chromate
    - solid content.

Achieved environmental benefits
Some benefits include:
- no chemical additive needed (no material conversion)
- no additional waste water contamination by chemicals (no salination).

Cross-media effects
Energy requirements for the process.

Operational data

It is possible to automate the filtration of membrane. Also, these filtration units require little space.

Applicability

Membrane procedures are suitable for the treatment of waste if the waste is pretreated, or if it involves defined waste with a proven suitability for membrane filtration. The materials giving rise to unfavourable changes in the membranes, such as adhesion or, swelling of the membrane, must be separated. Bearing these constraints in mind, membrane filtration is:

- suitable both for high and low-charged waste water
- usable in emulsion separation, independently of type, concentration or stability.

Type of substance	Effect on the membrane	Technique to overcome the problem in the membrane
Solids with grain size >0.5 mm	Blockage, wear of the membrane	Suitable with a pre-purification stage
Solvents	Swelling of the membrane, structural change, permeability reduces	Prevent introduction
Alkali solutions and acids with extreme pH values	Possible destruction of the membrane material	Adjust pH value
Organic materials (with cellulose acetate membranes)	Membrane damage by rot	By means of bactericides
Silicone (from 0.1 %)	Blockage of membrane	Prevent introduction into the membrane
Free oil (from 1.0 %)	Blocking of membrane [1]	Prevent introduction into the membrane
[1] Use of RO and possibly NF with 1 % oil levels will not work effectively over an extended operational period without very extensive pretreatments.		

Table 4.21: Techniques to consider in membrane technology
[121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

In principle, membrane technology can be used for the purposes shown in Figure 4.4:

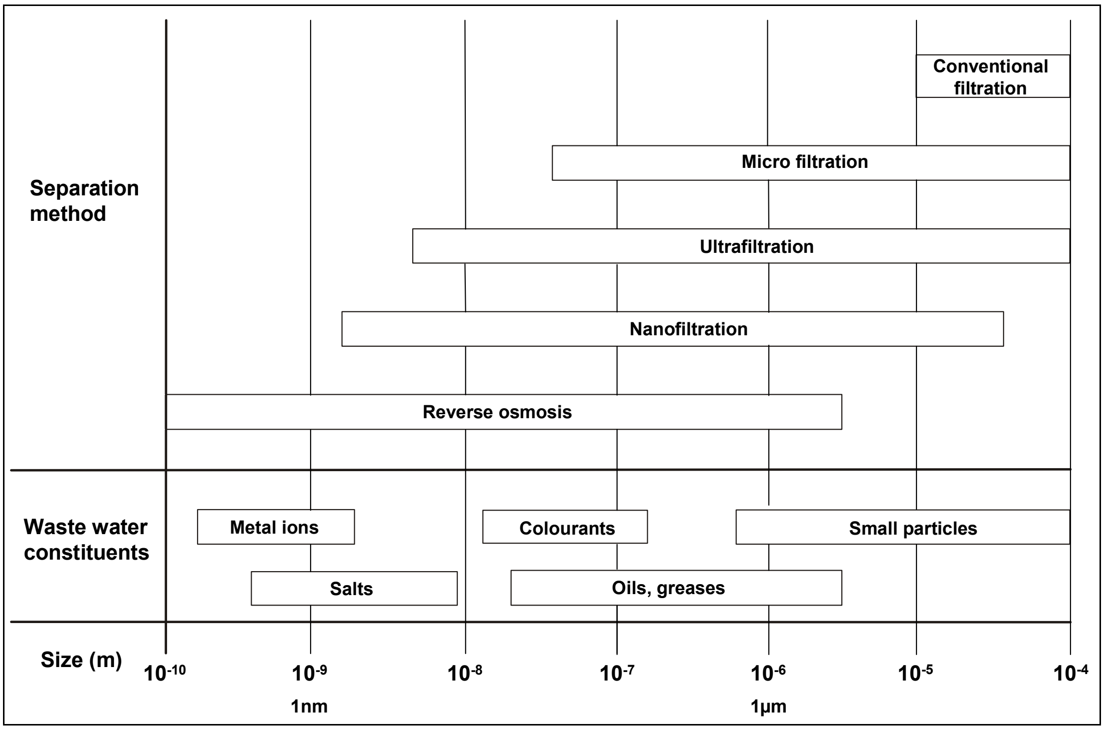


Figure 4.4: Classification of membrane technology by the separation task
[121, Schmidt and Institute for environmental and waste management, 2002]

Economics

Because it is typically automatised, staffing costs are low.

Reference literature

[121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

4.3.1.16 Sedimentation

Description

Settlement is carried out in clarifiers that need to be specifically designed with an inlet, outlet, settling zone and sludge blanket (or sludge zone). The addition of flocculation agents to the sludge and waste water to be treated is recommended to accelerate the sedimentation process and to facilitate the further separation of solids.

Achieved environmental benefits

Increases the sedimentation efficiency. Sedimentation of solids generally simplifies the waste treatment procedures which follow. To this extent, in the right part of the process, sedimentation is an advantage in the treatment of waste in Ph-c plants. However, unintentional sedimentation processes, e.g. in reaction containers, are a disadvantage since processes can be affected and often the build-up of sediment can only be removed at considerable expense.

Cross-media effects

Creation, typically, of a residue. The addition of flocculants implies that they will either appear in the treated waste water or they will be present in the separated solid.

Operational data

The efficiency of the sedimentation process is affected by the waste water and suspended solids characteristics and by variations in the flow and general operation. In practice, the following sedimentation agents have proven to be beneficial:

- milk of lime $Ca(OH)_2$
- iron (III) chloride $FeCl_3$
- polyelectrolytes.

Applicability

The solids may be discrete suspended particles that are self-settling, or there may be a range of sizes and surface characteristics, which then require the formation of flocculating suspensions to coagulate and settle the mass, i.e. through chemical conditioning. In certain cases, it is not necessary to use flocculation agents because solids are self-settling or because they are not effective.

Economics

Applying this technique allows savings to be made on the discharge and transport costs, since only the sediment needs to be managed and not the total aqueous suspension.

Example plants

Paper mills (sedimentation of the cellulose fibres that are too short) and other plants with high content in suspended solids in the waste waters.

Reference literature

[55, UK EA, 2001], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

4.3.1.17 Sieving

Description
See Section 2.3.2. Some techniques for sieving operations include:

a. avoiding overload of the sieving equipment (either optically by monitoring the equipment controls or automatically by blocking out the filler pump by means of the level indicator storage container's)
b. correctly cleaning the filter apertures as required (optical, empirical). Some good cleaning measures include applying rapid cleaning and steam or high pressure water jetting
c. ensuring that there is an unimpaired discharge of filter underflow and overflow at all times (through use of optical, filler pump shut-off mechanisms or other control).

Achieved environmental benefits
The sieving of waste is performed as an initial treatment procedure. The separation out of particles which may harm equipment, processes or products is beneficial for all successive waste treatment measures.

Operational data
The advantages of sieves are in their simple, robust construction, their low maintenance needs and the fact that they are user friendly, and offer good reliability. The disadvantages are generally caused by the wastes themselves, e.g. clogging of the filter apertures can occur as the result of the degree of viscosity of liquid waste, which then impedes separation.

Reference literature
[121, Schmidt and Institute for environmental and waste management, 2002]

4.3.1.18 Solvent extraction

Description
Some techniques include:

a. using well operated and regulated processes
b. returning the extraction solvent for re-use in a closed loop
c. using anti-foaming agents when faults occur in the extraction due to surface-active substances (e.g. tensides) resulting from the mixing processes
d. avoiding using solvents with comparable chemical characteristics to the component to be extracted, in order to avoid poor separation effects, e.g. azeotropic mixtures
e. improving the separative performance during extraction by increasing the temperature
f. separating substances which may have negative effects in pretreatment procedures.

Achieved environmental benefits
Enhances the environmental performance of the solvent extraction. Some reasons for using extraction include: its low energy consumption for the separation of substances, from low concentrated waste water up to the ppm range; the possibility of extracting insoluble substances, and also the high level of selectivity that can be achieved by using reactive components and suitable extracting agents during the extraction process.

Cross-media effects
Emissions of VOCs to the air.

Economics
There is a saving of raw material and transport costs if the distillation can be performed on site.

Example plants
Many systems return the extraction solvent for re-use in a closed loop.
Reference literature
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

4.3.1.19 Techniques when treating waste water containing precious metals

Description
Photographic liquid waste contains several toxic and not easily degradable compounds. By means of physico-chemical and biological treatment, including evaporation, the diffusion of these compounds to the environment is minimised. Some techniques are:

a. for black and white photographic waste water, recovery of metals if the concentration of silver is greater than 50 mg/l, and purification is followed by evaporation and incineration of the concentrate in a grate furnace or cement kiln
b. for colour photographic waste water, recovery of metals if the concentration of silver is greater than 100 mg/l and purification is followed by evaporation and incineration of the concentrate in a grate furnace or cement kiln.

Achieved environmental benefits
In comparison with detoxification, neutralisation and dewatering for the removal of metals by means of chemicals, there is a reduction in the consumption of chemicals and the sludge produced.

Cross-media effects
In comparison with a detoxification, neutralisation and dewatering for the removal of metals by means of chemicals, the consumption of energy is increased, e.g:

- electricity for the electrolysis
- heat for the evaporation.

Operational data
Sulphide precipitation and ultrafiltration generates sulphide sludge at approximately 5 to 10 kg/m^3 liquid photo processing waste water. From the sludge, silver and other metals are recovered in pyrometallurgic processes which generate slags as a residue. The physico-chemical and biological treatment of the desilvered photographic waste water generates sludge at approximately 0.1 to 0.2 t/t waste water.

Silver is recovered for re-use and concentrations of silver and other metals in the waste water are reduced. The recovery of silver is approximately 95 %. The silver content in the permeate of membrane filtration is <1 mg/l in the case of black and white photo processing waste water and <10 mg/l in the case of colour photo processing waste water.

Applicability
The techniques for recovery of metals are not only applicable to photographic waste waters, but also to other waste waters containing (precious) metals, e.g. the galvanic industry. Electrolysis gives a higher yield and costs less energy as metals are more precious and concentrations are higher. The capacity of one of the example plants for metal recovery ranges from 10 to 20 kt/yr.

The physico-chemical and biological treatment techniques for desilvered photographic liquid waste waters are applicable for similar waste waters. Table 3.81 shows the acceptance criteria for desilvered photographic liquid waste and similar waste waters (with the same processing path). The capacity of one of the example plants for physico-chemical and biological treatment is approximately 100 to 200 kt/yr.

Driving force for implementation
Effluent standards based on the Surface waters Pollution Act.

Example plants
Two example plants in the Netherlands.

Reference literature
[150, TWG, 2004], [156, VROM, 2004]

4.3.1.20 Techniques for the treatment of aqueous marine waste

Description
The treatment of aqueous marine wastes can be distinguished between waste waters containing oil and waste waters containing chemicals. Some techniques are:

a. applying specific pretreatment processes in the case of waste waters containing metals (see Section 4.3.1.19 above)
b. applying physico-chemical pretreatment and a biological treatment in the case of waste waters containing oil
c. treating the exhaust gases to reduce the VOC and odour emissions
d. defining acceptance and processing standards (maximum concentrations in the waste) for every treatment route
e. separating oils / chemicals, water and sludge
f. preparing the oil or chemical fraction for use as fuel if suitable
g. applying standards (maximum concentrations) for mixing wastes to be used as fuel
h. not mixing or diluting waste waters to meet effluent standards
i. dewatering the sludge and, if suitable, applying a thermal treatment for material re-use
j. treating the waste water.

Achieved environmental benefits
Compared to the discharge of untreated waste water or merely biological treatment, the described techniques reduce emissions of contaminants to surface waters.

Cross-media effects
- production of a sludge that has to be disposed of or undergo further treatment
- consumption of chemicals
- consumption of energy
- emissions to the air, e.g. VOC and odour.

Operational data
The removal efficiencies of flocculation/flotation and aerobic biological treatments by a waste water treatment installation are presented in Table 4.22:

Component	Removal efficiency flocculation/flotation (%)	Removal efficiency aerobic biological treatment (%)	Waste water treatment Total efficiency (%)[2]
Suspended particles	>99	-	>99
Oil	>99[1]	99	>99
COD	20	85	88
Phenols	-	99	99
Total N (Kjeldahl)	-	50	50
P	-	50	50
BTEX	75	99	99.7
PAHs	96	95	99
CN	-	75	75
EOX + VOX	30	97	98
EOX	85	85	98
Heavy metals	80	-	80
Cd	80	-	80
Hg	>90	-	>80

[1] removal of oil layer
[2] total of flocculation/flotation and biological treatments

Table 4.22: Removal efficiencies of flocculation/flotation and biological treatment of waste water

Emissions of VOC to the air are released from tanks during storage and transfer, from treatment installations and from seal leakages. Emissions can be reduced by enclosed installations, inspection and maintenance to avoid leakages.

Treatment of the exhaust gases by filtering, scrubbing or incineration can reduce these emissions. A biofilter or activated carbon filter may be applied to prevent the emissions of VOC and odour. An alternative for reducing these emissions is aeration with oxygen instead of air. This reduces the flowrate of the air input and the exhaust gas. The disadvantages are the higher consumption of oxygen and the higher consumption of pumping energy to compensate the reduction of the mixing due to the fact that less air is blown in.

If exhaust gas treatment is applied, emissions vary from approximately 0.01 kg/m^3 waste water in the case of incineration, with an efficiency of 99.9 %, to 0.05 kg/m^3 waste water in the case of a wet scrubber.

Applicability
The capacities of the example installations range from 200 to 500 kt/yr.

Driving force for implementation
Effluent standards based on the Surface Waters Pollution Act in the Netherlands.

Example plants
Three example plants in the Netherlands.

Reference literature
[150, TWG, 2004], [156, VROM, 2004]

4.3.1.21 Abatement techniques applied in Ph-c treatment plants

Table 4.23 shows the air abatement techniques applied in Ph-c treatment plants

Installation	Offgas treatment for the treatment area/ reactors [a)]	Air abatement/off-gas treatment in storage areas
Solidification	Bag filter	Bag filter
Multifunctional Ph-c installation	Scrubber for acids Scrubber for NH_3 in operation, if necessary	n.a.
Multifunctional Ph-c installation	Scrubber for acids Oxidising scrubber	Carbon filter for some tanks containing oily waste
Multifunctional Ph-c installation	Off-gas is used during the incineration of hazardous waste	n.a.
Multifunctional Ph-c installation	4- to 5-step treatment system: Water scrubber (eliminating aerosols containing oil and dust) Scrubber for acids Scrubber for NH_3 Biofilter, closed system Carbon filter in operation, if necessary	Ventilation for the whole plant, treatment of the off-gas
Multifunctional Ph-c installation	Scrubber for NH_3 Biofilter	Biofilter
Multifunctional Ph-c installation	Scrubber for acids Scrubber for NH_3	Ventilation
Multifunctional Ph-c installation	Scrubber in operation during cyanide or nitrite oxidation	Ventilation
Multifunctional Ph-c installation	Scrubber for acids Oxidising scrubber Biofilter for the organic part	Biofilter together with off-gas of biological treatment of MSW
Multifunctional Ph-c installation	Scrubber for acids Scrubber for NH_3 Biofilter (closed system) Off-gas funnel	Biofilter
Soil washing / attrition plant	1-step scrubber	n.a.

[a)] Many plants use the scrubbers only during Ph-c treatment in the reaction vessel. Other plants operate the air abatement system continuously.

n.a no information available

Table 4.23: Off-gas treatment in large Ph-c installations in Austria
[150, TWG, 2004]

Next Figure 4.5 and Table 4.24 shows the air abatement systems of a Austrian plant and the waste water parameters achieved after biological treatment of the waste waters.

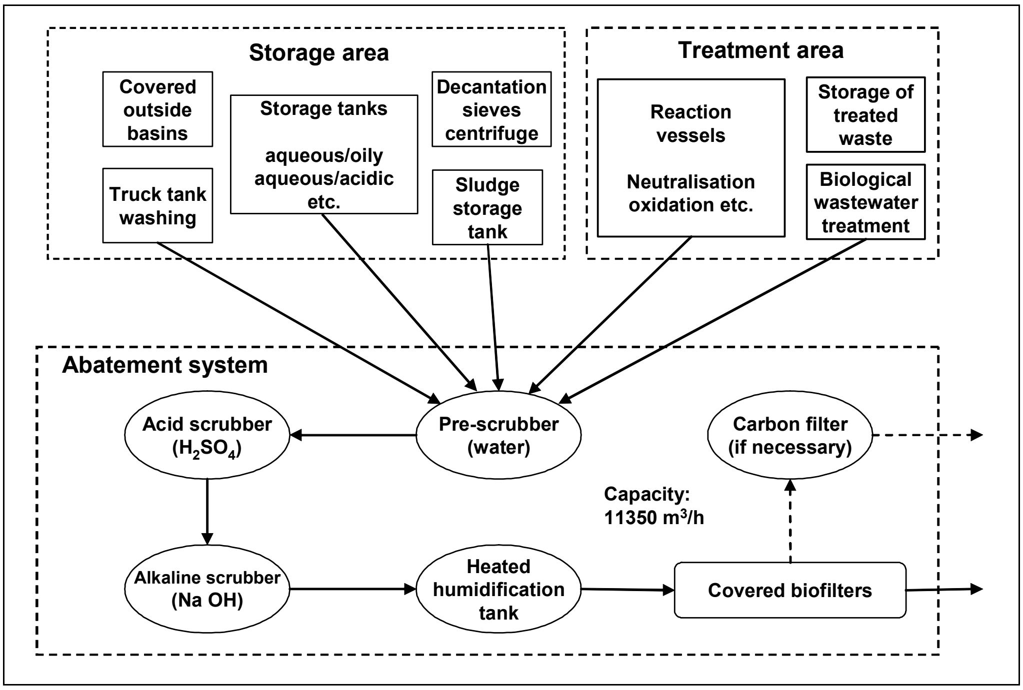


Figure 4.5: Air control and abatement system of a Ph-c plant
[150, TWG, 2004]

Parameter	Feed (primary effluent) (mg/l)		Effluent after biological treatment (sequential batch reactor) (mg/l)	
	Minimum	Maximum	Minimum	Maximum
COD	2500	12000	600	1500
NH_4-N [a)]	25	16000	<1	150
Nitrite	10	300	<1	<1
Nitrate	10	1000	<1	<1
Phenols	10	500	<2	<2
Oil content	--	--	<0.5	--
a) Effluent after biological treatment: Often around 20 mg/l				

Table 4.24: Effluent concentration of an Austrian plant before and after tertiary waste water treatment (on-site sequential batch biological treatment)
[150, TWG, 2004]

4.3.2 Techniques for the physico-chemical treatments of solids and sludges

4.3.2.1 Pretreatment before immobilisation

Description

Pretreatment before immobilisation basically consists of washing/leaching of salts with water, and the physico-chemical pretreatment of metals (especially insolubilisation of the amphoteric metals). The subsequent treatment, solidification, is not covered in this Section.

Achieved environmental benefits

This treatment produces a filter cake with a reduced toxicity and solubility and salted water. It helps to reduce the leachibility of the waste OUT and contamination by the leaching out of soluble compounds.

Operational data

The process is more sophisticated than the simple solidification one.

Applicability

Waste containing chromates, amphoteric metals such as Pb and Zn and waste with some soluble salts content typically need pretreatment before being subjected to the immobilisation process. This pretreatment allows the treatment of fly ashes and salts arising from the dechlorination of fumes in household waste incineration. It can also be applied to the fly ash resulting from both lime treatment of the fumes and from the bicarbonate of soda treatment. In the latter case (sodium bicarbonate), it dissociates the soluble and non-soluble solid components, and reduces the amount of disposal in landfills by recycling the soluble salts in a soda ash factory.

Economics

The investment cost is higher than for a solidification process alone.

Example plants

This is already applied in a large scale factory in France treating 1000 tonnes per year of fly ash produced in France.

Reference literature

[136, Straetmans, 2003], [150, TWG, 2004]

4.3.2.2 Laboratory activities

Description

Some techniques regarding laboratory activities include:

a. having the laboratory on site
b. applying quality control (to include leachability tests and compressive strength, i.e. for solidification processes), including screening each proposed waste to ensure any wastes containing process inhibitors are excluded. In the case where inhibitors are present, see technique c below. For each waste stream, laboratory scale testing should be carried out to maximise the effectiveness of the mix and the quantity of the absorbents/binders to be added, and to identify an optimum 'formula' to be used in later full scale treatment should the waste stream in question be found suitable. Any such testing should take into account the effects of different waste streams being treated in the same batch and in addition identify a minimum residence time within the reaction vessel. Records of which waste streams have already been tested should be kept, showing whether they have been accepted or rejected as suitable for treatment by the process (see Section 4.1.1)
c. addressing any inhibitors identified in the binder formulation with secondary binders/additives. The key issue is to confirm this to be the case by conducting treatability studies for each waste stream
d. specifying the length of time that samples need to be kept available for analysis. This needs to include a reference to the length of time taken to achieve full stability (see Cross-media Section below) of the end-product
e. demonstrating how batch non conformance waste will be dealt with
f. testing the leachability of inorganic compounds, using the standardised CEN leaching procedures and applying the appropriate testing level: basic characterisation, compliance testing or on-site verification
g. conducting acceptance procedures when waste arrives at the installation, including leachability tests on every load prior to treatment, to confirm the levels of key indicator substances identified at the pre-acceptance stage
h. analysing the following group of compounds that may cause landfilling problems: Cl, CN, F, sulphates, hydrocarbons, PAH, PCB, phenols, As, Cd, Cr total, Cr(VI), Hg, Ni, Pb, Zn.

Achieved environmental benefits

An on-site laboratory forms the essential element in providing assurances that the necessary process input controls are in place and that a consistent waste OUT is generated.

Cross-media effects
Cement or lime-based systems may take years to stabilise and decades/centuries or even longer to achieve equilibrium with the local environment. Because of this, talk about full stability may be technically unrealistic.

Applicability
Related to technique f in the description section above, the physico-chemical treatments are applied to monolithic and granular material (e.g. treatment of bottom ash).

Related to technique g in the description section above, it is sometimes questioned if it is environmentally and economically justified to carry out a leach testing on every load prior to treatment in the case of well characterised waste streams or if there is a minimum on load size.

Driving force for implementation
Landfill Directive 1999/31/CE and the Council decision 2003/33/EC (CEN) relate to the parameters that should be considered to determine if a waste can be landfilled:

- Landfill Directive (1999/31/EC) specifies the principles of characterisation of waste before landfilling which are: a) application of the 3-step characterisation procedure (basic characterisation, compliance testing, on-site verification), and b) Annex II of the Landfill Directive states that the parameters of composition, leachability, long term behaviour and general properties of a waste to be landfilled need to be known as precisely as possible
- The CEN procedures specify under which conditions and which type of tests need to be used
- 2003/33/EC establishes criteria and procedures for the acceptance of waste at landfills. This also includes waste acceptance criteria, sampling and test methods.

Related to the application of technique h (from the description section above) in France, PAHs and PCBs are not systematically analysed before stabilisation. Analysing is only carried out when PAHs and PCBs are found in large quantities (which can be concluded from the origin of the waste).

Reference literature
[51, Inertec, et al., 2002], [55, UK EA, 2001], [86, TWG, 2003], [150, TWG, 2004]

4.3.2.3 Immobilisation

Description
Some techniques include:

a. defining an acceptable range of characteristics of a waste that can be effectively treated by the process. This range will be determined by the ability of the process to immobilise the chemical/ion in question, to ensure the final product can meet a defined specification
b. using suitably designed reaction vessels for all immobilisation processes
c. performing these processes within controlled reaction vessels. Given the degree of process control that is needed to ensure the correct ratios of waste and reagent/binder entering the process and that sufficient mixing (and residence time) is achieved, it is essential that such vessels achieve these objectives. Automated loading, charging and mixing devices which can be monitored and controlled, will also be required
d. using suitable process monitoring within enclosed and abated systems
e. applying pre-acceptance procedures to assess waste
f. implementing measures to restrict dusty reagents
g. restricting wastes to those with low concentrations of VOCs or odorous components (see Applicability and Cross-media Sections below)
h. employing controlled and enclosed methods of charging
i. mixing reagents and waste using impellers or mixing systems integral to the mixing vessel

j. using screw feeders, gravity or pneumatic means for handling systems for bulk transfer of dry wastes and reagents
k. replacing the need to decant liquid wastes from drums and containers by utilising separate 'make-up' tanks to premix liquids and pumpable sludges
l. delivering the feedstock by pipe into the mixing vessel
m. using extraction systems designed to take into account the removal of the large volumes of air present due to the dimensions of the mixing areas and the need to have vehicular access for loading and unloading. It will also be necessary to demonstrate that the design of the extraction systems are capable of controlling all foreseeable emissions, other than in emergency situations
n. having a central abatement system in place to handle the flow of air, as well as the peak loadings associated with charging and unloading
o. detailing the methods of treatment and disposal of all spent scrubber liquors and absorbents, (for example, activated carbon and trapped emissions)
p. having a regular inspection and maintenance programme in place, including:
    - replacing the underground or partially underground vessels without secondary containment by aboveground structures
    - replacing structures without secondary containment
q. carrying out physico-chemical treatments, such as neutralisation reactions in the liquid phase, in order to enhance mixing and process control
r. guaranteeing that solid phase neutralisation reactions have been carried out to the completion of the reaction
s. using hydraulic binders complemented by specific chemical reagents, especially for:
    - mercury fixation as HgS and $Hg_3(SO_4)O_2$
    - fixation of metals as metallic hydroxide sludge (e.g. Zn, Pb, Cu, Cr, Cd) as insoluble compounds and by solidification
    - reduction of hexavalent chromium in basic conditions (e.g. by $FeSO_4$), followed by precipitation and solidification
    - fixation of organic compounds from that sludge from the chemical industry containing sulphates and organic salts, followed by precipitation of sulphates to ensure the structure durability, for example by adding clay to adsorb organic compounds
    - a high arsenic content (e.g. from the chemical or metallurgical industry, or from ore treatment) by oxidation of As (III), followed by stabilisation and solidification
t. considering the possibility of increasing the final product quality by using additives (for example, hydrophobic reactants, etc.)
u. not solely relying on stabilisation processes for the disposal of intractable wastes which are difficult to treat and expensive to incinerate. These include solid cyanides, oxidising agents, chelating agents, high TOC wastes, wastes containing low flashpoint solvents and gas cylinders
v. restricting the amount of reagents (including chemical and physical binders and solidification reagents) that can be added to prevent dilution
w. having immobilisation specialist practised on demand using specialist binders developed in laboratory test for a specific waste stream.

Achieved environmental benefits

Enhances the environmental performance of immobilisation techniques (e.g. reduction of permeability, reduction of specific surface, chemical buffering). Stabilisation is a cold process and consequently does not require energy. The waste OUT of these techniques typically has very good physico-chemical/leaching characteristics. Because the process is a cold process, fumes or air pollution are minor (e.g. generated by the use of fuels). Water permeability of $3.7 \cdot 10^{-11}$ m/s can be achieved in the final product when cement is used as immobiliser.

Cross-media effects

Waste OUT/waste IN ratios range between 1.2 and 2.4 in weight and generally between 0.9 and 1.4 in volume (due to the typical increase of the density of the waste OUT compared with the waste IN). Thus, the process leads to an increase in weight and a minor change in volume.

In order to avoid VOC emissions (see technique g in the description section above), waste containing VOCs could be treated in an enclosed mixing vessel (e.g. pugmill), treating the emitted VOCs that are not solidified by e.g. scrubbers. Such secondary treatments may avoid double handling (e.g. thermal desorption to deal with VOCs followed by stabilisation/solidification to deal with metals).

Inmobilisation is not able to reduce the content of any contaminant in the waste, only change the chemical composition by some chemical reactions. Organic wastes are typically not inmobilised by stabilisation/solidification they are typically adsorbed by the solid matter. Whatever stabilisation/solidification finally reaches as a process, it is considered that the waste OUT is not stable for a long period of time and the compounds of the waste OUT may escape (e.g. leaching).

The probable increase of the pH and alkaline capacity of the mixture by this treatment can lead to an increase of the leaching properties for the amphoteric metals (for pH above 12.5 lead, cadmium), species sensitive to pH like arsenic and cyanides as well as some organic components.

Operational data

This technique is easy to use and is a relatively simple process. The energy consumption of the treatment is low. When cement is used as a stabilisation material the ratio of waste to be treated to the cement used is between 1:3 and 1:4, depending on the type of waste.

Applicability

These techniques are most likely to be effective in the treatment of inorganic wastes where solubility is already quite low. With this technique, a large range of waste can be treated (liquids, solids, many chemical pollutants, ashes, etc.). Waste containing chromates, amphoteric metals such as Pb and Zn, and waste with some soluble salts content, need pretreatment before the immobilisation process. Some wastes not suitable for immobilisation include:

- flammable and highly flammable wastes (e.g. low flashpoint solvents)
- wastes containing volatile substances. Sometimes very low concentrations of VOCs may be accepted
- oxidising agents. Sometimes very low concentrations of oxidising agents may be accepted
- odorous wastes. Sometimes very low odour materials may be accepted
- waste containing highly soluble organic waste and a high COD content
- waste containing molybdenum
- waste containing soluble inorganic salts
- solid cyanides. Sometimes very low concentration of cyanides may be accepted
- chelating agents. Sometimes very low concentration of chelating agents es may be accepted.

Some of the wastes mentioned above may be treated by some specific reagents. For example, cement (as shown in Table 4.26) and lime reagents are compatible with oxidising agents.

Economics

Cold processes are considered economically attractive techniques. They typically require simple equipment and incur low investment (concrete mixers, silos, pumps, etc.) and operational costs.

Reagents/binders are used when possible to lower the treatment costs (fly ashes from power stations, slag from steel mills, the residues of cement furnaces). Operators are not always in a position (because of regulations, of availability in the surrounding, of interest in a specific waste, etc.) to use wastes as reagents, although it is of course generally economically viable.

Driving force for implementation
Landfill Directive 1999/31/CE. Simple physical dilution or absorption, which does not lead to any associated physico-chemical change, is not an acceptable treatment process. For example, the absorption of a liquid into sawdust, so that it is no longer a liquid waste, is not acceptable as a pretreatment for landfill.

Example plants
13 plants stabilise around 400 kilotonnes of hazardous waste before landfilling, according to the French regulation and, from 2004 – 2005, to the EC regulation. Mobile units are also available to treat some waste spots on industrial sites.

In Portugal, one plant stabilise MSW incineration fly ashes before they are landfilled.

Reference literature
[51, Inertec, et al., 2002], [52, Ecodeco, 2002], [53, LaGrega, et al., 1994], [55, UK EA, 2001], [136, Straetmans, 2003], [150, TWG, 2004]

4.3.2.4 Cement solidification

Description
Generally wastes are mixed with portland cement and additives to control the properties of the cement, and enough water to ensure that hydration reactions will take place to bind the cement. Both stabilisation and solidification processes take place. The wastes are thereby incorporated into the cement matrix. Typically, the waste IN will react with water and the cement to form, to some extend, metal hydroxides or carbonates which are usually less soluble than the original metal compounds in the waste matrix.

Cement-based solidification techniques rely on the use of equipment that is typically readily available. The mixing and handling associated with the processes are well developed and the technique is robust with respect to variations in waste IN characteristics.

The solidified product is either landfilled in surface level or underground deposits. In some countries, it may be utilised as a backfilling material in old salt mines.

Achieved environmental benefits
The main advantage of cement solidification is the reduced contact between water and waste IN and to some extent the formation of less soluble metal hydroxides or carbonates. Amphoteric metals can also be treated. The solidified product is relatively easy to handle, and the risk of dust formation is very low. The release of heavy metals from the products in the short term is typically relatively low. The technique does, in some cases, facilitate utilisation of the waste OUT as backfilling or construction material in the mining industry.

Recent developments in this technology have been undertaken by incorporating additives to bind difficult contaminants before encapsulation. Difficult contaminants are considered to be arsenic, lead, phenols (including PCP), PCBs and dioxins. There is evidence that cement can catalyse or participate in the reductive dechlorination of TCE.

Cross-media effects
Most studies have focused on the possible short term releases of contaminants from the waste OUT. The long term behaviour of the waste OUT is much less understood. It must be expected that the leaching of lime over time will change the chemical properties of the waste OUT, and also that increased leaching may occur as the pH decreases. The time required for a complete release from stabilised waste OUT can, however, be expected to be in the range of several hundred to a thousand years. The high pH level of cement-based systems can result in a significant leaching of amphoteric metals (Pb and Zn).

The drawbacks of this method are that leaching of soluble salts is not hampered and that this can eventually result in physical disintegration of the solidified product, thus allowing further leaching. In this case, the entry of air may result in some carbonation, partially rectifying the increase in porosity and loss of strength.

The addition of cement and additives increases the amount of waste to be handled; typically about 30 – 50 % of the waste IN dry weight is added as cement and additives, and 30 to 100 % of the total dry weight is added as water. Thus, the waste OUT is typically increased from 20 - 30 kg/tonne waste input to about 40 – 60 kg/tonne waste, including an addition of water corresponding to 50 % of the total dry weight.

If the heavy metals are not recovered from the residues, which is potentially possible but a costly and energy consuming process, the contaminants will sooner or later be released. It should be emphasised that these time perspectives mean that the dominant part of the metals in questions will be released at a time when all leachate collection activities from the landfills will probably have been discontinued for many years. In addition, the location of the deposit may have been forgotten, as the area in question will most probably have by then been used for other purposes for a long time.

Cement may contain some toxic components such as pulverised fuel ash, cement kiln dust, blast furnace slag and bitumen.

Operational data
Energy and water consumption varies and is not quantified. The operation and control of equipment used by the technique is considered relatively simple and comparable with standard practices in the concrete industry.

Applicability
Solidification is typically performed at dedicated plants located near the end-destination of the final material; thus individual incinerators have no need to install solidification equipment. The technique can be used on all types of FGT wastes. Solidification with cement has also been used on many other types of hazardous wastes, including for the disposal of low level radioactive waste. More information on the applicability of the cement technique can be found in Table 4.26 in the next Section 4.3.2.5.

Economics
In most cases the waste IN can be delivered to existing plants. Treatment costs for cement solidification alone is estimated to about EUR 25 per tonne waste IN.

Driving force for implementation
The technique is relatively simple to use and the necessary technical knowledge is widely available. The leaching characteristics of the solidified product can be improved considerably compared to the untreated waste IN. Stabilisation of FGT wastes by cement solidification has long been, and is still considered, acceptable by authorities in many countries worldwide. The main reason for implementing this technology in Holland has been lack of hazardous waste landfill capacity.

Example plants
The technique is probably the most commonly used method for the treatment of FGT wastes and is widely used in Europe and Japan. Some examples of cement solidification are listed below:

Country	Characteristics
Austria	A plant for cement solidification for slag and ashes from MSW incineration is in operation in Vienna
Germany	Several salt mining companies accept several types of wastes (e.g. FGT waste, slags, demolition material from buildings) and perform cement solidification on these by using residues as filler material. The solidified wastes OUT are chiefly utilised as backfilling material or for reinforcement. Cement solidification is for some mines performed at one central plant using varying recipes according to final destination and requests. From the central solidification plant, the product is transported to the recipient mine
Sweden	At one landfill site in Sweden (Hogdalan) cement solidified FGT waste are cast into blocks and placed at a surface level landfill after hardening
Switzerland	A variation of cement solidification is used in Switzerland (initially funded by the Swiss government and Sulzer) where waste IN are washed with water at liquid solid ratio of 2:1 and dewatered prior to mixing with cement. This has the benefit of removing most of the soluble salts from the waste IN, thus improving the longevity of the solidified product. After solidification, the waste OUT is deposited at surface level landfills before hardening. In some plants, the mixture is cast into moulds to produce blocks, that are then transported to surface landfills

Table 4.25: Cement solidification examples
[124, Iswa, 2003], [150, TWG, 2004]

Reference literature
[113, COWI A/S, 2002], [124, Iswa, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.3.2.5 Use of other reagents in the immobilisation process

Description
Some techniques are:

a. encapsulation by bitumen
b. carbonisation using CO_2
c. immobilisation with clay minerals.

Achieved environmental benefits
Fly ash particles can be encapsulated by bitumen, and potential contact with water is thus restricted. This improves the leaching properties of the fly ash; probably allowing less heavy metals to be released than in the case of cement solidification.

Waste incineration residues may be stabilised by carbonation (using CO_2), rather than hydration (with or without cement addition). Carbonation has a dramatic influence on the leaching of Pb and Zn and results in a lower pH product (around 9) but without loss of acid neutralisation capacity.

Cross-media effects
On bitumen encapsulation, no information on the possible leaching of dioxins from the solidified ash particles has been found, but it is noted that the solidification method itself does not reduce the original content.

Applicability

Waste component	Cement-based reagent	Pozzolan-based reagent	Thermoplastic reagent	Organic polymer reagent
Nonpolar organics such as: • oil and grease • aromatic hydrocarbons • halogenated hydrocarbons • PCBs	May impede setting. Decreased durability over a long time period. Volatiles may escape upon mixing. Demonstrated effectiveness under certain conditions	May impede setting. Decreased durability over a long time period. Volatiles may escape upon mixing. Demonstrated effectiveness under certain conditions	Organics may vaporise upon heating. Demonstrated effectiveness under certain conditions	May impede setting. Demonstrated effectiveness under certain conditions
Polar organics such as: • alcohols • phenols • organic acids • glycols	Phenol will significantly retard setting and will decrease the durability in the short run and over a long time period	Phenol will significantly retard setting and will decrease the durability in the short and over the long run. Alcohols may retard setting.	Organics may vaporise upon heating	No significiant effect on setting
Acids: • hydrochloric acid • hydrofluoric acid	No significant effect on setting. Cement will neutralise acids. Types II and IV portland cement give better durability characteristics than Type I. Demonstrated effectiveness	No significant effect on setting. Compatible, will neutralise acids. Demonstrated effectiveness	Can be neutralised before incorporation	Can be neutralised before incorporation. Urea formaldehyde demonstrated to be effective
Oxidisers such as: • sodium hypochlorate • potassium permanganate • nitric acid • potassium dichromate	Compatible	Compatible	May cause matrix breakdown. Fire risk	May cause matrix breakdown. Fire risk
Salts such as: • sulphates • halides • nitrates • cyanides	Increased setting times. Decreased durability. Sulphates may retard setting and cause spalling unless special cement is used. Sulphates accelerate other reactions	Halides are easily leached and retard setting. Sulphates can retard or accelerate reactions	Sulphates and halides may dehydrate and then rehydrate, causing splitting	Compatible
Heavy metals such as: • arsenic • cadmium • chromium • lead • mercury	Compatible. Can increase setting time. Demonstrated effectiveness under certain conditions	Compatible. Demonstrated effectiveness on certain species (lead, cadmium, chromium)	Compatible. Demonstrated effectiveness on certain species (copper, arsenic, chromium)	Compatible. Demonstrated effectiveness with arsenic

Table 4.26: Reagent applicability for waste stabilisation
[53, LaGrega, et al., 1994]

Bitumen encapsulation has been used on fly ash only and not for the residues from dry and semi-dry FGT systems, indicating that these may present problems.

Example plants

Solidification treatment by bitumen has been practised in the Netherlands, carbonisation of waste incineration residues have been practised in the UK and immobilisation by clay minerals in Austria.

Reference literature

[53, LaGrega, et al., 1994], [124, Iswa, 2003], [150, TWG, 2004],

4.3.2.6 Phosphate stabilisation

Description

Chemical stabilisation using phosphate as the stabilisation agent is used. The treatment process is relatively simple, and consists of a mixing device (such as a pugmill) into which the wastes IN are fed at a controlled rate. A proprietary form of soluble phosphate is then added to the mixer. After the phosphate is thoroughly mixed with the waste IN, a conveyor at the end of the mixer then removes the treated product. In some cases, depending on the characteristics of the waste IN, other additives such as lime are used. Reaction kinetics are fast and the material is considered fully treated without further curing. Sometimes phosphate addition is used together with carbonation in order to bind some metals in the waste (e.g. Pb).

Achieved environmental benefits

The process retains salts in the waste OUT. Compared to the other similar processes relatively small amounts of water are added along with the phosphate. The process produces no waste water.

Cross-media effects

There are currently no suggestions for utilisation of the treated product. A substantial leaching is possible after landfilling as is the case with some heavy metals due to increased solubility (e.g. Cd). The release of salt and heavy metals in the landfill is expected to be higher than is the case with other treatments. Phosphate stabilisation may enhance phosphorus compound mobility of deposited waste. In one case, it has been shown that the total phosphate availability has increased from 2 mg/kg (before treatment) to 4900 mg/kg (after treatment).

Operational data

The specific amounts of water and phosphate, as well as other additives, are likely to vary according to the properties of the waste IN, however no quantification of this has been made available.

Applicability

The process is in all but one case implemented as an integrated unit at the incinerator, but it could also be set up to act as a centralised plant treating residues from more than one incinerator. The process was originally developed to treat MSW incinerator residues, however several other waste types (e.g. contaminated soil, slags, sludges, etc.) have been tried and tested.

Economics

The treatment cost is about EUR 15 per tonne of FGT waste. In addition to this, a royalty is charged for the use of the patented process amounting to EUR 5 – 10 per tonne. Investment costs are in the order of about EUR 150000 – 500000 per installation depending on existing equipment.

Driving force for implementation
The main reason for implementation of this technique is its simplicity of operation. Currently, it finds extensive commercial use in the United States, Japan and Taiwan. The treated product is generally accepted as suitable for landfilling in these countries.

Example plants
The process is currently used in the United States, Japan and Taiwan at about 90 MSW incinerator facilities, treating over 2 million tonnes of bottom ash and FGT waste per year.

Reference literature
[124, Iswa, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.3.2.7 Thermal treatments of solid waste

Description
These techniques includes vitrification, melting and fusion of solid wastes (see Section 2.3.3.2). Its application to solid waste from waste incinerators is covered in the WI BREF.

Achieved environmental benefits
Several techniques can be used for heating the solid wastes: electrical melting systems, fuel fired burner systems or blast melting. These differ only in the way the energy is transferred to the solid material. Generally techniques are inspired from furnaces used in iron and steel production.

Depending on the melting system, metal alloys may be recovered from the reaction chamber. Depending on the temperatures in the reaction chamber and the state of oxidation or reduction of the gas phase, heavy metals (especially Cd and Pb) may be volatised and removed with the off-gas. All process configurations need off-gas treatment systems to minimise emissions.

An inherent advantage of these processes is the resulting destruction of organic pollutants, i.e. dioxins. Thermal treatment facilities in general reduce the volume to about 30 – 50 % of the input volume. Melting increases the density of the products to typically 2.4 – 2.9 tonnes/m^3.

Melted and vitrified products generally have very good retention properties, but Swiss studies show that sintered products also reach about the same level of stability with regard to retention. Vitrification typically yields the most stable and dense products.

Cross-media effects
A major drawback to these techniques is that they require substantial amounts of energy input.

Vitrification and melting result in a mobilisation of volatile elements such as Hg, Pb and Zn during the treatment process, which in some processes is used in combination with other parameters to produce a recyclable product low in heavy metals. Due to the release of vaporised heavy metals from the process, thermal treatment requires the additional of a flue-gas treatment system.

Thermal treatment processes use substantial amounts of energy. Additionally, the processes produce solid residues from the off-gas treatment. On the other hand, metals can be recovered from the process and, in some cases, even the vitrified product can be recycled.

Operational data
Typically in the order of about 700 – 1200 kWh energy is used per tonne of treated material to reach and maintain the elevated temperatures, althought figures of up to about 8000 kWh/tonne have been reported. Energy consumption and operation varies with the furnace type and plant design.

Applicability

Usually, the waste IN should comply with certain requirements, for example: water content <5 %, unburned contents <3 %, metal content <20 % by weight, and ash size <100 mm.

Thermal treatment is used for the treatment of bottom ashes, as well as for combinations of bottom ash and FGT waste. Due to the typically high contents of salts and heavy metals in the FGT waste, the separate treatment of FGT waste may necessitate a requirement for extensive off-gas treatment, thus reducing the overall benefits of separately treating these materials.

Economics

The technique is typically rather expensive compared to other treatment options. Treatment costs are reported to be in the order of EUR 100 – 500/tonne of input. Investment costs could be about EUR 20 million for a plant with a capacity to deal with 1 – 1.5 tonne/hour.

Driving force for implementation

The main reason for implementing the technique is the good retention properties of the final product; especially in the case of vitrifying, and the significant reduction in volume. In densely populated areas, such as Japan, landfill capacity can be a scarce resource and landfilling can thus be relatively costly. Organic compounds such as dioxins and furans are almost completely destroyed.

Example plants

There are 30 – 40 melting and vitrification plants in Japan and there are also plants operating in Europe and the US.

Country	Characteristics			
US	A vitrification process includes initial steps such as water extraction, dewatering and drying at 500 °C before the addition of glass forming additives and melting. The initial washing and drying is carried out to remove chlorides and residual organic carbon			
Japan	Plants for the thermal treatment of both bottom ash and FGT waste:			
		In operation	Planned	Capacity (tonne/day)
	Electric melting:			
	Electric arc	4	2	655
	Plasma arc	4	2	183
	Electric resistance	2	3	148
	Burner:			
	Reflecting surface	12		209
	Rotating surface	5		84
	Blast melting:			
	Coke bed	3		170
	Residual carbon combustion	1		15
	Total	31	7	1464

Table 4.27: Thermal treatment plants
[124, Iswa, 2003]

Reference literature

[124, Iswa, 2003], [150, TWG, 2004]

4.3.2.8 Recovery of salts by solution/evaporation

Description

When solid wastes are produced, the recovery potential can be considered. The recovery of, e.g. salts (NaCl, $CaCl_2$, HCl and gypsum) may be a possibility. These products could be obtained by evaporation or recrystallisation of the salt from the flue-gas cleaning system of waste water, either locally or at a centralised evaporation plant.

When the scrubber fluid is treated separately and subjected to evaporation, recoverable products like salts or hydrochloric acid can be obtained. The reutilisation potential of such products strongly depends on the product quality. In salt recovery, the scrubber liquid is treated with sodium hydroxide and calcium carbonate to produce solid gypsum, which after separation leaves a liquid containing mainly sodium and calcium chloride. The recovered products are subjected to quality control or even treated further for quality improvement and then traded off.

Achieved environmental benefits

The main objective of the operation is to avoid the discharge of saline waste water to the sewerage system. This is achieved by evaporation of the scrubber liquid from the wet flue-gas treatment system.

If solid sodium chloride needs to be separated individually from the above solution this is achieved by evaporation of the solution to a salt content of more than 30 %, at which level pure salt is crystallised. The above recovered salt products are most commonly reutilised in areas with a de-icing demand in winter time.

The re-use of the recovered salts and gypsum may save natural resources.

Cross-media effects

The major drawbacks of external waste water evaporation for salts not only related to operational and material problems but also to the high energy consumption necessary for evaporation.

Operational data

The evaporation of waste water containing salt is dependent on the salt concentration, which can vary greatly. Apart from problems of corrosion, the relatively high investment and operational costs need to be taken into account.

For the production of gypsum only a few operational problems exist. However, the gypsum quality is determined not only its purity with respect to the presence of other undesirable components but also due to its colour. Normally, a production of recyclable products of about 2 - 5 kg/tonne of waste can be expected.

By producing calcium chloride, focus should be put on the extreme corrosion potential that may arise and risk an unintended phase shift from a solid to a liquid state and vice versa.

Applicability

Can be applied in municipal waste incinerators with wet flue-gas treatment systems. For MSW incinerators with wet scrubbing of the incineration flue-gas, no discharge of the waste water is permitted due to legislation and local demands. The cleaned waste water from the wet scrubbers will still contain salts that are normally not desirable in the sewage pipe system because can cause corrosion or increase the salt content of fresh water bodies. For this reason the waste water is normally treated thermally and, where the waste water is used for cooling, by injection to and evaporation in the raw incinerator flue-gas. Here, no recoverable products are obtained.

Evaporation of treated saline waste water can be done at both centralised and decentralised plants. In the latter case, the MSW incinerator itself could supply the energy needed for evaporation.

For gypsum production, this could be achieved primarily operational changes only, i.e. implementation and operation of suitable dewatering devices, including cyclones, pumps, etc.

Economics

The costs for evaporation and storage of the recovered products are several times the costs for production of the same salts from natural resources. Thus, this technique is primarily applied for environmental reasons rather than for economic reasons.

Due to the production of already large amounts of high quality gypsum from energy production processes at power plants, gypsum produced in the above manner from MSW incinerators is only used for applications with a lower demand of gypsum quality. If re-use is not possible, then the gypsum has to be disposed of, thus incurring a corresponding disposal cost.

Driving force for implementation

Due to legislation, the discharge of scrubber liquid from wet flue-gas systems should be minimised. Even though the waste water is intensively treated for removal of, e.g. heavy metals and other harmful impurities, this hardly affects the total amount of salts. A substantial reduction of salt emission from the individual MSW incinerator to the local surrounding area is only accomplished by evaporation of the scrubber liquid. By separation of the solid gypsum, the amount of FGT waste for disposal is reduced.

Example plants

Evaporative processes have been implemented with success in several countries, especially in Germany where several incineration plants have applied this technology.

Reference literature

[124, Iswa, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.3.2.9 Acid extraction

Description

A number of techniques use acid extraction; some examples are given in Table 4.28:

Process	Characteristics
Acid extraction process	This process combines an acid extraction of soluble heavy metals and salts by using the (acidic) scrubber blowdown. Before using the scrubber liquid, mercury is removed by either a filtration (when activated carbon is introduced into the scrubber) and/or a specific ion exchanger. Both boiler ash and fly ash are treated this way. The L/S ratio in the extraction step is about 4; pH is controlled at 3.5 by the addition of hydrated lime. Within the residence time of about 45 minutes, sulphate (from the SO_2 scrubber) is precipitated to gypsum. The solid residue is dewatered, then countercurrently washed on a belt filter and finally landfilled, normally as a mixture with bottom ash. The filtrate has to be treated in order to remove heavy metals by neutralisation, precipitation and ion exchange. The dewatered and rinsed filter cake contains about 25 % zinc and is therefore recycled in metallurgical processes
Combination of acid extraction with thermal treatment	This process combines acid extraction with thermal treatment. First, boiler and fly ash are washed with the first stage wet scrubber solution, and dewatered. Then the solid residues are treated in a rotary kiln for one hour at around 600 °C destroying majority of the organic compounds and volatilising Hg. The off-gas is treated in an activated coal filter. The waste water is treated to remove heavy metals. The scrubber solution from the second scrubber is used to wash the bottom ash and to neutralise acidic effluent streams
Acid extraction sulphide process	This process combines fly ash and NaOH scrubber solution with water with an L/S ratio of 5. After mixing, the pH is adjusted to about 6 – 8 with HCl to extract heavy metals, and NaHS is added to bind heavy metals as sulphides. Then a coagulation agent is added and the slurry is dewatered. The filter cake is landfilled, and the waste water is treated in a subsequent treatment unit to remove heavy metals

Table 4.28: Acid extraction technologies
[124, Iswa, 2003], [150, TWG, 2004]

Achieved environmental benefits

The process can remove a significant part of the total amount of heavy metals from the waste IN (Cd: ≥85 %; Zn: ≥85 %; Pb and Cu: ≥33 %; Hg: ≥95 %); the leachability of the material is reduced by a factor $10^2 – 10^3$. Zinc, cadmium and mercury are recycled.

Cross-media effects
The dioxin content of the bottom ash increases when the treated ash is disposed of 'as combined' with bottom ash; however, the leaching potential of the mixture is higher because of the higher density.

Operational data
Most of the plants that operate for 24 hours can adapt the weekly operation period (4 – 7 days) according to the arising FGT waste.

Applicability
The system can be used only on incinerators with a wet FGT system having a permit allowing a discharge of treated waste water.

Economics
The process costs of treating the FGT waste are about EUR 150 – 250/t (including charges for recycling the zinc filter cake).

Driving force for implementation
This technique provides a method to treat solid waste according to Swiss legislation at competitive (compared to the export for German underground disposal) costs.

Example plants
Start-up of the first plant was in 1996. Six plants currently operate in Switzerland and one in the Czech Republic.

Reference literature
[124, Iswa, 2003], [152, TWG, 2004]

4.3.2.10 Excavation and removal of contaminated soil

Description
Some techniques include:

a. identifying and operating ways to reduce fugitive emissions by proper management of the site
b. enclosing the remediation within a dome and applying treatment to the air
c. controling the rate of excavation, the amount of contaminated soil area that is exposed, and the duration that soil piles are left uncovered. The timing of excavation can also be important. Scheduling excavation during times of the day or seasons of the year when wind speeds and temperatures are low can reduce emissions. The work can also be scheduled to avoid seasons with dry soil conditions to further minimise emissions.

Achieved environmental benefits
Reduces the fugitive emissions generated by the excavation and removal of contaminated soil. VOC emission control also can be achieved by controlling the operating conditions within preset parameters.

Cross-media effects
Some releases of volatile contaminants are inevitable during excavation. Stagnant wind conditions may lead to unacceptable ambient air concentrations at the work site.

Applicability
Enclosure of the remediation within a dome is not a commonly use measure.

Reference literature
[30, Eklund, et al., 1997]

4.3.2.11 Thermal desorption of soil

Description

See Section 2.3.3.9. Some techniques include:

a. using of a bench-scale test to determine the suitability of thermal desorption and the best residence time and temperature to use. The effectiveness of thermal desorption is related to the final soil temperature that is achieved, which in turn is a function of residence time and heat transfer. The temperatures and residence times effective in bench-scale systems also have proven to be effective in pilot scale systems
b. applying the appropriate temperature. The typical treatment temperature range for petroleum fuels from leaking underground storage tank sites is 200 to 480 °C. For the treatment of soils containing pesticides, dioxins, and PCBs, temperatures need to exceed 450 °C
c. reducing the moisture content of the soil to be treated within a specified range, this being applied due to the cost of treating waste with a high water content. The typical acceptable moisture range for rotary dryers and asphalt kilns is 10 – 30 %, while thermal screw systems can accommodate higher water loadings of 30 – 80 %. To remove VOCs, the soils should ideally contain 10 – 15 % moisture as the water vapour can carry out some of the VOCs
d. having in place collection and control equipment such as afterburners, thermal oxidisers, fabric filters, activated carbon, or condensers for the treatment of gases.

Achieved environmental benefits

Flexibility, as thermal desorption can treat a wide range of organic contaminants and the systems can be mobile. Thermal desorbers operate at lower temperatures, so significant fuel savings may result when compared to incineration. They also produce smaller volumes of off-gases to be treated. Typical specifications for thermal desorption systems are shown in Table 4.29.

	Rotary dryer	Asphalt plant	Thermal screw	Conveyor furnace
Mobility	Fixed and mobile	Fixed	Mobile	Mobile
Typical site size (tonnes)	450 – 23000	0 – 9000	450 – 4500	450 – 5000
Soil throughput (tonnes/hour)	9 – 45	23 – 90	3 – 14	5 – 9
Maximum soil feed size (cm)	5 – 8	5 – 8	3 – 5	3 – 5
Heat transfer method	Direct	Direct	Indirect	Direct
Soil mixing method	Shell rotation and lifters	Shell rotation and lifters	Auger	Soil agitators
Discharge soil temperature (°C)	150 – 300 [a] 300 – 650 [b]	300 – 600	150 – 250 [c] 300 – 250 [d] 500 – 850 [e]	300 – 800
Soil residence time (minutes)	3 – 7	3 – 7	30 – 70	3 – 10
Thermal desorber exhaust gas temperature (°C)	250 - 450[a] 400 – 500[b]	250 – 450	150	500 – 650
Gas/solids flow	Co-current or countercurrent	Co-current or countercurrent	Not applicable	Countercurrent
Atmosphere	Oxidative	Oxidative	Inert	Oxidative
Afterburner temperature (°C)	750 – 1000	750 – 1000 [f]	Generally not used	750 – 1000
Maximum thermal duty (MJ/hr [g])	10500 – 105000	5300 – 105000	7400 – 10500	10500
Heatup time from cold condition (hours)	0.5 – 1.0	0.5 – 1.0	Not reported	0.5 – 1.0
Cool downtime from hot condition (hours)	1.0 – 2.0	1.0 – 2.0	Not reported	Not reported
Total petroleum hydrocarbons				
Initial concentration (mg/kg)	800 – 35000	500 – 25000[h]	60 – 50000	5000
Final concentration (mg/kg)	<10 – 300	<20[h]	ND – 5500	<10.0
Removal efficiency (%)	95.0 – 99.9	Not reported	64 – 99	>99.9
BTEX				
Initial concentration (mg/kg)	Not reported	Not reported	155	Not reported
Final concentration (mg/kg)	<1.0	Not reported	<1.0	<0.01
Removal efficiency (%)	Not reported	Not reported	>99	Not reported

[a] Carbon steel materials of construction

[b] Alloy materials of construction

[c] Hot oil heat transfer system

[d] Molten salt heat transfer system

[e] Electrically heated system

[f] Not used on all systems

[g] Total duty of thermal desorber plus afterburner

[h] Vendor information

ND: not detectable

Table 4.29: Comparison of features of thermal desorption and off-gas treatment systems [30, Eklund, et al., 1997]

Cross-media effects

In order to destroy contaminants, the desorption process needs a subsequent afterburning and waste gas treatment. The reason is that desorption merely strips them from the solid or liquid phase and transfers them to the gas phase. Therefore, devices to control air emissions are necessary. The efficiency of the thermal desorption process will vary with the chemical and physical properties of the specific contaminants. Metals (e.g. lead) tend to remain in the soil after treatment, so additional soil processing or treatment may be required (e.g. stabilisation). Thermal desorbers may operate near or above 500 °C, so some pyrolysis and oxidation may occur, in addition to the vaporisation of water and organic compounds.

Applicability

Applicable to soils contaminated with volatile compounds at the operating temperature. High molecular weight organic compounds may foul or plug baghouses or condenser systems. Therefore, the types of petroleum products that can be treated by specific technologies may be limited. Rotary dryers can typically treat soils that have an organic content of less than 2 %. Thermal screw units may treat soils that contain up to 50 % organics.

Economics
Typically cheaper than incineration.

Driving force for implementation
Thermal desorption differs from incineration with regard to the regulatory and permitting requirements. Perhaps most importantly, thermal desorption enjoys more public acceptance than other thermal treatment methods.

Reference literature
[30, Eklund, et al., 1997], [51, Inertec, et al., 2002], [150, TWG, 2004]

4.3.2.12 Vapour extraction

Description
See Section 2.3.3.10. As the vapours are removed from the solid waste, they are treated to reduce air emissions. Direct combustion is theoretically possible if the hydrocarbon content of the exhaust gas is high enough, but the concentration typically drops significantly during removal. Therefore, natural gas or some other fuel would be needed to maintain combustion. Also, for safety reasons, dilution air is typically added to maintain the VOC concentration below the lower explosive limit. For lower levels of hydrocarbons, catalytic oxidation or carbon adsorption may be effective.

Achieved environmental benefits
Air emissions are released from a point source and, thus, can readily be controlled. The success of the method varies with the volatility (vapour pressure) of the contaminants present.

Cross-media effects
Significant residual contamination may remain in the solid waste after treatment.

Operational data
The equipment is simple to install and operate.

Applicability
The treatment is applicable to excavated soil. However, it is not applicable for saturated soils or for soils with low air permeabilities, but it is applicable to the treatment of soil contaminated with PCBs.

Economics
Large volumes of excavated soil can be treated in a cost-effective manner.

Reference literature
[30, Eklund, et al., 1997], [100, UNEP, 2000], [150, TWG, 2004], [152, TWG, 2004]

4.3.2.13 Soil washing

Description
See Section 2.3.3.13. Some techniques include:

a. recycling the blowdown water as much as possible
b. using carbon filters for the treatment of collected air emissions from the waste site or soil washing unit
c. ensuring that the sludge and solids from waste water treatment are subjected to appropriate treatment and disposal.

Achieved environmental benefits

Installation	Contaminants	Concentration in the untreated soil (ppm)	Range of removal efficiencies (%)	Residual concentrations (ppm)
1	Oil and grease		50 – 83	250 – 600
2	Pentachlorophenol		90 – 95	<115
	Other organics		85 – 95	<1
3	Oil and grease		90 – 99	<5 – 2400
4	Volatile organics		98 – >99	<50
	Semi-volatile organics		98 – >99	<250
	Most fuel products		98 – >99	<2200
5	Aromatics		>81	>45
	Crude oil		97	2300
6	Total organics		96	159 – 201
	PAHs		86 – 90	91.4 – 97.5
7	Oil		>99	20
8	Hydrocarbons		96.3	82.05
	Chlorinated hydrocarbons		>75	<0.01
	Aromatics		99.8	<0.02
	PAHs		95.4	15.48
9	Fuel oil	7666	65	2650
10	Fuel oil	7567	73	2033
11	Fuel oil	9933	72	2833

Table 4.30: Summary of the performance data for soil washing
[30, Eklund, et al., 1997]

Table 4.30 below presents some indicative general efficiencies for soil washing treatment.

Pollutants	General Efficiency [1]
TPH (C_{10}-C_{40})	90 – 98
PAHs	90 – 97
BTEX	90 – 97
PCBs	90 – 97
Metals	
As	60 – 80
Cd	60 – 80
Cr	80 – 90
Cu	75 – 85
Hg	85 – 95
Ni	85 – 90
Pb	90 – 95
Zn	85 – 95
[1] General Efficiency = (1 - conc in decontaminated sand/conc in polluted soil) * 100	

Table 4.31: Efficiencies of different components for soil washing
[123, Perseo, 2003]

Reference literature

[30, Eklund, et al., 1997], [123, Perseo, 2003]

4.3.2.14 Solvent extraction

Description

See Section 2.3.3.11.

Achieved environmental benefits

Compound	Initial concentration (mg/kg)	Final concentration (mg/kg)	Removal (%)
Anthracene	28.3	0.12	99
Benzene	30.2	0.18	99
Benzo(a)pyrene	1.9	0.33	83
Bis-(2-ethylhexyl)phthalate	4.1	1.04	75
Chrysene	6.3	0.69	89
Ethylbenzene	30.4	0.23	99
Naphthalene	42.2	0.66	98
Phenanthrene	28.6	1.01	96
Pyrene	7.7	1.08	86
Toluene	16.6	0.18	99
Total xylenes	13.2	0.98	93

Table 4.32: Results of the remediation of API separator sludge by solvent extraction
[30, Eklund, et al., 1997]

Applicability

Applicable for the removal of PCB from soil. The contaminated solvent must then be treated to destroy the PCBs.

Reference literature

[30, Eklund, et al., 1997], [100, UNEP, 2000]

4.3.2.15 Evaporation

Description

Evaporation is typically an important part of the Ph-c treatment facility. The evaporation treatment facility concentrates the hazardous waste. The concentrate is typically burned. The sewage (condensate) is stored temporarily and after analysis and control, it will be transported to a waste water treatment plant. The exhaust air will be cleaned with a carbon filter.

Before evaporation certain pretreatments are carried out in the Ph-c treatment facility. These are flocculation, precipitation, ultrafiltration and organic splitting. After evaporation, flocculation is carried out to the condensate if it is contaminated with oil. The exhaust air is treated by alkali launderer and carbon filter.

Achieved environmental benefits

Reduce the amount of waste water produced. The achievable levels in the exhaust air and in the waste water is shown in the Table 4.32 below.

Compound	Value	Unit	Charge	Unit
Parameters of the exhaust air				
TOC	63	mg/Nm³	96	kg/yr
Parameters of the waste water produced				
Temperature	30	°C		
pH-value	9.3			
Conductivity	900	µS/cm		
sedimentary substances (105 °C)	0.1	mg/l	2	kg/yr
BOD	3000	mg/l	60000	kg/yr
COD	5000	mg/l	100000	kg/yr
Hydrocarbons	2	mg/l	40	kg/yr
Phenol		mg/l		kg/yr
AOX	0.1	mg/l	2	kg/yr
Nitrite	0.01	mg/l	0.2	kg/yr
Cyanide	0.02	mg/l	0.4	kg/yr
Al	2	mg/l	40	kg/yr
Fe	0.1	mg/l	2	kg/yr
As	0.01	mg/l	0.2	kg/yr
Cr total	0.1	mg/l	2	kg/yr
Cr(VI)	0.01	mg/l	0.2	kg/yr
Cu	0.1	mg/l	2	kg/yr
Hg	0.001	mg/l	0.02	kg/yr
Ni	0.1	mg/l	2	kg/yr
Pb	0.1	mg/l	2	kg/yr
Zn	0.1	mg/l	2	kg/yr
Treated waste: 20000 tonnes per year				

Table 4.33: Achievable levels of evaporation process carried out to waste waters
[147, UBA, 2003]

Reference literature
[147, UBA, 2003]

4.3.2.16 Purification and recycling of FGT wastes

Description
The sodium-based FGT wastes are mainly constituted of sodium chloride (as a result of HCl neutralisation), sodium sulphate (as a result of SO_2 neutralisation), sodium carbonate (result of sodium bicarbonate excess), fly ash and adsorbent (activated carbon or lignite coke).

In flue-gas single filtration systems, fly ash is mixed with neutralisation salts and the soluble part represents about 50 % of waste IN; in flue-gas double filtration systems, the first filter catches most of the fly ash and sodium-based FGT wastes collected at the second filter contain about 90 % soluble salts.

The process includes the following steps:

a. mixing the FGT waste with hydraulic binders: prepares the solidification of the unsoluble part
b. dissolving in water and adding additives: the soluble part is dissolved and most heavy metals are precipitated
c. filtering this suspension: resulting products are a self-solidifying filter cake with a very low soluble fraction (after washing), and a raw brine containing soluble salts
d. purifying the brine (with various steps including ion exchange resins) in such a way that it may be re-used in the manufacture of sodium carbonate (soda ash).

This process has no outputs other than the solidified filter cake (to be landfilled) and the purified brine, which replaces part of the fresh raw material used by the soda ash plant: there is no liquid effluent at all.

Achieved environmental benefits

The technology described here realises the separation between soluble and unsoluble parts of the FGT waste, solidifying the unsoluble part and purifying and re-using the soluble part (constituted of inorganic salts) in some industries. Therefore:

- the landfilled solid part of FGT waste has a very low soluble fraction and so its solidification is better; so there is a lower consumption of hydraulic binders and a lower quantity of ultimate waste
- the soluble part of FGT waste is re-used in the chemical industry, replacing the use of fresh materials (salt is one of the main raw materials for soda ash plants). This soluble part is recycled at a rate higher than 95 %.

The treatments do not generate liquid effluents (all liquids are re-used as process water to form the recycled brine) and no significant air emissions are reported (ambient temperature process).

Cross-media effects

Not identified.

Operational data

The process does not require high energy input: it works at ambient temperature.

Applicability

It is applied to the FGT waste coming from the dry sodium bicarbonate flue-gas cleaning process used in municipal solid waste incineration. This process is implemented in dedicated and centralised plants located close to the soda ash plant using the produced purified brine, and which receive FGT waste coming from various MSW incineration plants.

Economics

This process is to be compared with the solidification and landfilling of FGT waste. From this point of view, (1) the solidification is much eased by the separation of the soluble part, and (2) the quantity of ultimate residues is reduced, this process has been reported to be competitive in some countries. Operational costs are low and the investment cost of the treatment plant is the key factor. So this process must be implemented in centralised units serving numerous incineration plants.

Driving force for implementation

This process is favoured by the following observed evolutions:

- severe ruling on landfilling: when safe solidification required
- resistance to new landfilling site projects as there is a trend to landfill as little as possible
- trend to promote recycling.

Example plants

Two plants work industrially using this process or slight variations of it: one in Italy (Toscana), capacity 10 kt FGT waste/yr, and one in France (Lorraine), capacity 50 kt FGT waste/yr. Both supply purified brine as raw material to a soda ash plant.

Reference literature

[150, TWG, 2004], [152, TWG, 2004]

4.3.3 Physico-chemical treatments of specific wastes

4.3.3.1 Treatment of oils contaminated with PCB

Description
The process is the dehalogenation of oils contaminated with PCBs from electrical transformers. The process also alows the elimination of low boiling compounds and oxidation products, which are responsible for the low dielectric properties of contaminated oil. At the end of the process, a filtration process is carried out in order to eliminate the by-products of the reaction.

Achieved environmental benefits
The process produces an oil with dielectric characteristics that make it possible to be re-used for the same purpose, with a content of PCB of less than 1 ppm.

Applicability
Applied to oil transformers with PCB contents of between 25 – 2000 ppm. The process can be applied to:

- dehalogenation and recovery of bulking ex-transformers mineral oils contaminated with PCBs
- cleaning and recovery of operating transformers containing mineral oils contaminated with PCBs. This step is performed by means of recirculation of the dehalogenated mineral oil and it permits the extraction of the residual PCB absorbed in the different components of the transformers (e.g. paper and wood).

Economics
The concentration range mentioned in the above Applicability section, is the typical range where this technique is found to be economically viable. Technically this is not a problem when applied at higher concentrations but it has been found that there are other types of PCB treatment processes more economically viable.

Driving force for implementation
It exists mobile systems that can be applied to transformers in operation without the need to move them.

Example plants
One example is operational in Italy.

Reference literature
[52, Ecodeco, 2002], [150, TWG, 2004]

4.3.3.2 Thermochemical conversion of waste asbestos

Description
Thermochemical conversion technology uses a combination of chemical treatment and heat to bring about a re-mineralisation of asbestos and other silicate materials. The re-mineralisation process accomplishes several goals including:

- conversion of asbestos minerals into non-asbestos minerals, without the need for melting
- destruction of organic compounds, through pyrolysis and/or oxidation
- immobilisation of metals and radionuclides.

The process involves shredding and then mixing material containing asbestos with fluxing agents and heating the fluxed mixture. The presence of the fluxing agents at elevated temperatures (approximately 1200 °C) results in the rapid re-mineralisation of asbestos fibres, which are converted into non-asbestos minerals such as diopside, wollastonite, olivine and glass.

The processing equipment consists of four primary systems which are feed preparation, rotary hearth converter, off-gas treatment, and product removal.

Pyrolysis of the organic compounds takes place in the rotary hearth. The pyrolysis products are directed via an induced draft to a thermal oxidation unit that destroys any residual organic contamination that might be present in the off-gas. From the thermal oxidiser, the off-gases are cooled and scrubbed of any particulates and acid components that might be present. The presence of demineralising agents accelerates molecular diffusion in inorganic waste during heating, which destroys inorganic compounds such as asbestos and causes a simultaneous oxidation and molecular bonding of metals and radionuclides within the waste media. This results in the immobilisation of metals and radionuclides. The process also results in significant volume reduction of the waste. The amount of volume reduction is dependent upon the type of material being treated and can range from 10 % for soils to over 90 % for materials containing asbestos or primarily organic materials.

Achieved environmental benefits

The technology provides treatment effectiveness equivalent to that of vitrification without the requirement for melting the waste. In particular it:

- converts asbestos materials into inert material
- results in a significant volume reduction of the waste. The volume of the treated product can be significantly reduced from the original waste (up to 90 %), but may ultimately require landfill disposal depending on the contaminants present.

The process also results in the destruction of organics, including PCBs to 99.9999 % destruction removal efficiency. Toxic metals are stabilised in the sintered product through molecular bonding and the technology developer believes that, based on preliminary testing, the process will also be effective for radionuclides.

Applicability

The process is also effective on other types of waste including demolition debris and predominantly organic waste. The technology is applicable to liquid and solid wastes that are reasonably homogeneous or that can be made so without excessive expense. The process can treat wastes contaminated with a variety of contaminants including organic contaminants such as VOCs; semi-volatile organic compounds; PCBs and dioxins; inorganic contaminants such as asbestos and cyanide; metals including arsenic, lead, chromium, barium, zinc, selenium, cadmium; radionuclides that can be vitrified such as transuranic elements, caesium, thorium and uranium; and mixtures of these contaminants.

Wastes for which there are limited data or for which it is believed that the technology is not economically viable or technically compatible include mercury, gaseous radionuclides such as ^{14}C, explosives and some chemical agents (although here it is believed that the technology may be applicable, but there are no data to support such a claim).

Economics

The technology provides treatment effectiveness equivalent to that of vitrification without the requirement for melting the waste. This makes the technology less expensive and more versatile than vitrification for certain wastes. The capital cost for the 37 tonnes per day unit is approximately USD 3 million. Using the assumptions presented at the end of this section, a 37 tonne/day system can treat material containing asbestos for approximately USD 175 – 225 per tonne.

The three largest most significant contributors to the overall cost are fuel, equipment, and labour. Fuel makes up approximately 36 % of the total cost, equipment makes up 30 %, and labour about 22 %. Other items such as reagents, maintenance, water, electricity, personal protection equipment and filters make up the remaining 12 % of the overall cost.

The cost estimates presented in this section are based on the following assumptions:

- system description: 37 tonne/day system, direct fired with heat recovery, with dry lime scrubber
- capital cost: based on a 7 year capital recovery period at a real discount rate of 3.0 % (2002)
- operating conditions: 24 h/day operation, 80 % operating efficiency, 9 person crew
- cost includes fuel (kerosene), electricity, process chemicals, personal protection equipment, regular maintenance, and HEPA filters
- overheads and profits are also included
- disposal of treated materials is not included
- transportation to the treatment facility is not included.

Driving force for implementation
Waste asbestos is typically disposed of in landfills. However, some of the asbestos can be contaminated with radionuclides, PCBs, metals. For this reason, those materials may require pretreatment prior to landfill disposal.

Example plants
A new plant is currently proposed in Ireland.

Reference literature
[94, USA DoE, 2002], [150, TWG, 2004]

4.3.3.3 Treatment of waste containing mercury

Description
Some techniques are:

a. pretreat the waste containing mercury as follows:
    - shredding/crushing of batteries and button cells
    - sorting/breaking/separating of thermometers and contactors
    - centrifuging the sludge containing mercury in order to remove most of the metallic mercury. The residual sludge has a low content of mercury and is treated in the vacuum distillation process
    - shredding/sieving the gas discharge lamps, removing the iron and separating it in fractions. The fluorescent powder containing mercury is treated in the vacuum distillation
    - end-cut/air-push treatment of the gas discharge lamps through heating and cooling the ends break. Afterwards, the fluorescent powder containing mercury is blown out (air-push). A selection unit can be added to this pretreatment technique. This detects the powders in order to selectively blow them out. Re-use of the powders is possible

b. carry out the following sequence of treatments:
    - separate and concentrate the mercury by evaporation and condensation
    - treat the off gases with dust filters and activated carbon filters
    - return the dust and the contaminated carbon from the gas treatment into the process

c. treat the distillate (water and organic fractions) by:
  - incineration in a waste incinerator
  - conducting the gases from the distillation through an after-burner (at approximately 850 ºC) and a condenser. The off-gases are cleaned by flue-gas treatment (e.g. scrubber, dust filter and activated carbon filter). The separated dust and the contaminated carbon are returned to the distillation vessel. This alternative raises the recovery rate
  - purifying the water fraction (after separation) and returning the deposit to the distillation vessel. This alternative raises the recovery rate.

Achieved environmental benefits
The mercury is recycled as a secondary raw material. The destination of the residue from the vacuum vessel depends on the waste treated. It can be used as a secondary raw material (e.g. for batteries) or landfilled (e.g. in the case of sludge containing mercury).

In a thermal soil remediation plant, with a throughput of 2 t/h of soil containing mercury and with mercury raw gas concentrations of up to 20 mg/Nm^3, a maximum removal rate of 99.9 % has been reported. It has also been reported that the mercury content of the soil (1 - 300 mg/kg) decreased to less than 5 mg/kg following thermal treatment. Another treatment reported a resulting percentage of the mercury emitted to the air as being 0.0015 %. The emissions range from 0.04 to 0.2 mg/Nm^3.

In the vacuum distillation of the sludge containing mercury (1 – 4 % mercury), 99.6 % of the mercury is recovered. About 0.1 % of the mercury is left in the residue and about 0.15 % comes along with the distillate, which is to be incinerated. The latter percentage ends up in the off-gases. By means of the activated carbon filter, 99.9 % of this mercury is separated. The maximum concentration of mercury in the residue is 50 mg/kg DM.

Cross-media effects
- consumption of energy for the distillation process and possible pretreatment
- consumption of activated carbon and water in the gas treatment
- emissions to air.

Operational data
The consumption of electricity for the heating of the vacuum vessel and for the vacuum pump amounts to 3.5 GJ/t waste. The consumption of cooling water is approximately 13 t/t waste containing mercury. For the treatment of the sludge containing 2 % mercury, the activated carbon needed amounts to 24 kg/t sludge.

Because of the hazardous nature of the vapours containing mercury, safety measures are required. These include exhaust systems; test measuring; locks; safety procedures for filling, emptying and (dis)connecting the vacuum vessels; and decontamination facilities. To minimise the risk of explosion, other safety measures, such as an air tight operation of the system; automatic pressure control; and smoke and spark free areas are applied.

Applicability
Vacuum distillation is applicable to sludge containing mercury from the oil and gas production industry, batteries, catalysts, activated carbon filters, thermometers, waste from the dental sector, fluorescent tubes, blasting grit and soil. Different waste streams are separately treated in the vacuum distillation. The capacities of the example installations range from 300 to 600 t/yr of waste containing mercury.

Driving force for implementation
- landfilling is banned for several wastes containing mercury. In comparison with direct landfilling or incineration of the waste containing mercury, the amount of waste is less and contains no mercury and diffusion into the environment is prevented
- the preference order for waste management in accordance with the Waste Framework Directive and the Sixth Environmental Action Programme of the European Union.

Example plants

A thermal soil remediation plant in Sweden, two example plants in the Netherlands for the vacuum distillation treatment. Example plants where pretreatment is applied: one in the Netherlands (shredding of gas discharge lamps) and one in Belgium (end-cut/air-push treatment).

Reference literature

[81, VDI and Dechema, 2002], [150, TWG, 2004], [152, TWG, 2004], [156, VROM, 2004]

4.4 Techniques to consider for treatments applied mainly to recover the materials from waste

This section contains techniques considered to have a good environmental operating performance (e.g use of a good energy system) or that can help lead to a good environmental performance (e.g. environmental management systems). They relate to treatments to recover mainly materials from waste.

4.4.1 Waste oil

This section covers the techniques to be considered in the determination of BAT for the re-refining of waste oil.

4.4.1.1 Generic techniques to increase the yield of re-refining

Description

The yield of a re-refining plant varies between 55 to 75 %, depending on the process and to a minor degree on the composition of waste oil. Some techniques to increase efficiency include:

a. sending the residue from the vacuum distillation column to a selectopropane unit, where 80 % of the brightstock can be recovered, reducing the residue content at the same time
b. sending the bottom residue from the vacuum distillation column to a thermal cracking unit to produce gasoil
c. selecting the appropriate vacuum in the vacuum distillation units (e.g. a three-stage group with steam ejectors at 17 mm Hg). Vacuum can be generated by dry vacuum pumps or high efficient multistage steam injectors.
d. using a scrubbing unit to reduce VOC emissions and to recuperate raw material
e. using sieves to remove matter such as polymer fibre
f. having in place an intermediate tank between the dehydrotreatment and the distillations, in order to separate the materials that can provoke fouling of the following plant section (i.e. the furnace and distillation column) and also utilising a sufficient residence time for the additive reaction with the used oil to occur. The precipitate from this reaction is extracted from the bottom of the tank and pumped to storage, where the dehydrated oil content can be separated to allow its re-use.

Achieved environmental benefits

Increases the efficiency of the waste oil re-refining treatments. Related with technique b in the description section above, the use of dry vacuum pumps does not generate contaminated water.

Cross-media effects

Increases the use of energy or other utilities. The use of steam injectors as the vacuum system generates contaminated water.

Operational data

The operation of dry pumps may be affected by (solid) impurities.

Driving force for implementation

In the EU there already exists a legally binding precept to promote the re-refining of waste oil into base oil.

Example plants
Emissions to the air are partially controlled on some sites and uncontrolled on others.

Reference literature
[5, Concawe, 1996], [7, Monier and Labouze, 2001], [14, Ministry for the Environment, 2000], [36, Viscolube, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [150, TWG, 2004]

4.4.1.2 Selection of waste oils to be re-refined

Description
Waste oils suitable to be recycled are:

- (black) engine oils, which have homogeneous characteristics and are sought by re-refining plants
- black industrial oils are potentially suitable for regeneration but due to the content of additives and other substances are not typically preferred by re-refining plants
- light industrial oils, which are relatively clean. They can either be re-refined on-site or can be re-used for other purposes. Their market is very specific and independent from the classical supply routes of recycling.

Achieved environmental benefits
Improvement of the feedstock quality can enhance the environmental performance of an installation as well as the quality of the product. Segregated used lubricants can have a higher recovery value as fuel and as a new material for re-refining. If chlorinated compounds (e.g. solvents or PCBs) are prevented to enter in the re-refining process, then operational and environmental problems can be avoided.

Applicability
One report states that 60 to 65 % of waste oils are eligible for regeneration, although other experts suggest a figure of around 50 % of waste oils. The waste oils most suitable for regeneration are those that are not too heavily polluted, and that have a high viscosity index and an absence of esters and biolubricants. (Black) engine oils represent more than 70 % of the waste oil stream. Black industrial oils represent about 5 % of all waste oil, with light industrial oils representing about 25 %. Experts consider the following waste oils to be re-recyclable:

- engine oils without chlorine (EWL code: 130205)
- hydraulic oils without chlorine (EWL code: 130110)
- non-chlorinated mineral diathermic oils (EWL code: 130306)
- engine oils with chlorine (EWL code: 130204) – although only under certain conditions (i.e. limitation of chlorine or PCB content)
- hydraulic oils with PCB (EWL code: 130101) – although only under certain conditions (i.e. limitation of chlorine or PCB content)
- hydraulic oils with chlorine (EWL code: 130109) – although only under certain conditions (i.e. limitation of chlorine or PCB content).

Driving force for implementation
Economic reasons to produce a good product.

Reference literature
[7, Monier and Labouze, 2001], [55, UK EA, 2001], [86, TWG, 2003], [150, TWG, 2004], [153, TWG, 2005]

4.4.1.3 Distillation/clay process

Description
See Section 2.4.1.5.

Achieved environmental benefits
This process potentially has a high adverse environmental impact, due to the large quantity of the oily clay to be disposed of. High temperature activated clay allows a lower clay/oil ratio, thus increasing the overall yield and reducing the quantity of oily clay to be disposed of. Compared to the acid/clay process, there is less oily clay to be disposed of.

Cross-media effects
Poor product quality and low yield.

Operational data
The lubricating oil yield expected with this process is in the region of 50 % on a dry basis.

Example plants
No plants have been identified.

Reference literature
[56, Babtie Group Ltd, 2002]

4.4.1.4 Distillation and chemical treatment or solvent extraction

Description
This consists of a series of vacuum cyclone evaporators followed by a chemical treatment of the lubricating oil cuts obtained.

Achieved environmental benefits
The lubricating oil yield expected with this process is in the range of 65 – 70 % on a dry basis. Adequate process selection can lead to the removal of virtually all PAHs, for instance by utilising solvent extraction. Some processes of this type do not generate residues because they transform the residues into products (e.g. production of a fertiliser by re-utilisation of the reaction waters).

Applicability
Medium sized refining plants (~25 kt/yr).

Economics
Financially attractive. The investment cost of a 108 kt/yr installation is USD 29 million (1994). Assumptions: applies vacuum distillation plus clay or chemical treatment, storage: 15 days and working capital: 15 days.

Example plants
A plant designed using this process is in operation in Spain.

Reference literature
[5, Concawe, 1996], [86, TWG, 2003]

4.4.1.5 Solvent extraction process and distillation

Description

See Section 2.4.1.5. The Interline propane extraction process, improved by Sener, comprises three stages and no finishing step is required:

a. chemical pretreatment, with reagents and catalysts
b. liquid propane extraction of the lubricant bases, separating water and asphalt
c. atmospheric and vacuum distillation, to separate the light fractions and the base oils for lubricants.

Achieved environmental benefits

The process does not produce solid waste. The chemical treatment of the resulting oil fraction with a mixture of chemicals converts the organically bound chlorine into NaCl. After further distillation, all end-products have a reduced chlorine content (less than 10 ppm). The chemical reactor removes contaminants and virtually all chlorine down to less than 5 ppm.

Operational data

The lubricating oil yield declared for this process is 79 % on a dry basis. Another source shows that the yields that are foreseen by the technology providers are 72 – 74 % of base oils and 21 – 22 % asphalts on a dry basis.

Applicability

There is a possibility of re-refining in areas with low productions of waste oil, because the plant is well adapted to relatively small capacities (25 – 30 kt/yr).

Economics

Reduced capital and operating costs. Technology providers claim that this technique reduces investment and operational costs, when compared with other re-refining technologies. The economy of the process is well balanced for relatively low capacity plants (25 – 30 kt/yr).

Example plants

A plant in Spain, working since 2000, shows that air emissions can be reduced by directing the vent streams and gas phase of the the distillation units to a thermal oxidiser where pollutants are oxidated at 850 ºC for a residence time of two seconds.

Reference literature

[5, Concawe, 1996], [11, Jacobs and Dijkmans, 2001], [86, TWG, 2003], [150, TWG, 2004]

4.4.1.6 Thin film evaporator and different finishing processes

Description

The vacuum distillation (thin film evaporator - TFE) is a common component in many re-refining plants. A technique to consider is to apply mechanical seals on rotating shafts in wiped thin film evaporators.

Achieved environmental benefits

TFE technology together with	Yields (%) (related to the input for each activity)
Clay treatment	Total yield: 54 – 73 % Dewatering: 88 – 92 %; TFE distillation 80 – 81 %; Vacuum distillation 76 %, clay treatment 95 %
Hydrotreatment	High product quality The lubricating oil yield declared by the licensors is in the region of 72 % on a dry basis Two existing plants reported yields of up to 94 – 98 % Other sources give the following yields: 88 % dehydradistillation; 84 % TFE distillation; 86 % hydrofinishing giving a total yield of 64 %
Solvent extraction	Total yield ranges from 50 – 67 % 88 – 92 % dehydration distillation; 80 – 91 % vacuum distillation; 83 – 91 % finishing extration
Solvent extraction and hydrofinishing	Total yield 91 % dehydration distillation 81 % vacuum distillation; 97 % finishing extraction

Table 4.34: Achieved environmental benefits of TFE technology
[13, Marshall, et al., 1999], [139, UBA, 2003], [150, TWG, 2004]

Cross-media effects
TFE installations without further treatment produce a dark coloured oil, which is suitable for a diesel extender but not as a base oil suitable for blending into lubricants. Experience reported so far suggests odour problems may occur.

Applicability
The size of these installations ranges from 25 – 160 kt/yr.

Economics
The investment necessary for a vacuum distillation and hydrotreatment installation of 108 kt/yr capacity is USD 43 million (1994). Some other more recent data showed that the cost of TFE clay installation with a capacity of 100 kt/yr is EUR 221/t oil; the cost of a TFE hydro installation with a capacity of 50 kt/yr is EUR 333/t oil; and the cost of an TFE solvent installation with a capacity of 50 kt/yr is EUR 308/t oil.

Example plants
A plant in Newcastle (Australia) and two in Germany (85 and 160 kt/yr respectively) use this technology. At least six different commercial processes are available.

Reference literature
[5, Concawe, 1996], [13, Marshall, et al., 1999], [150, TWG, 2004]

4.4.1.7 Thermal de-asphalting process

Description
For more information on thermal de-asphalting (TDA) see Section 2.4.1.5.

Achieved environmental benefits
The lubricating oil yield claimed by the licensor on a dehydrated waste oil basis is 74 % with clay finishing (97 % dewatering defuelling, 80 % de-asphalting, 95 % finishing) and 77 % with hydrotreatment (97 % dewatering defuelling, 80 % de-asphalting, 96 % finishing) on a dry basis.

Applicability
This process is applied in large installations of 100 – 180 kt/yr and in installations of 40 - 100 kt/yr for hydrotreatment.

Economics
The cost of a TDA clay installation with a capacity of 100 kt/yr is EUR 280/t oil and for a TDA hydro installation of EUR 304/t oil.

Example plants
One plant in Italy and two more outside the EU.

Reference literature
[13, Marshall, et al., 1999], [36, Viscolube, 2002], [86, TWG, 2003], [150, TWG, 2004]

4.4.1.8 Recycling in a lubricating oil refinery

Description
See Section 2.4.1.5.

Achieved environmental benefits
The lubricating oil yield expected with this process is in the range of 65 – 70 % on a dry basis. This technology improves the quality of the re-refined oil, when compared with existing re-refining plants using pre-flash, de-asphalting and clay finishing. Moreover, the oil quality is claimed to be even higher in some respects compared to the conventional mineral oil produced on the same production run.

Economics
With regard to the location of the plant, the pre-existence of some infrastructure and other equipment will of course reduce the capital cost. It is difficult to quantify any saving because of the maintenance and upgrading costs which would be necessary in any case.

Capital cost (1995): USD 45 million. Assumptions: treatment of 108 kt/year, storage of 15 days and working capital of 15 days.

Example plants
This route has recently been commercialised in Germany.

Reference literature
[5, Concawe, 1996], [13, Marshall, et al., 1999]

4.4.1.9 Hydrotreatment

Description
See Section 2.4.1.4. A technique to consider is to scrub (see Section 4.6.10) or incinerate (see Section 4.6.14) the acid off-gases from hydrotreatments.

Achieved environmental benefits

Hydrotreatment is a very efficient finishing process because, it:

- reduces or removes the remaining metals and metalloids of the waste oil
- reduces the Conradson carbon (measurement of the tendency of a hydrocarbon to form coke)
- reduces the organic acids and compounds containing chloride, sulphur and nitrogen
- restores the colour, UV and thermal properties
- reduces PAHs when operating under high pressure and at high temperatures
- allows a viscosity index equal to or better than the original feed.

Cross-media effects

Hydrogen needs to be generated or purchased. It seams that hydrotreatment does not alter the synthetic oil content already present in the waste oil.

Operational data

Hydrotreatment typically increases the safety risks (due to the need for the handling of hydrogen being under pressure and at an elevated temperature). Pressure: 100 barg partial pressure; Temperature: 340 °C; Catalyst: NiMo.

Economics

The capital cost of the hydrotreatment plant is very high. Table 4.35 gives some examples

Plant	Cost
Modern re-refining with hydrotreatment without collection	EUR 4 – 47/tonne [1]
Average collection cost within Europe	EUR 110/tonne
Modern re-refining with hydrotreatment when collection cost is included	EUR -106 to-63/tonne
Severe hydrofinishing standalone plant	EUR 10 million
Severe hydrofinishing standalone plant if Claus unit fitted, H_2 production, sour water stripper and amine units are also necessary	EUR 20 million
Hydrotreatment for a 108 kt/yr installation	USD 65 million (1994)[2]

[1] value at plant gate (1994) assuming an IRR of 15 % after tax and working capital of 15 days. A new report from Europia (2003) reports values of EUR 300 – 333/tonne

[2] solvent extraction and hydrotreatment, storage: 15 days and working capital: 15 days

Table 4.35: Economics of hydrotreatment plants
[5, Concawe, 1996], [36, Viscolube, 2002], [86, TWG, 2003], [150, TWG, 2004]

Driving force for implementation

To increase the quality of the products.

Example plants

Hydrotreatment is the only re-refining process endorsed by the American Petroleum Institute (API). Two hydrofinishing plants exist in Italy (one severe hydrofinishing and another mild hydrofinishing).

Reference literature

[5, Concawe, 1996], [7, Monier and Labouze, 2001], [13, Marshall, et al., 1999], [36, Viscolube, 2002], [66, TWG, 2003], [86, TWG, 2003], [150, TWG, 2004]

4.4.1.10 Direct contact hydrogenation process

Description

See the description of direct contact hydrogenation (DCH) in Section 2.4.1.5.

Achieved environmental benefits
Some benefits of the technique include the following:

- the process is very efficient at separating contaminants from waste oil
- halogenated and oxygenated compounds are destroyed
- generate cleaner products (e.g. lower sulphur (<0.03 w/w-%) fuels)
- the entire waste oil is treated in a reducing environment that exhibits the formation of polymeric and carbonaceous by-products
- the treatment is further catalytically treated to convert the toxic sulphide compounds present to non-toxic sulphates
- hydrogen rich gas is recycled
- the acid gases generated in the conversion reactor are neutralised with caustic solution.

Cross-media effects
Hydrogen needs to be generated or purchased. Solid materials requiring disposal will include the spent catalyst, sodium chloride and sodium sulphate. It produces a low COD, sulphide free and organochloride-free aqueous effluent and a stable heavy residue which is claimed to be suitable for asphalt blending.

Economics
Economically attractive high quality products and a higher yield per tonne of input.

Driving force for implementation
Increase the base oil quality produced by:

- better quality and characteristics than those of virgin oils
- group II base oil with low sulphur and phosphorus, low aromatic content
- increase viscosity index and oxidation stability.

Example plants
The direct contact hydrogenation process has been used industrially since the first plant was completed in Germany in November 2003.

Reference literature
[5, Concawe, 1996], [139, UBA, 2003], [150, TWG, 2004]

4.4.1.11 Solvent extraction

Description
See Section 2.4.1.4.

Achieved environmental benefits
Does not result in polluted clay as a waste product.

Cross-media effects
Only 98 % of the solvent is regenerated after extraction of the base oil.

Applicability
Fully applicable in the sector.

Economics
Cheaper than the hydrofininishing option.

Example plants
At least one plant is operational in Germany

Reference literature
[86, TWG, 2003]

4.4.1.12 Caustic soda and bleaching earth treatment

Description
See Section 2.4.1.5.

Achieved environmental benefits
A high lubricating oil yield is obtained as a result. The base oil produced is of high quality (group II) with greater yields of base oils than other available technologies. Neutralisation is carried out with acid and clay treatment. Only 25 % of clay and acid is used compared to the usual clay / acid amount.

Operational data
Use of caustic soda.

Applicability
Applied to waste oils.

Economics
It is reported to be economically attractive because there are high quality products and a higher yield per tonne of input.

Driving force for implementation
This technique increases the base oil quality:

- same quality and characteristics as virgin oils
- group I base oil with low sulphur and phosphorus, low aromatic content
- high viscosity index and oxidation stability.

Example plants
An installation has been operating in Germany since 2000.

Reference literature
[5, Concawe, 1996], [150, TWG, 2004]

4.4.1.13 Treatment in a refinery

Description
There are two possible mixing options in a refinery:

Mixing with the feedstock (typically crude oil)
The pretreated oil is mixed with the crude oil and the blend passes the desalter before it is fed to the crude oil distillation unit of an existing refinery. In this option, the waste oil passes through all the refinery processes, and the main part of the waste oil ends up in the bottom product of the vacuum column. This vacuum residue contains most of the metals and sulphur components from the waste oil. Its final use depends on the refinery.

Blending into the vacuum residue
Pretreated waste oil is used as a supplementary component to be mixed with the bottom product of the vacuum column. In this option, the waste oil hardly enters some of the refinery units of the plant. The blend contains all the metals, chlorides and sulphur components originating from the waste oil.

Tests have shown that most of the metals from the used oil go to the asphalt bottoms. The vacuum gasoil quality is not altered apart from only slightly elevated chlorine contents and might be considered suitable for use in the catalytic cracking operation. However, tests have also indicated that additional pretreatment of the pre-flashed used oil will be necessary to reduce polyorganic chlorides which are not removed by the pre-flash operation. Otherwise, these chlorides would distil with the light ends of the vacuum column, causing corrosion of the overheads of that column and to any downstream hydrotreatment.

Achieved environmental benefits

Along with its use to provide a secondary feedstock to the fuels unit, it reduces the crude oil requirements to the complex. It typically reduces the utility consumption of the lubricant plant because the regeneration of waste oils requires less utilities than virgin basestock production, mainly due to the minor content of wax (therefore less dewaxing is required). The reduction of emissions of sulphur oxides are minor.

Cross-media effects

The (potential) presence of organic chlorides can produce a weak acid during hydrotreating, resulting in severe corrosion problems and potential incidents. The normal refining process sequence does not remove all the metals from waste oil, with the result that the metals left can poison the catalytic cracker catalyst.

Moreover, refineries may blend the waste oil, without further processing, with heavy oil and use it as a secondary feedstock for the fuel unit. Burning this fuel may yield higher SO_x and metal emissions. In some countries, these heavy fuel burners are not equipped with an off-gas treatment system, because the permits of these industries adapt a bubble principle (see the Refinery BREF).

Operational data

This technique can be integrated in the refinery works. Mixing waste oil with a crude oil alternative is not applied because of the severe technical problems the waste oil may cause in the plant, e.g. catalyst fouling and severe corrosion.

Recycling of waste oil within a mineral oil refinery is generally not applied because of the severe technical problems the waste oil may cause in the plant. Some examples are the presence of metals in the waste oil, which can poison the catalytic cracker catalyst bed, and the presence of organic chlorides in the waste oil, which can cause corrosion problems as they are converted to weak hydrochloric acid in the hydrotreating stages.

Applicability

This technique creates a distortion in the product slate of the mineral oil refinery. For example, to meet the needs of their heavy lubricant customers, the mineral oil refinery will have to produce that fraction also required (by increasing the crude consumption to the fuels unit).

The technical feasibility of the technique is not guaranteed because it may cause severe technical and operational problems.

Economics

The approximate value of used oil without collection EUR 27/t (the value at the plant gate (1994) assuming an IRR of 15 % after tax and a working capital of 15 days) and of -83 including the collection cost (at an average collection cost of USD 110/t within Europe). With regard to the location of the plant, the pre-existence of some infrastructure and other equipment can reduce the capital cost. It is difficult to quantify the saving for this because of the maintenance and upgrading costs which may be necessary to utilise this resource.

The investment cost is USD 11 million (1994) with the following assumptions: 120 kt/year, storage: 15 days and working capital: 15 days.

Economic advantages are linked to the process synergies as well as to the reduction in the crude oil and energy consumption. According to [7, Monier and Labouze, 2001], integration of a thermal cracking unit would be economically more preferable for refineries than integration of a re-refining unit.

Driving force for implementation

The potentially severe operating problems make this method of treatment unattractive for refinery operators.

Example plants

The process does not yet have any industrial application. The method has been the subject of a pilot study in France and a study in Canada.

Reference literature

[5, Concawe, 1996], [6, Silver Springs Oil Recovery Inc., 2000], [7, Monier and Labouze, 2001], [11, Jacobs and Dijkmans, 2001], [86, TWG, 2003], [150, TWG, 2004]

4.4.1.14 Water management in waste oils re-refining installations

Description

Some techniques include:

a. ensuring that any effluent water (e.g. water distilled from the used oil, process water including the caustic scrubber blowdown) are treated before discharge
b. using a waste water treatment unit (e.g demulsifier and flocculant, flocculation and biological treatment, ultrafiltration and microfiltration). More information can be found in Section 4.7
c. re-using the cleaned waste water as cooling water by applying a suitable WWTP and by generating water products that may be re-used outside the installation
d. feeding the effluent water to the heater along with the oils in order to incinerate the harmful constituents.

Achieved environmental benefits

Three examples on the achieved values treatments are shown in Figure 4.6, Figure 4.7, Figure 4.8 and Table 4.36 and Table 4.37.

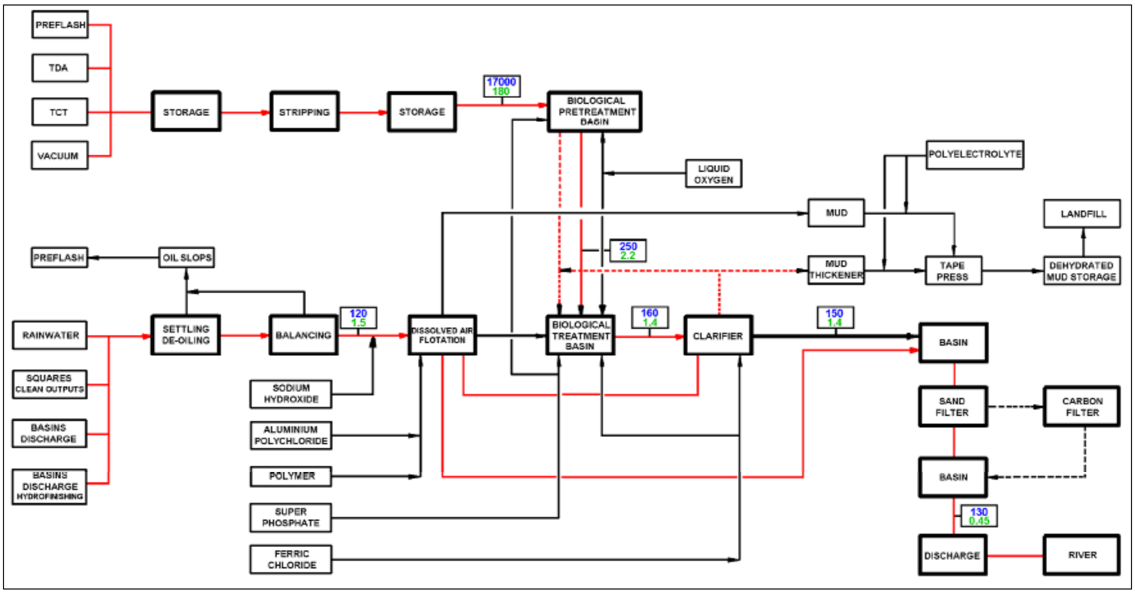


Figure 4.6: Achievable levels in a waste water treatment used in a re-refining process
[36, Viscolube, 2002]
Note: Figures in boxes are all given in ppm. The upper figures correspond to COD and the lower figures correspond to phenol content

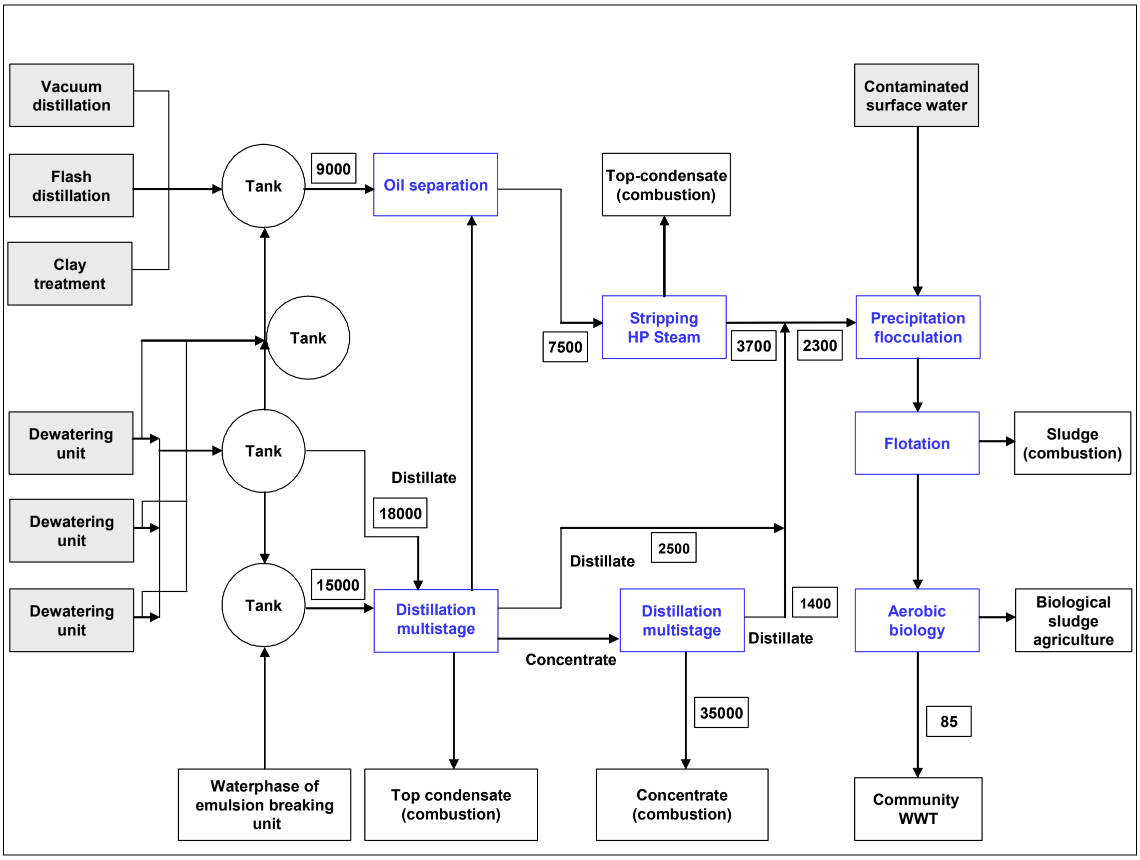


Figure 4.7: Waste water treatment used in a re-refining process (TFE/clay treatment) [139, UBA, 2003]
Note: Values in the figure correspond to TOC contents in ppm

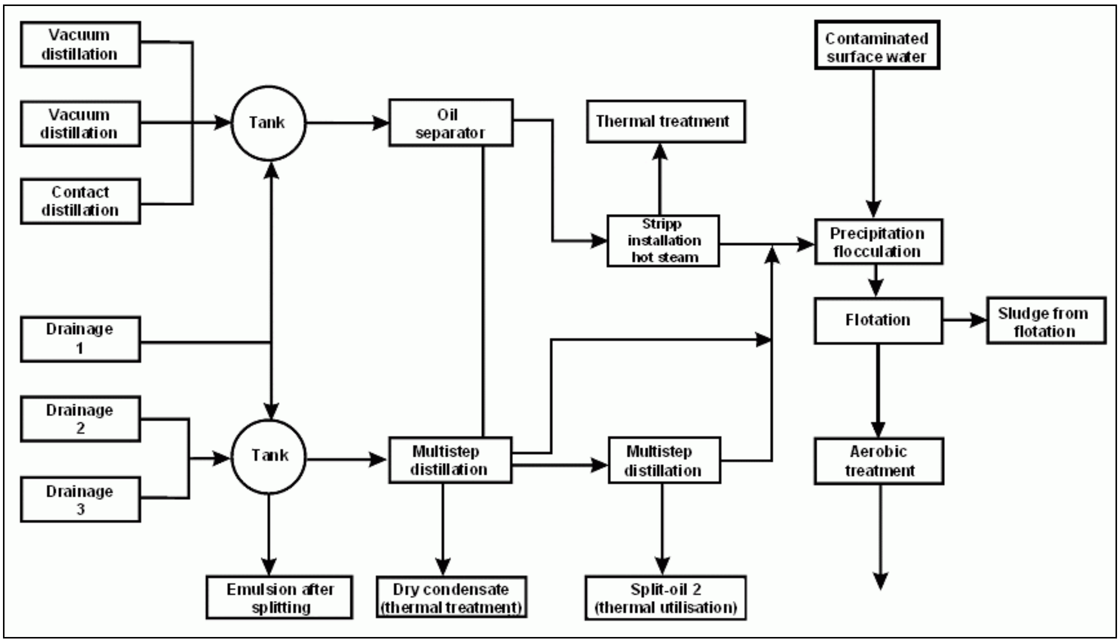


Figure 4.8: Waste water treatment used in a waste oil treatment plant [150, TWG, 2004]

The parameters in the Table 4.35 below can be achieved with a waste water treatment plant the same as above.

Parameter	branch precipitation/flocculation (mg/l)	branch biology (mg/l)	downpipe in-house biology (mg/l)
COD			200 – 500
TOC	1800 – 3500	1300 – 2200	60 – 150
Nitrite- N		1 – 20	<0.1 – 1.0
Total nitrogen		80 – 280	10 – 60
Total phosphorous		1 – 15	2.0 – 5.0
AOX		0.1 – 0.4	<0.10 – 0.25
Hydrocarbons	50 – 300	<1.0 – 10	<0.1 – 2.0
Benzene and derivatives		0.01 - 0.03	<0.01
Phenol index		1 – 50	<0.2
Pb	<0.05 – 0.06	<0.05	<0.05
Cd	<0.02	<0.02	<0.02
Cr	<0.02 – 1.0	<0.02	<0.02
Fe	1 – 10	1 – 20	1 – 10
Cu	<0.02 – 0.2	<0.02 – 0.1	<0.02 – 0.1
Ni	<0.02 – 0.5	<0.02 – 0.3	<0.02 – 0.1
Zn	<0.1 – 1.0	<0.1 – 0.1	<0.1

Table 4.36: Composition of different inputs and outputs from different streams of the WWTP in a waste oil refinery
[150, TWG, 2004]

Waste water parameter	Value (ppm)
Hydrocarbons	<0.01 – 5
COD	20 – 400*
Phenols	0.15 – 0.45
* Values of 400 can be achieved without dilution of the treated waste water with other water streams	

Table 4.37: Achievable levels in the effluent after biological WWTP in waste oil treatment units
[42, UK, 1995], [150, TWG, 2004], [152, TWG, 2004], [153, TWG, 2005]

Cross-media effects

WWTPs typically generate ammonia and VOC emissions to the air.

Operational data

Biological treatment is an option to consider, however it has not been found to be reliable. Daily monitoring of the sewer discharge includes the monitoring of ammonia levels, but not total nitrogen. There is no monitoring of phosphorus levels.

Example plants

The biological section of a UK oil recovery plant consisted of four aeration units which were used tanks to treat the aqueous layer from oil treatment as well as landfill leachates. There are some re-refining processes that do not generate waste water for external treatment. These systems make a total utilisation of the water contained in used oil (e.g. utilisation of treated water as refrigeration fluid or in the production of a fertilising compound).

Reference literature

[36, Viscolube, 2002], [42, UK, 1995], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [139, UBA, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.4.1.15 Waste management in waste oils treatment installations

Description
Some techniques include:

a. burning the non-lubricant recovered oils in a heater equipped with a gas scrubber to raise energy for the plant
b. treating and disposing of all used filters
c. applying a thermal treatment for all residues
d. using the residues from the vacuum distillations and evaporators as asphalt products.

Achieved environmental benefits
Reduces the amount of residues generated by the treatment.

Driving force for implementation
To reduce waste generation.

Example plants
Typically used in waste oil regeneration facilities.

Reference literature
[56, Babtie Group Ltd, 2002], [150, TWG, 2004]

4.4.2 Waste solvents

4.4.2.1 Selection of waste solvents to be recycled

Description
Waste solvents composed by monostreams are typically regenerated. A waste solvent can be considered regenerative if, e.g.:

- it is a monostream (one batch from one waste generator)
- it yields a minimum of 60 % distillate
- it has a certain minimum amount per load
- the costs of distillation are the same as or lower than for incineration.

Achieved environmental benefits
Avoid environmental problems in the installation. By means of distillation, waste solvents are separated into a reusable solvent and a non-reusable distillation bottom.

Applicability
Non-chlorinated solvents, CFCs and halons.

Reference literature
[150, TWG, 2004], [156, VROM, 2004], [157, UBA, 2004]

4.4.2.2 Improvement of regeneration treatment of waste solvents

Description
Some techniques include:

a. applying azeotropic distillation
b. applying vacuum distillation
c. using thin-film evaporators
d. heating the feed stream with the distillate by means of a heat-exchanger and insulation measures
e. applying a cascade re-use of solvent (i.e. where the solvent is used once for high quality cleaning and then used again for other cleaning or for operations that do not require a pure solvent)
f. using vapour balancing systems and directing the waste gas to abatement techniques (e.g. activated carbon filtration, enclosed systems and using vapour balance lines during loading). The removal efficiency of an activated carbon filter is at least 90 %.
g. using distillation for the separation of organic solvents from solids
h. using rectification for the removal of contaminating substances and achieving a certain quality of the wastes OUT
i. dewatering by means of a decanter if the solvents contain water.

Achieved environmental benefits
Improves the separation of waste solvents and the efficient use of solvents. The energy consumption of distillation can be reduced (e.g. techniques b-d in the description section above).

Emission values of 50 mg C/Nm³ in the waste gas after the treatment mentioned in technique f in the description section above are achievable.

Cross-media effects
The application of cascade re-use of solvents could develop using solvents in open devices and for instance, to clean machines or coating devices. In such cases a defined composition of the solvent mixture needs to be known and the solvents should not contain volatile organic compounds which are asignated as risk materials for human health.

Distillation of waste solvents produce emissions of hydrocarbons to the air and waste water that need to be treated.

Operational data
The use of vapour balancing systems during solvent charge is typically used to reduce fugitive VOC-emissions (e.g. Germany). The waste gas is usually treated by adsorption on activated carbon.

Applicability
The distillation technique is applicable to all regenerative solvents and refrigerants. The capacities of the example installations range from approximately 2 – 60 kt/yr.
Azeotropic distillation is commonly used to enhance solvent recovery. An azeotrope or azeotropic mixture is a mixture of liquids that behave as a single substance when boiled (i.e. both the vapour and the liquid have the same composition). Azeotropic distillation consists of adding a substance (typically steam) to form an azeotropic mixture with the solvent to be recycled. The azeotropic mixture will have a lower boiling point than the original mixture and recovery of the solvent will thus be facilitated.

Vacuum distillation is designed to handle solvents with higher boiling points (above 200 °C).

Driving force for implementation

Some organic solvents are especially dangerous compounds for human health. Some restrictions (e.g. closed installations) are mentioned in Directive 1999/13/EC.

Preference order for waste management in accordance with the Waste Framework Directive and the Sixth Environmental Action Programme of the European Community.

Example plants

Re-refining of N-methyl-2-pyrrolidone (NMP) used in electronic manufacturing.

Reference literature

[53, LaGrega, et al., 1994], [130, UBA, 2003], [150, TWG, 2004]

4.4.2.3 Waste water treatment in waste solvent facility

Description

See Section 4.7. Some techniques that have been used in waste solvent facilites are waste water stripping plants, bio-reactors, waste water staple tanks, waste water intermediate storage tanks and ultrafiltration facilities.

Achieved environmental benefits

The characteristics of the effluent after treatment is shown in the Table 4.38:

Compounds	Average value	Units
Colour	-	
Odour	-	
pH	8.7	
Electric conductivity	989	µS/cm
P total	0.46	mg/l
N total	32.9	mg/l
COD	18	mg/l
BOD_7	<3	mg/l
Sb	<0.01	mg/l
Pb	<0.010	mg/l
Cd	<0.002	mg/l
Cr total	<0.002	mg/l
Co	0.006	mg/l
Ni	<0.002	mg/l
Zn	0.02	mg/l
Lightly volatile halogenated hydrocarbons	4	µg/l
AOX	320	µg/l
Note: Data from 2002		

Table 4.38: Characteristics of the effluent of a WWTP in a waste solvent regeneration facility [130, UBA, 2003]

Cross-media effects

See Section 4.7.

Operational data

See Section 4.7.

Applicability

See Section 4.7.

Economics

See Section 4.7.

Driving force for implementation
See Section 4.7.

Example plants
Waste solvent treatment plants typically have waste water treatment facilities.

Reference literature
[130, UBA, 2003]

4.4.2.4 Evaporation of distillation residues

Description
Vacuum dryer and other drying techniques are in use for distillation bottoms.

Achieved environmental benefits
Increase the percentage of solvent recovered. Valorisation of 99 % of the container solvents. This can reduce the total solvent concentration by approximately a factor of ten. Also resins and pigments may be valorised. At the same time they may reduce odour and VOC emissions that may be generated by the bottoms.

Cross-media effects
The solid residue that is generated should be treated. VOC are emitted to the air and they are treated before being emitted.

Operational data
Energy (heat and power) is necessary to run such systems. There are systems for the treatment of up to 4000 tonnes of distillation residues per year. From that, it is posible to obtain between 1500 to 2000 tonnes of solvents per year. The specific kneading energy is up to 0.1 kWh/kg. The separation of heating and cooling zones facilitate efficient product temperature control.

Applicability
It does not need so much surface and it is easily applicable to existing installations. It is applicable to distillation residues of painting solvents, polymers, elastomers, pharmaceutical products and food products. VOCs arise from a wide range of waste types. Obvious examples are waste oil and solvents. For example, a distillation bottom sludge may have a significant concentration of solvent, which, if the material was in liquid form, may render it suitable for recovery.

Economics
Investment cost of EUR 1.2 million. Operating costs vary between EUR 100 to 150 per tonne of residue treated.

Driving force for implementation
To improve the recovery of solvents and waste minimisation

Example plants
At least six installations use this system around the world. At least four are in the EU. Drying techniques are in use in the UK for the distillation of bottom sludges.

Reference literature
[50, Scori, 2002], [55, UK EA, 2001], [66, TWG, 2003], [150, TWG, 2004]

4.4.2.5 Full automatisation of residue incineration

Description

In a solvent distillation plant the discharge of the distillation sludge is optimised. For working and environmental protection reasons the process of discharge is now fully automatised. Because of the high heating value the transfer of the sludge to the in-house incineration plant is fully automatised.

Achieved environmental benefits

Treatment of the residues from waste solvent treatment.

Applicability

This technique of quasi-dry discharge does not necessarily have to be the adequate solution when process is optimised as a whole.

Example plants

A solvent distillation plant located in Münster (Germany).

Reference literature

[150, TWG, 2004]

4.4.3 Waste catalysts

4.4.3.1 Generic techniques used in the treatment of waste catalyst

Description

Some techniques include:

a. applying heat recovery in the form of energy production or recuperation. For this aim, recuperative burners, heat-exchangers and boilers can be used to recover heat. Steam or electricity can be generated for use on or off site, e.g. to preheat process or fuel gases
b. using oxygen or oxygen enriched air or oxygen in the burners
c. preheating the combustion air used in burners
d. preheating the material charged to the furnace
e. automatically controlling the point of extraction using dampers and fan controls so that the systems are deployed when and where they are needed, for example, during charging or during ‘roll out’ of a converter.

Achieved environmental benefits

Heat and energy recovery, which is an important factor in this industry due to the high proportion of costs that energy represents.

The use of oxygen enriched air or oxygen in the burners reduces the overall energy consumption by allowing the complete combustion of carbonaceous material. At the same time, waste gas volumes are significantly reduced allowing smaller fans, etc. to be used.

The advantage of preheating the combustion air used in burners is well documented. If an air preheat of 400 °C is used, there is an increase in flame temperature of 200 °C, while if the preheat is 500 °C the flame temperature increases by 300 °C. This increase in flame temperature results in a higher efficiency and a reduction in overall energy consumption. The alternative to preheating combustion air is to preheat the material charged to the furnace. Theory shows that 8 % energy savings can be obtained for every 100 °C preheat and in practice it is claimed that preheating to 400 °C leads to a 25 % energy saving, while a preheat of 500 °C leads to a 30 % energy saving.

Applicability
The technique used to recover heat varies from site to site, depending on a number of factors such as the potential uses for heat and energy on or near the site, the scale of operation and the potential for gases or their constituents to foul or coat heat-exchangers

Many techniques aimed at energy recovery are relatively easy to retrofit but occasionally there may be some problems with deposition of metal compounds in heat-exchangers. A good design is based on a sound knowledge of the compounds released and their behaviour at various temperatures. Heat-exchanger cleaning mechanisms are also used to maintain their thermal efficiency.

Reference literature
[125, Ruiz, 2002]

4.4.3.2 To improve control of the process

Description
Some techniques include:

a. adjusting the temperature levels and residence time of the catalyst in the unit, in order to achieve desired levels of carbon and sulphur
b. applying cooling prior to a bag filter installation
c. using sealed furnaces, which can allow a very high capture efficiency of the fumes
d. using ducts and fans to convey the collected gases to abatement or treatment processes. Variable speed fans are used to provide extraction rates that are suitable for changing conditions such as the gas volume, with a minimum energy consumption
e. having a good temperature control during the regeneration process
f. designing the residence time in the pretreater to be very short (in the order of a few minutes), to minimise attrition normally associated with fluidised bed processes
g. applying sizing (i.e. length graded) technology after regeneration. The length grading technology removes short catalyst particles (typically those with lengths 1 – 2 times the diameter) that cannot be removed with conventional screening. In an example, length grading was set up to accept only a relatively small cut, to increase the average length by 0.1 – 0.2 mm without discarding too much material.

Achieved environmental benefits
Improves the control of the process and the efficiencies of abatement techniques. The effectiveness of collection depends on the efficiency of the hoods, the integrity of the ducts and on the use of a good pressure/flow control system.

Operational data
Applying cooling prior to a bag filter installation is an important technique as it provides temperature protection for the filter and allows a wider choice of fabric. It is sometimes possible to recover heat at this stage. The temperature of the gases after this heat-exchanger can be between 200 and 450 ºC. The second heat-exchanger reduces the gas temperature to 130 ºC before the bag filter. The heat-exchangers are normally followed by a cyclone, which removes larger particles and acts as a spark arrester.
Driving force for implementation
Product requirements.

Reference literature
[125, Ruiz, 2002]

4.4.3.3 Abatement techniques used in the waste catalyst regeneration sector

Abatement technique	Location where it is applied	Section in this document where the abatement technique is analysed
Fabric filter	Exit of the furnaces	4.6.5
Wet scrubbers	Exit of the furnaces	4.6.11

Table 4.39: Abatement techniques applied to waste catalyst regeneration plants
[125, Ruiz, 2002]

4.4.4 Activated carbon

4.4.4.1 Choice of furnace used to regenerate the waste activated carbon

Description
The options are 'multiple hearth hurnaces', 'direct fired rotary kilns' and 'indirect heated kilns' (where there is no contact between the kiln content with flue-gases generated from a burner).

Achieved environmental benefits
The multiple hearth furnace has significant advantages over other types of furnace from the standpoint of regeneration efficiency because the temperature of each hearth may be independently controlled. The direction of the exit gases may be either co-current or countercurrent to the flow of carbon. In some designs, the afterburner may be incorporated within the furnace at the 'zero' hearth level. The multiple hearth furnace shows better mass transfer and temperature control characteristics than the rotary kiln and has a carbon residence time of typically one to two hours. Carbon losses may be up to 10 % by weight.

Direct fired rotary kilns may be operated with the carbon flowing either co-currently or countercurrently to the flow of combustion air. In the countercurrent mode of operation, the exit gases leaving the kiln are at a higher temperature than in the co-current mode, which allows the potential for designing the afterburner to less stringent criteria while still destroying gaseous contaminants.

Indirectly heated kilns offer the advantages of eliminating the need for the mixing of burner flue-gases with process gases. The lower volume of gas requiring heating saves on energy and the size of abatement equipment. Burner flue-gases that have indirectly heated the kiln are then directed to the base of the stack where they may be combined with the kiln off-gases to reduce the visibility of the emitted plume. This method may offer the advantage of affording higher partial pressures of steam in the kiln, which is likely to reduce formation of oxides of nitrogen. Also the formation of halides is likely to be promoted rather than elemental halogens, with the halides being more easily removed in downstream scrubber systems.

Operational data
Owing to the absence of exposed metal surfaces, rotary kilns are normally able to operate at higher temperatures than multiple hearth furnaces. Carbon losses on rotary kilns may be in the range 5 – 15 % by weight. Careful attention needs to be paid to the seals between the rotating kiln and the end plates to prevent any leakage of gases and particulate matter. Fugitive emissions from this area are normally controlled by operating the kiln at a slightly negative pressure.
Indirect furnaces are normally contructed with a metal tube and are not likely to be suitable for industrial applications due to corrosion problems that may appear during treatment of some industrial carbons.

Applicability
The applications of the indirect fired kiln are generally for the treatment of industrial carbons where more onerous temperature criteria apply to the afterburner.

Example plants

The indirect fired kiln concept is becoming more widespread. Infrared furnaces are relatively new in application and are predominantly found in the United States. Their mode of firing is by infrared elements and indirect heating of the carbon. As a result, they avoid the production of a combustible gas, production which can result in lower volumes of air requiring treatment in the abatement chain. They are, however, limited to maximum capacities of around 1000 t/yr.

The only known indirect fired rotary kiln example in Europe was in the UK and this is believed to be no longer functional.

An activated carbon regeneration plant located on a drinking water site using a multiple hearth furnace: the plant consists of silos for containing spent and reactivated carbon, separate spent and reactivate transfer water system to transport carbon from silos and to and from the furnace. The unit also has a direct transfer system to the water works for treating the carbon from that particular site. Spent and reactivated carbon is transported from other sites using bulk road tankers.

Reference literature

[29, UK Environment Agency, 1996], [41, UK, 1991], [42, UK, 1995], [150, TWG, 2004]

4.4.4.2 Flue-gas treatment

Description

Some techniques include:

a. using an afterburner for the gases exiting the furnace or kiln. The afterburner needs to be in operation at all times when carbon is present in the kiln
b. designing the regenerator and associated ducting and equipment to operate under a reduced pressure, in order to prevent the escape of regenerator gases into the air
c. applying heat recovery. Typically this involves gas/gas heat-exchangers to allow the preheat of combustion air and flue-gas reheating. There may also br a waste heat boiler used for the generation of steam, which is also used in the reactivation of the carbon
d. cooling the flue-gases with a quench section or venturi scrubber
e. using an aqueous or caustic scrubber. Spray absorption techniques may also be used. It will be necessary to provide a pH control on the scrubber liquor
f. routing the flue-gases to the stack via an induced draft fan with partial reheating of the flue-gases
g. using either wet or dry electrostatic precipitators, venturi scrubbers or fabric filters. Inertial separators, e.g. cyclones when used alone, are unlikely to meet low emission values.

Achieved environmental benefits

Reduces the emissions of the flue-gas generated. A spray dryer followed by fabric or ceramic filters has the additional advantage of allowing further neutralisation reactions to occur between the trapped solid residues and the exhaust gas stream. This can lead to a reduction in alkali requirements for a spray dryer of 10 – 15 % against a wet scrubber.

Table 4.40 shows the achieveable levels for key substances in the context of the processes concerned.

Substance	Achievable levels (mg/Nm^3)
Total particulate matter	20
Hydrogen chloride	30
Sulphur dioxide (as SO_2)	50
Oxides of nitrogen (as NO_2)	350
Carbon monoxide (measured after last injection of air)	50
VOC (as C) (excluding particulate matter)	20
Dioxins and furans (International Toxicity Equivalent – ITEQ)	1 ng/m^3
Notes: The above concentrations are for non continuous monitoring.	

Table 4.40: Air emissions benchmark release to air
[29, UK Environment Agency, 1996]

Cross-media effects

Technique f in the Description section, requires reheating of the flue-gas.

Operational data

The regenerator includes an afterburner chamber, which is equipped and operated in such a way so that the flue-gas resulting from the regeneration of the carbon is raised, after the last injection of air, in a controlled and homogeneous fashion and taking account of the most unfavourable conditions, to a temperature of at least 850 ºC as measured at the inner wall of the combustion chamber. This needs to be held for at least two seconds in the presence of at least 6 vol-% oxygen dry gas, as measured at the exit of the afterburner. For carbon which has been used in industrial applications where halogenated or other thermally resistant substances are likely to be present (e.g. containing more than a certain small percentage), the temperature is typically raised to at least 1100 ºC. The residence time, minimum temperature and the oxygen content of the exhaust gases needs to be verified. However, in some circumstances not specified by the TWG, it may be possible to achieve an equivalent effect with less stringent conditions (some generic information on this issue can be found in the WI BREF).

Applicability

Flue-gases from either multiple hearth furnaces or rotary kilns generally follow a similar path of treatment. In the case of co-currently fired rotary kilns, it may be possible to achieve these same conditions without an afterburner.

The flue-gas treatment depends on the application to which the carbon has been put and the nature of the fuel used to fire the kiln and afterburner. The equipment described above may typically be used for carbons that have been used for potable water treatment and for food grade applications. For carbon used in industrial applications, more extensive abatement measures may be required.

Waste gas treatment facilities may vary depending on the application for which the carbon has been used. More stringent requirements may be needed for carbon that has been used for industrial applications. In these cases, further chemical scrubbing may be needed to attain the desired achievable release levels. It may also be necessary for the post-regeneration stage to be maintained at temperatures of at least 1100 ºC for a two second residence time in the presence of at least 6 vol-% oxygen and dry gas, to ensure complete oxidation of certain refractory compounds.

Driving force for implementation

In certain local circumstances and because of visual issues (e.g. visible plume suppression), sometimes technique c and f in the description section above are required by certain authorities.

Reference literature

[29, UK Environment Agency, 1996], [41, UK, 1991], [42, UK, 1995], [150, TWG, 2004], [152, TWG, 2004], [153, TWG, 2005]

4.4.4.3 Waste water treatment plants

Description

These processes need a system for the treatment of the liquid effluent generated in the flue-gas treatment plant. Some techniques include:

a. applying two-stage hydroxide precipitation at different pH values
b. utilising sulphide precipitation to remove metals
c. utilising flocculation, settlement, filtration or centrifuges to separate the suspended materials. A preliminary chemical or physical pretreatment stage may also be necessary to condition the suspended solids and improve the separation
d. adjusting the pH to promote the precipitation of specific chemicals and to achieve an acceptable effluent
e. using natural zeolites, ion exchange resins, activated carbon and reverse osmosis techniques to remove noxious impurities (e.g. pesticides). Concentration by evaporation is also a possibility
f. applying a biological treatment to remove BOD, phenols, cyanides and ammonia.

Achieved environmental benefits

Table 4.41 indicates the achievable release levels for key substances in the context of the processes concerned.

Substance	Achievable [1]	Units
COD		
Suspended solids	50 [2]	mg/l
Cadmium	5 [3]	µg/l
Mercury	1 – 10	µg/l
Other heavy metals	<0.5	mg/l
Dioxins and furans, PAHs and other organics		
Simazine	1 [4]	µg/l
Atrazine	1 [4]	µg/l

Notes:
[1] The levels quoted represent a flow weighted monthly average concentration
[2] By sedimentation or settlement. Lower releases may be achieved by filtration, if necessary, depending on the receiving water and the level of contamination with other pollutants
[3] By precipitation and filtration which can be expected to achieve 70 % reduction. Subsequent treatment in the biological treatment plant of a sewage treatment works will reduce this to below the limit of detection
[4] For waste water carbons, trace quantities of pesticides may be leached from granulated activated carbon (GAC) into waste water prior to discharge to sewer. Many GAC regeneration plants install small GAC filters on the outlet to the sewer as a precaution

Table 4.41: Achievable water emission values
[29, UK Environment Agency, 1996], [150, TWG, 2004]

Applicability

Applied to the effluent from quenching or scrubbing flue-gas treatment.

Example plants

Many examples exist in the sector.

Reference literature

[29, UK Environment Agency, 1996], [150, TWG, 2004]

4.4.4.4 Pollution control techniques applicable to activated carbon regeneration

Pollution control techniques for the abatement of particles and acid gases	Applicability to activated carbon regeneration
Primary measures for particulate control	Furnace temperature Turning rate of the rotary furnace Fuel type
Secondary measures for particulate and acid gases control	Mechanical collectors Wet scrubbers Dry scrubber Electrostatic precipitators (ESP) Fabric filters
Primary measures for NO_x control	Reduce furnace and combustion temperatures Reduce excess air and thus lower the concentration of atomic oxygen in higher temperature zones Reduce residence time in all higher temperature areas Control the furnace heat release rate, and eliminate high temperature peaks Flue-gas recirculation (FGR) Air staging Fuel staging Furnace insulation Low entrance of secondary (cold) air Reduced air/fuel ratio
Secondary measures for NO_x control	Selective catalytic reduction (SCR) Selective non-catalytic reduction (SNCR) The DESONOX process The SNOX process The EDTA-Chelate process The SO_x NO_x RO_x BOX

Table 4.42: Applicability of techniques in the activated carbon regeneration for the treatment of flue-gases
[41, UK, 1991], [150, TWG, 2004]

4.4.5 Resin regeneration

4.4.5.1 Techniques for the regeneration of resins

Description
Some techniques include:

a. applying a pH balancing system
b. applying hot water regeneration.

Achieved environmental benefits
Increases the rate of resins regeneration. The alternative use of heat (i.e. hot water) to regenerate resins, potentially provides reductions in effluent volume and requires lower energy requirements, particularly where heat recovery is employed on the regenerated fluid.

Applicability
Hot water regeneration is only possible for thermally stable resins.

Economics
The principal technique employed to control releases to water is a pH balancing system. Such a system can cost in the region of GBP 30000 to 40000. This compares with a total plant cost in the order of GBP 250000, excluding civil works. Hot water regeneration lowers the operating costs.

Reference literature
[41, UK, 1991], [42, UK, 1995]

4.4.5.2 Pollution control techniques applicable to activated carbon and for resin regeneration

The same type of techniques can be used as are used for activated carbon regeneration. Thus refer to Section 4.4.4.4.

4.5 Techniques to consider for the preparation of waste to be used as fuel

This section contains techniques considered to have a good environmental operating performance (e.g use of a good energy system) or that can help lead to a good environmental performance (e.g. environmental management systems). Techniques in this section contain those relevant to preparation of waste to be used as fuel.

4.5.1 To improve the knowledge of the waste fuel prepared

Description
This technique is related to the one described in Section 4.1.1.1 on Waste composition characterisation and related to Quality Management System (QMS). Mixing and blending (see Section 4.1.5) also plays an important role on this issue. The quality assurance of the preparation of waste to be used as fuel is driven by the need to meet the specification set by the receiving facility. Some techniques include:

a. delivering a report to the customer covering the main physical and chemical properties of the waste fuel, in particular:

   - origin and EWL number
   - net calorific value
   - ash content
   - water content
   - volatile matter content
   - biomass content
   - chemical composition (especially C, H, O, N, S, P, Cl, F, Al, K, Na, heavy metals).

b. limiting the amount of relevant parameters for any waste that is to be used as fuel in any co-incineration plant (e.g. chromium (VI), total chromium, lead, cadmium, mercury, thalium, PCB, sulphur and the total halogen content for the use in cement kilns).

Achieved environmental benefits
Passes on knowledge to the user of the fuel about the possible emissions and any operational problems that may be generated by the use of the material as fuel. The waste fuel user needs to provide sufficient specifications of the waste fuel to be used to reduce the possible impact on the emissions, quality of residues generated by waste fuel user, corrosion behaviour and the quality of products.

Operational data
Laboratory work is required (analyses).

Applicability
The actual blend of waste solvents in particular is set by a good knowledge of the constituents, to meet calorific values and limits on contaminants, for example, chlorine and heavy metals.

Driving force for implementation
CEN/TC 343 solid recovered fuels and WG 2 ‘Specifications and classes’. The use of waste fuels and the displacement of pollutants to residues or products increasingly becomes an important issue. Therefore the use of some waste fuels has to be restricted, depending on the subsequent treatment. New discussion or regulations limiting chromium (VI) in cement to no more than 2 ppm because of health and safety reasons may restrict the use of some wastes containing chromium. Some guidances is also available (e.g. North Rhine Westphalia in Germany).

Reference literature

[14, Ministry for the Environment, 2000], [55, UK EA, 2001], [74, ENDS, 2002], [86, TWG, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.5.2 Prepare different types of waste fuel

Description

The preparation of different types of waste fuel needs to consider the technical characteristics of the combustion process to using it (e.g cement plant, lime plant, power plant (hard coal, lignite), specialised waste fuel combustion). These combustion processes have different technical characteristics.

The extent of the waste treatment operation depends on the waste fuel application. Some examples are:

a. type of waste used to prepare the waste fuel
b. techniques used for waste fuel storage
c. kind of furnace feeding (bulk material, blow feeding)
d. fuel mix used in the combustion process
e. type of combustion process, grate firing with diameter <150 mm or pyrolysis with diameter <150 mm with a high tolerance of metals and heavy particles
f. type of feeding of the waste fuel: blow feeding of a blast furnace with d <20 mm (cement kiln, lignite power plant) only for parts with a velocity of less than 2 or 3 m/s
g. tolerance to some components: e.g. a chlorine content of <0.3 % also depends on the fuel mix (cement) in contrast to e.g. <5 % in some waste fuels.

The types of solid waste fuel that can be prepared from non-hazardous waste typically fall into one of the following categories:

- from MSW (mainly household waste)
- from mixed commercial bulky household waste and other waste
- from dry monostreams or homogeneous selected waste streams
- from filter cakes, sludges and other wet wastes.

The treatment has used an influence on the physico-chemical characteristics of the waste fuel prepared. For example comminution can be carried out up to the required grain size of the solid waste fuel. Another example is that the cleaning may separate the trash content and foreign impurities by mechanical processing and comminution. That means that it is possible to have a fuel yield from 100 to x % of fuel quality because of increasing the water and ash contents.

Achieved environmental benefits

Provide the user with the required physico-chemical properties of the waste fuel.

Operational data

The technology used to prepare a certain waste fuel depends on the characteristics of the input material and the requirements of the users and this is not covered in this Section. For example, the extent of mechanical and biological processing depends on the origin of the waste. One type of waste from different origins may have different compositions/qualities. For example paper/cardboard 03 03 08, paper production 15 01 01, packaging material 19 12 01, mechanical processing 19 12 12, mechanical processing (including mixtures) 20 01 01, and municipal waste all have different compositions. Another example can be nappies, a) as a residue from production b) as a high calorific fraction from municipal solid waste (approx. 15 – 20 % of weight nappies).

The influence of waste collection (and in case of consumption waste, the national or regional habits) on the characteristics of the waste streams needs to be considered.

Driving force for implementation
Some guidances are also available (e.g. North Rhine Westphalia in Germany).

Reference literature
[150, TWG, 2004], [152, TWG, 2004]

4.5.3 Techniques for preparation of solid waste fuel

This section contains techniques applied to the preparation of solid waste fuel from hazardous and non-hazardous waste. The applicability sections for these techniques give more guidance as to where the techniques are applied. However, techniques in Sections 4.5.3.1 to 4.5.3.5 are relevant for any type of waste. Techniques in Sections 4.5.3.6 to 4.5.3.12 are mainly applicable to non-hazardous waste. Only one technique specifically for hazardous waste has been included and is in Section 4.5.3.13.

4.5.3.1 Selection of techniques used for the preparation of solid waste fuel

Description
Some techniques include:

a. classifying solid waste (e.g. household waste) and crushing the bulky fraction waste before the sorting operation
b. applying a magnetic separator
c. carrying out the mixing and sieving operations in closed areas
d. using nitrogen mixing devices to make the atmosphere inert when there is risk of explosion.

Achieved environmental benefits
Classifying and crushing operations are essential to achieve satisfactory sorting results and to facilitate the subsequent thermal treatment. Other reasons are that these techniques may also prevent indirectly fugitive emissions of dust and VOC.

Operational data
Size reduction requires much energy at high costs but maybe inevitable in cases with bulky material.

Applicability
Hazardous and non-hazardous waste. Technique a in the description section above is not adapted to the production of waste fuel from hazardous waste. This technique might be advantageous but there are other strategies which work as well. Technique d is applied to hazardous waste with risk of explosion.

Some special wastes from non-hazardous waste preparation may not need some of the special techniques mentioned above. Some examples identified are the installations which produce waste fuels from source separated streams e.g. waste from cuttings from plastic manufacturing or wastes from the processing of waste paper. However, this exception depends on the experience of the WT operator with the specific waste. That means that the WT operator should know the customer(s) quite well, the composition of waste processed and the way the customer collects the waste. Only in this way can parts which may otherwise cause problems in the WT installation or in the quality of the waste fuel produced be avoided.

Driving force for implementation
Technique d from the description section above is typically regulated by legislation addressed to prevent accidents.

Example plants

The safety of the mixing device can be ensured by adding nitrogen to make the waste inert. The resultant reduction of the oxygen content (working conditions between 6 to 8 % of oxygen) is by the addition of nitrogen to make the atmosphere inert. For example, such a technique allows waste with a flashpoint of lower than 0 °C to be mixed.

Reference literature

[122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004], [152, TWG, 2004]

4.5.3.2 Drying the solid waste fuel

Description

Depending on the water content and the physical characteristics of the wastes, a first step of dewatering can be applied. It may consist of one of the following operations: gravity thickening, centrifugal thickening, flotation thickening, gravity belt and rotary drum thickening. Some techniques include:

a. using thermal drying for the material. In convection (direct or adiabatic) dryers, there is a direct contact between the heating medium and the product to be dried. The moisture from the fuel is removed by the heating medium. In conduction dryers, there is no direct contact between the heating medium and the product. Heat transfer takes place through heating surfaces. Moisture is removed by the carrier gas, which is approximately 10 % of the quantity used in convective processes. Therefore, conduction dryers may be preferred for dusty or odorous wastes
b. using a biological degradation/drying system. According to the applied process, the degradation is more or less distinct; sometimes the focus is on the drying. Depending on the applied system, incidental process water arising during the biological degradation will have to be cleaned before being released to the watercourse. To maintain the biological activity, the system is fed with air. The exhaust air is collected and also has to be cleaned.

Achieved environmental benefits

Increases the heating value of the solid waste and in some cases, achieves satisfying sorting results.

Cross-media effects

In the case of thermal drying, heat is necessary. A study shows that in the case of drying sewage sludge, the energy recovery is higher in the case of thermal drying. The reasons are that the required energy for biological drying (provided by the organic material in the sewage sludge) is higher and the calorific value of the waste fuel tends to be lower.

Applicability

Radiant dryers are not applied for drying waste solids. Applicable to the dewatering and drying of sludges.

Biological drying is more applicable to non-hazardous waste.

Reference literature

[64, EIPPCB, 2003], [86, TWG, 2003], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004]

4.5.3.3 Magnetic separation of ferrous metals

Description
Some techniques include:

a. installing an overband magnetic separator lengthwise over the conveyor belts right above the trajectory of the material
b. resorting the material with a magnetic drum separator or with a magnetic pulley, since small ferrous particles could still remain under a non magnetic layer
c. increasing the conveyor belt's velocity gaining a low level of the material
d. use the overfed feed design for the magnetic drum separator.

Achieved environmental benefits
Magnetic separators can be used to extract iron and steel as a resource, e.g. extracting tinplate cans from lightweight packaging. This can also be used to provide the essential service of removing any ferrous metals from the waste, thereby avoiding downstream operating troubles and improving the product quality, e.g. magnetic separators are used in cable recycling processes to remove the metals, to protect the knives of rotary cutters from blunting or snapping and for the subsequent cleaning of the copper product.

Installation in line (lengthwise) to the belt is preferred since it aids effective separation of the loosened material out of the trajectory. If the magnet is aligned transversally to the material (i.e. suspended across the conveyor belt), the power of the magnet must be several times higher than in a lengthwise alignment, since sometimes non magnetic objects are situated on top of ferrous items, which the magnet then has to work through.

By sorting municipal solid waste (MSW) with a certain content of plastics with a large surface area, overband magnetic separators will inevitably extract these plastics together with the ferrous items. To minimise this discharge, increasing the belt velocity is recommended. Generally, overband magnetic separators give very high results, up to 98 w/w-% iron output.

The advantage of the overfed layout in magnetic drum separators is that ferrous parts are directly placed in contact with the strongest magnetic field and, as a consequence, fine-grained and slightly magnetisable items can be well separated.

Operational data
The mode of operation of how the material can be fed into a magnetic drum separator is either via an overfed layout or an underfed layout. In an overfed layout, the material is charged onto the drum, right before the crest, by using a vibrating chute. In this case, only magnetisable items are held on the drum shell until they reach the limit of the magnetic field, at which point the material falls off the drum and it is collected behind a non-magnetisable separating plate.

In an underfed layout, the drum shell attracts ferrous metals through the air gap and drops them – similar to an overband magnetic separator – but not before leaving the magnetic field. For homogenous feeding, the use of vibrating chutes is indispensable.

Applicability
Used when ferrous metal is present in the waste. Usually magnetic separators cannot extract stainless steel. This is due to the fact that stainless steel is not, or is only slightly, magnetisable.

Normally in waste processing, the underfed operation is only relevant for special applications, e.g. shredder scrap processing. The approach pole of this drum causes a strong and far-reaching magnetic field to securely extract the shredded and compacted scrap. The transport of the ferrous material to the dropping line will be achieved by additional weak poles. Because of the strong abrasion during scrap sorting, the drum shell is manufactured with 8 mm thick plate made of hard manganese steel.

Driving force for implementation

The application of magnetic separation depends on the type of waste processed and the waste fuel requirements. Some examples are:

- using ferrous (or non-ferrous) metal separation to reduce abraison if a fine comminution with cutting is necessary for the product requirements
- ferrous or non-ferrous separation or/and separation of fine fraction by screening is helpful if the ash content is limited
- enrichment with an air classifier is necessary if the firing technology allows only particles with a low sedimentation velocity in the solid waste fuel.

Reference literature

[126, Pretz, et al., 2003], [150, TWG, 2004]

4.5.3.4 Separation of non-ferrous metals

Description

Some techniques include:

a. conditioning the grain size of the non ferrous elements of the waste to be between 3 and 150 mm before their separation by an eddy current separator
b. using a high frequency alternating magnetic field in order to improve the separation of fine-grained non-ferrous metal
c. positioning the magnetic pole system eccentrically
d. using vibrating chutes to achieve a single grain layer, in order to give good sorting results
e. separating the fine-grained ferrous particles with a magnetic drum in an overfed layout before feeding the eddy current.

Achieved environmental benefits

Eddy current separators can sort out non ferrous particles with a grain size between 3 and 150 mm. So a pre-screening might be advantageous to increase the separation of non-ferrous metals from the waste.

The magnetic pole system is positioned either eccentrically or centrically. Central pole systems experience problems with small iron particles, which can find a way between the conveyor belt and the drum shell. These particles are attracted along the whole perimeter of the drum, become hot and can lead to damage of the plastic drum. Additionally, the position of the magnetic pole system in eccentric systems is variable, so that the strongest field can be directed to the rejection zone.

Operational data

It is difficult to separate longish and planar components, such as aluminium foil and copper wires, because of the weak eddy current in these materials.

Reference literature

[126, Pretz, et al., 2003], [150, TWG, 2004]

4.5.3.5 All-metal separators

Description

In the preparation of solid waste fuel, all-metal separators are mainly applied for plastics processing. High throughputs can be realised if the material is diversified before auto recognition. Normally, all-metal separators operate with a detection coil which is placed transverse to the direction of transport and cut into single segments. If a metal particle enters the high frequent alternating magnetic field of the coil it influences the field. This change is collected by an electronic controlled microprocessor which is able to identify the coil segment close to the metal particle. This particle is separated by one or more air jets located close to the detection coils. The metals are separated by a partition plate.

Achieved environmental benefits

Improves the metal separation of waste.

Applicability

Detection coils are able to detect metal particle sizes of approx. 1 mm and larger. The shape and the mass are not important for the separation process.

Driving force for implementation

All-metal separators are applied for the automatic separation of ferrous and non-ferrous metals. These aggregates are applied if the content of metal in the feed material is low, when other metal separation operations do not work efficiently enough because of very high demands on the product qualities or when downstream aggregates have to be protected e.g. rotary cutters.

Example plants

Applied in plastic processing.

Reference literature

[126, Pretz, et al., 2003]

4.5.3.6 Positive and negative sorting

Description

Two different processing strategies exist: positive and negative sorting:

a. positive sorting means that only the desired materials with high calorific values and low contents of harmful substances are sorted out of the material flow. This strategy leads to a higher amount of landfill material and often to a higher quality of the produced solid waste fuel
b. negative sorting strategies only separate the materials which are not desired in the product (e.g. if it is required to reduce the content of chlorine in the waste steam because it may cause problems when the waste stream is incinerated or co-incinerated, one possibility may be to reduce the content of PVC plastic in the waste stream). With this strategy the amount of landfill material might be less because other materials which might contain a higher content of harmful substances end up in the product.

Achieved environmental benefits

Improve the quality of the waste separated or to avoid problems with the futher treatment of certain waste streams.

Cross-media effects

Some contaminants cannot be sorted out, because they are retained or are hidden in the material, so scanning devices cannot recognise them.

Applicability
Applied in the production of solid waste fuel from municipal solid waste. Depending on the required quality, negative or positive sorting may be applied. If a high grade material flow is requested, negative sorting is advisable and the revenue for the product is higher than for positive sorting, but the amount of product produced is less.

Economics
With regard to the economic aspects of positive and negative sorting, it is not possible to make a general statement.

Driving force for implementation
Depending on the extent of processing and the desired quality of the solid waste fuel, the amount of materials sent to landfill can vary widely.

Example plants
Some waste strategies just separate the inert material and metal fraction, and also lower the organic and water contents. The rest ends up in the product, which thus automatically lowers the amount of material going to landfill.

Reference literature
[126, Pretz, et al., 2003], [150, TWG, 2004]

4.5.3.7 Use of pneumatic assistance for size reduction

Description
The use of pneumatic assistance for processing the material discharged from comminution (size reduction).

Achieved environmental benefits
Some benefits are:

- the unwanted content of extremely fine-grained material in the end-product is reduced
- the rotors, including the cutters and the housing, are cooled down
- the energy demand is reduced
- the transportation of material is assisted.

Applicability
Applied in size reduction activities.

Reference literature
[126, Pretz, et al., 2003]

4.5.3.8 Drum screens

Description
Depending on the velocity of the drum, different operating modes may be utilised: cascade or cataract. Figure 4.9 shows these modes.

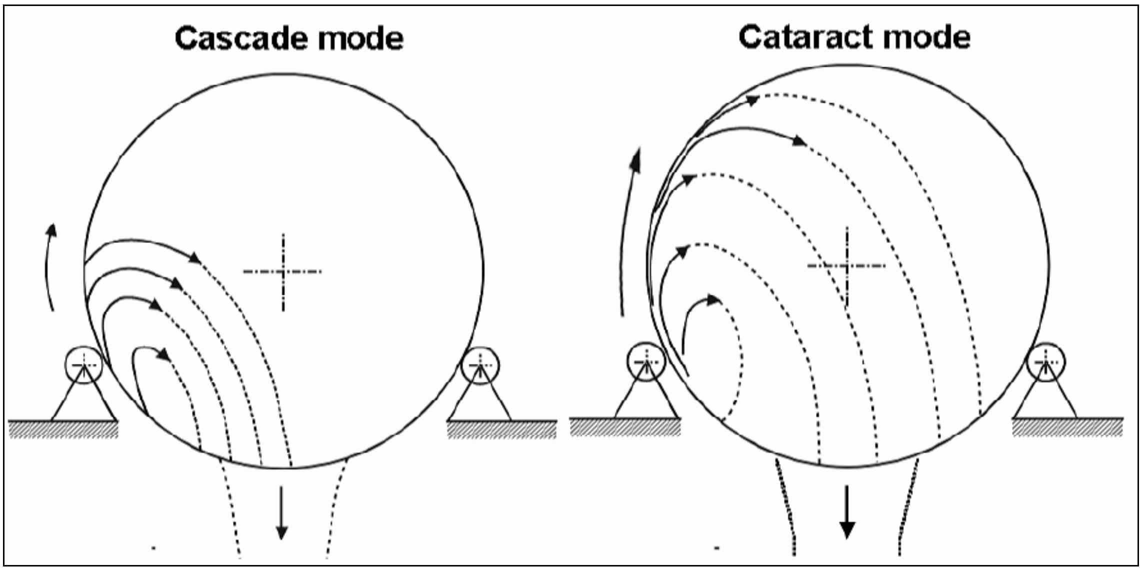


Figure 4.9: Drum screeners
[126, Pretz, et al., 2003], [150, TWG, 2004]

The drum screen shows the best results at a rotational speed of 70 % of the critical speed in the cataract mode. The disadvantage of the cascade mode is that the screen will create lumps and fines will not be well liberated.

To increase the efficiency, lifters are fixed inside the screen to pick up the material and to carry it higher, so that the material falls down on free area. Feeding material with a high content of coarse particles (approx. 100 – 250 mm) often causes problems with blocking of the screen, which then leads to a decrease in efficiency and a high content of fine particles in the overflow.

Achieved environmental benefits
Improves the separation ratio. Advantages are the operation does not need vibrations to be set up, greater homogenisation is possible and the cleaning of surfaces of adhering small particles which often contain a high content of heavy metals substances is possible.

To protect the screen against blocking, bushings which can be welded on have proven to be effective.

Reference literature
[126, Pretz, et al., 2003], [150, TWG, 2004]

4.5.3.9 Improvements of the dust filters in the cyclones of air classifiers

Description
Re-use of the air that has been used for air classifiers and blow-down. Approximately 30 % of the air of the circular flow is discharged on the pressure side of the ventilator and cleaned by a dust filter.

Achieved environmental benefits
This operation offers the following advantages:

- the filter to separate the dust can be designed much smaller, since the air to be cleaned is less than 1/3 of the volume from the conventional operation
- no air loaded with dust is discharged at the loopholes for the feeding conveyor or the heavyweight discharge
- the circulating air does not concentrate dust particles or moisture
- the air velocity at the separation zone can be precisely adjusted by butterfly valves.

Operational data
The amount of air consumed by the air classifiers depends on the geometry of the classification duct.

Applicability
In terms of applications in recycling processes, not all available air classifiers can be applied. In most cases, they need to be specially designed to treat large particles.

The air velocity for dry papers, thin-walled plastics and plastic films for example is approx. 11 - 12 m/s. The minimum recovery of this high calorific lightweight material is approximately 70 %. The throughput rate of air classifiers is limited by the specific load, with a maximum capacity of 0.35 kg solids/(m^3air · h).

Reference literature
[126, Pretz, et al., 2003], [150, TWG, 2004]

4.5.3.10 Near infrared spectroscopy

Description
Material which has to be separated is often fed on a belt conveyor. The conveyor usually operates at fast velocities so that its function is almost like an isolating device. Halogen lamps and the detector are installed above the belt conveyor. The detector consists of a near infrared spectroscopy (NIR) sensor which scans the whole width of the belt conveyor and transmits the characteristic spectrums of the different materials to a data processor. The signals are compared with a database. The analysis considers the calculation of the actual position on the belt conveyor and the measurement results in only a split second. The sorting then occurs with an air jet batten in front of the discharge end. The air jet lifter is equipped with several single air jets at a distance of about 30 mm apart. Each air jet is fed by a pressure reservoir and is steered by magnetic valves. The data processor transmits a signal if the detection of a particle is positive and the air jet blows it out. Here one or more air jets can be activated. The pressure surge blows out the particle which is then separated from the material flow by a partition plate.

Achieved environmental benefits
The application is the selective separation of beverage cartons, paper, cardboard, mixed plastics such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET) and polyvinyl chloride (PVC). The actual recovery of potential recyclables depends on the waste qualities, although approx. 80 to 90 % separation is achievable. The achievable product qualities are 90 to 97 %. It also reduces the heavy metal content (e.g. Sb, Cd, Pb) and Cl of the waste stream because specific waste containing these components may separate.

Cross-media effects
The application of this technique generates a waste stream with a higher content of chlorine and metals that need to be treated.

Operational data
The separation of dark brown and black materials is impossible since the NIR light is almost completely absorbed and hence no irradiation is reflected to the sensor.

Applicability
Auto recognition devices can sort particle sizes between approx. 30 and 300 mm. The operation width of the belt conveyors varies between 500 to 1400 mm. The throughput of pre-classified light packaging with particle sizes between 50 and 200 mm amounts to between 1 and 6 t/h.

This technique is applied to reduce the content of some compounds in the waste fuel in order to achieve the quality required in the waste fuel produced.

Driving force for implementation

Reduction of the heavy metal and chlorine content of the solid waste fuel. Some standards are actually prepared by CEN TC 343 WG 2. Chlorine is one of the parameters used to define recovered fuel classes. The chlorine content actually discussed is around 3 %, which means that plastics containing organic chlorine, i.e. essentially PVC, are accepted in a limited proportion.

Example plants

Several examples exist in Germany on the use of NIR for the production of solid waste fuel.

Reference literature

[126, Pretz, et al., 2003], [150, TWG, 2004], [153, TWG, 2005]

4.5.3.11 Automatic picking

Description

The material passes a vibrating chute which feeds a conveyor belt. A metal detector is located under the conveyor belt, which sends specific data of each particle to the computer unit. Additionally, a colour camera located above the conveyor belt processes particle information to the computer unit. Both information lines are analysed by special software, before the computer unit transmits impulses, instructing the nozzles to blow out the single particle or to allow it to pass (positive or negative sorting). Both the accepted and the rejected products are then transported by single belts to further treatment or storage.

Achieved environmental benefits

Increases the classification efficiency of the different materials of the waste.

Applicability

With a belt width of 1200 mm and depending on the feed material, it is possible to handle a throughput of 2 – 8 t/h, for a grain size of 3 – 250 mm.

Example plants

Automatic picking is gaining increasing recognition in the waste treatment sector, especially if a product with certain specifications is required.

Reference literature

[126, Pretz, et al., 2003]

4.5.3.12 Pelletising and agglomeration

Description

Disc agglomerators consist of a metal housing with one or more discs inside. The inner side of the reactor is filled with material discontinuously. The discs, which have superstructures to stir the material much better, start to rotate converting the frictional energy into frictional heat. The material is homogenised by stirring and then begins to melt with the rising frictional heat. At the moment the material begins to plasticize, the energy consumption rises and can provide the signal to empty the reactor. After the process, the material has to be cooled down.

Achieved environmental benefits

Increases the density of the products.

Cross-media effects

Because of the complete melting, the energy consumption for this process is much higher than for pelletising.

Operational data
Depending on the equipment for discharge, the material may be granulated.

Applicability
Due to the fact that such systems rely on the melting of some waste components, it can only be applied when those components are available (e.g. plastics).

Reference literature
[126, Pretz, et al., 2003], [150, TWG, 2004]

4.5.3.13 Cryogenic grinding

Description
Cryogenic grinding is a treatment of size reduction and sieving of deep cooled full and empty packagings under inert atmosphere. The aim is to separate the used packaging of paint, ink, and similar substances into fractions, e.g. to be used as fuel and as secondary metals and plastic but reducing the emissions of VOC and volatile compounds due to the low temperatures used.

The first operation is the separation between the liquid and the solid fraction. The solid fraction is further processed by grinding, sieving and metal separation at temperatures of - 100 °C to - 196 °C (typically with liquid nitrogen). At these temperatures, the materials become brittle and an easy separation, by using classical tools, is possible.

In the cryogenic treatment of used packaging of paint and similar materials, the following steps are included:

a. comminution in a shredder and addition of nitrogen for inertisation of the atmosphere. The liquid fraction (e.g. paint sludge) is separated by sieving
b. cryogenic (deep cooling) treatment with liquid nitrogen (-196 ºC). Through this treatment, the material hardens and, due to the different coefficients of components expansion, the binding reduces
c. separation of the packaging (e.g. metal and plastic) and the content (e.g. paint sludge) by means of a hammer mill an a vibrating sieve
d. collection of the metal fraction by ferromagnetic separation for re-use
e. addition of sawdust to the sludge as an adsorbent to make it solid. The plastic fraction and the sludge are sent for recycling as a fuel.

Achieved environmental benefits
Due to the inert atmosphere used during the grinding process, the risk of explosions are minimised. The sludge fraction is prepared to be used as fuel. In comparison with the direct incineration of such wastes, the recovery of energy is higher because metals are eliminated before incineration. The separation of other materials, e.g. metals and plastic, enables its use.

Cross-media effects
Electricity is required for the cryogenic process and for the production of nitrogen. Air emissions, e.g. VOCs and volatile hydrocarbons, may be generated. To reduce the VOC emissions to air, the off-gases are collected and cleaned by means of an activated carbon filter. The exhaust gases are cleaned of volatile hydrocarbons by means of an activated carbon filter. The residual emissions are estimated to be 0.06 kg/t used packaging waste.

Operational data
The end-product of the operation are organic waste as a powder, metals, non-ferrous metals and plastics. The consumption of electricity by the cryogenic process is approximately 31 kWh/t used packaging waste. The amount of nitrogen consumed is approximately 0.67 t/t used packaging waste. As an adsorbent to the sludge, sawdust is used. The amount consumed is 170 kg/t waste. The used sawdust is a waste material, which means a saving of primary materials.

Applicability
Some examples are the preparation of solid waste fuel from used packaging of paint and similar substances. This equipment is frequently used for the processing of metal and plastic packagings, filled with paints, ink, oil sludge, varnish, glue, resin, etc. and rubber based wastes (e.g. tyres). Packaging of other hazardous wastes, e.g. pesticides, halogenated chemicals and laboratory chemicals, cannot be treated by this process because of the risk of toxic substances diffusion.

Example plants
In the Netherlands there is an example plant with a capacity of 17500 tonnes per year

Reference literature
[122, Eucopro, 2003], [150, TWG, 2004], [156, VROM, 2004]

4.5.4 Techniques for preparation of liquid waste fuel

4.5.4.1 Generic techniques for preparation of liquid waste fuel

Description
Some techniques include:

a. using heat-exchange units external to the vessel. There, water vapour is driven off and the oil feedstock may be heated to 90 °C, which serves to separate the majority of suspended (as opposed to dissolved) water. This occurs as a result of the reduction in the viscosity of the oil phase (brought about by the increased temperature), using gravity separation to achieve the desired result as the water sinks to the tank bottom
b. using carbon adsorption or condensation to avoid VOC emissions. When using condensation the collected organic fraction can be used as boiler feed
c. removing the high solid content from liquid waste to be used as fuel. For this, warm oil from the heating vessels is typically passed over open filters to remove the solids. These are situated either in open yards or in buildings. VOCs are emitted when warm oil passes through the filters to remove the solids. The filters used are typically of the vibrating metal mesh type, more commonly used in relation to mineral aggregates. Extraction of the vapour from filtration needs to be possible from hoods over open filters. Centrifuges can also be used for the purpose of separating any solids from oil with the advantage of minimal emissions
d. removing oil from liquid effluent prior to discharge to foul sewers or other waters, usually by oil/water interceptors, tilting plate separators and/or filtration techniques and then using the oil as fuel
e. ensuring that in a multi-chamber oil interceptor every single chamber oil interceptor is large enough to allow six minutes retention at maximum foreseeable flowrates
f. using a vertical agitator without any bearing inside the tank.

Achieved environmental benefits
Cleans and reduces emissions from the treatment of liquid wastes. It is crucial to the sale of the liquid waste fuel that any high solids content, that the warm oil retains, is removed.

Cross-media effects
VOC emissions may be significant when the oil is drawn off from a process tank into open channels and also when warm oil is passed over the tilting plate separator.

Operational data
Carbon adsorption may be affected by the presence of water vapour. The action of removing the solids is aggressive and the filters need to be robust to deal with the solids and also the warm oil. Oil interceptors cannot separate water miscible substances.

Tilted plate separators (technique d noted in the Description section above) require much less retention time. Oil/water interceptors are sized based upon their design, the maximum foreseeable flowrates and the emission values required.

Applicability
Applicable to oil reprocessing: The primary objective is to produce a fuel oil from the waste oil. Two technologies of blending are appropriate to homogenise the liquid fuel:

- a long marine mixer installed on the roof of the tank
- a pumping system which blends the top and the bottom of the tank by loop circulation.

Drying and heating operations need to take into account the emissions and the flammability hazards.

Reference literature
[55, UK EA, 2001], [122, Eucopro, 2003], [152, TWG, 2004]

4.5.4.2 Thermal cracking of waste oils

Description
See Section 2.5.2.4.4.

Achieved environmental benefits
The use of thermal cracking in a refinery reduces the CO_2 emissions, as it reduces the refinery crude intake.

Economics
Thermal cracking is capital consuming: capital costs and fixed operating costs represent about 80 % of the overall cost (WO purchase excluded). A thermal cracking plant costs in the order of a third to half the amount of a regeneration plant of similar size (although that comparison is not necessary relevant since the outputs produced are different). Experts agree that thermal cracking with its lower capital cost allows plants to be profitable at the 30 kt/yr plant size. No subsidies are necessary.

Parameter	Capacity A	Capacity B	Capacity C	Units
Capacity	40	50	80	kt/yr
Capital costs	11	13	20	EUR million
Specific cost	135	123	112	EUR/tonne of WO
Cost on internal return on finance (1)	50	46	44	
Revenues	144	144	144	EUR/tonne of WO
WO gate fee	-10	-21	-32	
(1) on the basis of a 15 % risk adjusted rate of return on finance (included in the cost line).				

Table 4.43: Cost and waste oil gate fees for three different capacities of grass-root thermal cracking plant
[7, Monier and Labouze, 2001], [150, TWG, 2004]

The investment cost for using waste oil as fuel in severe reprocessing is USD 12 million (1995) for a treatment of 54 kt/yr (assumptions: storage: 15 days, working capital: 15 days). The investment cost for the Texaco Trailblazer producing marine diesel oils is USD 11 million (1994) for a treatment of 54 kt/yr (same assumptions as above). Other information shows that the approximate value of used oil when used in severe reprocessing (the value at the plant gate (1994) assuming an IRR of 15 % after tax and working capital of 15 days) without collection is USD 47/t and –63 including the collection cost (average collection cost assessed at USD 110/t within Europe).

Reference literature

[5, Concawe, 1996], [6, Silver Springs Oil Recovery Inc., 2000], [7, Monier and Labouze, 2001]

4.5.4.3 Membrane filtration as a mild reprocessing of waste oils

Description

Have a pretreatment to protect the membrane system.

Achieved environmental benefits

Better quality of the waste oils and protection of the membranes.

Applicability

Commonly used when treating waste oil by membrane filtration.

Economics

Significant added cost. Typically, the value of the plant required, including that for the protection of the membrane step, is expensive compared to the added value of the product.

Example plants

Reflects operational experience.

Reference literature

[150, TWG, 2004]

4.5.5 Preparation of gas fuel from waste

Description

Gasification and pyrolysis are ways to prepare a gas fuel. See the Waste Incineration BREF for information on the transformation of organic waste into a gas that can be used as fuel or as synthesis gas.

Achieved environmental benefits

Produces clean fuel gas, with the contaminants being retained during the process in several fractions.

Operational data

Gasification allows the advantage of accepting mixed wastes, e.g. waste oils and plastic, which is particularly significant in the case of waste oil being returned to their original container.

Applicability

Economics

Because large scale plants are typically necessary to reach the break-even point, only existing plants can be used to treat wastes. However, recent developments have shown that small plants treating 10 – 15 t/day can be cost-effective.

Driving force for implementation

The scale of such plants is much larger than would be required for the disposal of used oil, so they are not normally built specifically for this purpose. Where, however, such plants are built for other purposes, they would provide a safe disposal route for used oil which preserves its energy content.

Example plants

Some applications exist in Europe.

Reference literature
[5, Concawe, 1996], [58, CEFIC, 2002], [150, TWG, 2004]

4.5.6 Prevention and abatement techniques applied for the preparation of waste fuel from hazardous waste

Technique	Cross reference in this document	Applicability
Dust preventive measures		
Applying closing and underpressure for all the reception, production and storage areas	4.6.1	
Applying an overpressure of the working places (control room, vehicles cabin, etc.) ensures that no dust reaches the workers	4.6.1	Can be applied to existing facilities without a complete redesign of the facility
Ensuring the preparation and mixing operations are carried out in closed areas with channelled exhaust air	4.6.1	
Handling pulverulent wastes in closed areas	4.6.1	Can be applied to existing facilities without a complete redesign of the facility
Using closed vessels/mixers/filters/screens/magnetic separators/homogenising equipment	4.6.1	Can be applied to existing facilities without a complete redesign of the facility
Using spray/atomiser systems to moisturise ambient and confined air in order to prevent dust emissions.	4.6.1	
Ensuring that before transport, loads of fresh sawdust, pulverulent waste or solid waste fuel are efficiently covered	4.1.4.1	Can be applied to existing facilities without a complete redesign of the facility
Applying a dust retention net	4.6.5	Can be applied to existing facilities without a complete redesign of the facility
Dust abatement techniques		
Wet scrubber	4.6.11	Not used in the existing waste fuel production plants due to the fact that some dusts are hydrophobic and that the wet residue cannot be easily re-used in waste fuel production
Cyclones	4.6.3	Not commonly used in the sector. This technique may only be used in combination with a bag filter
Bag filters	4.6.5	Widely used in the sector
Electrostatic precipitator	4.6.4	
Waste water treatment		
Activated carbon treatment	4.7	Low contaminated waste waters
Thermal treatment	4.7	High contaminated waste waters

Table 4.44: Prevention and abatement techniques applied to the production of waste fuel from hazardous waste
[122, Eucopro, 2003], [152, TWG, 2004]

4.6 Waste gas treatments

This section contains techniques used in the waste treatment sector to reduce, abate or control the emissions to air. Emphasis needs to be placed on the prevention of the production and displacement of pollutants.

Point source emissions relate to those emissions that result from the collection of gas from a vessel or area and that are passed on, either via abatement or directly, to a stack or vent.

This section only covers those techniques most relevant to the waste treatment sector. In general, most techniques have already been described and analysed in other BREFs (special reference is made to the 'Waste water and waste gas treatment and management' BREF and waste incineration BREF). For this reason, it is not intended in of this section to provide a complete analysis of each of the different techniques. Instead, this section will focus only on issues relevant to the waste treatment sector, including discussions on what are considered to be good achievable emission values. Preventive techniques were covered in the previous section since they are very dependent on the type of process/activity carried out.

4.6.1 Generic prevention techniques

Description
Some techniques include:

a. using an enclosed system with extraction, or under depression, to a suitable abatement plant, especially during processes involving the transfer of volatile liquids or handling wastes that generate VOC emissions, including during tanker charging/discharging
b. applying a suitably sized extraction system which can cover the holding tanks, pretreatment areas, storage tanks, mixing/reaction tanks and the filter press areas, or having in place a separate system to treat vent gases from specific tanks (e.g. activated carbon filters from tanks holding waste contaminated with solvents)
c. completely enclosing the entire site (e.g. in a dome)
d. using synthetic soil covers. The synthetic cover may be a thin (0.1 – 0.15 mm) plastic sheeting or consist of relatively thick (0.75 – 1 mm) plastic sheeting or geotextile material. The resistance of various polymers to chemicals, weather, gas permeability, and tears is documented. Typically the barrier material will be available in large rolls and can be quickly applied to even large soil piles. The synthetic cover must be secured against wind
e. using wind barriers.

Achieved environmental benefits
Reduces fugitive emissions to the air (e.g. VOC and odour). The effectiveness of soil covers will depend on the depth of the cover and the percentage of contaminated soil that can be covered. Measured emission rates may be substantially reduced (e.g. >95 %) by the addition of compacted soil; however, lateral migration of VOCs may still occur.

If warranted, complete enclosure of the excavation site can be accomplished to minimise fugitive emissions. The enclosure acts to collect any emissions, which can then be vented to some type of control device suitable for point sources. The enclosure may be either air supported or self supported. If properly designed and operated, the enclosure may reduce fugitive emissions to negligible levels.

For small work areas, the use of wind barriers can reduce fugitive emissions (e.g. VOC) by lowering the effective wind speed at the soil surface. Commercial, porous wind fence material that is typically used for dust control has been found to be more effective than solid fence material.

Facilities which discharge odours and dust may be enclosed to prevent emissions and to reduce the amount of contaminated air which has to be cleaned afterwards. A well operating exhaust air collection system ensures a minimum of germs, fungi, spores, odours and dust particles. This may have positive effects on the physical health of the employees and reduces times absent due to sickness.

Cross-media effects
A positive side effect of enclosure is the reduction of noise for workers on site.

The synthetic cover barrier can be left in place indefinitely, although physical and photodegradation of the polymer will tend to limit the effective lifetime of thin barriers to a few weeks.

Soil covers will be less effective over long time periods and their use will tend to increase the total volume and mass of material that must be treated.

Operational data
The most commonly used VOC control approach for area sources, e.g. during excavation, is the use of covers to provide a physical barrier to vapour transport. The simplest barrier is the use of relatively clean soil as a cover for contaminated soil. The soil layer increases the necessary transport distance for vapour diffusion and thus greatly reduces, at least temporarily, the emission rate. The effectiveness of the cover will depend on its permeability to the vapours that are present and the percentage of the soil pile that is adequately covered. Laboratory measurements of a 0.5 mm PVC membrane showed relatively poor performance for limiting vapour diffusion.

Self-supported domes are more practical if trucks or other heavy equipment must regularly enter and leave the structure.

With respect to the need for dust removal in biological treatment plants, the upstream process plays a crucial role. In the humid exhaust gas from the biological process, potential dust emissions are effectively removed. All mechanical steps for the processing of dry materials inevitably lead to dust emissions. In this case, encapsulation of the aggregates in question is necessary. In these mechanical steps, the exhaust air has to be subjected to effective dust removal. Values of less than 10 mg/Nm^3 can be achieved by different techniques. Techniques in the prevention of the formation of bioaerosols and dusts in biological treatment plants include:

a. ensuring that the optimum moisture content is maintained during the aerobic process
b. ensuring that the digested material is turned regularly
c. maintaining good housekeeping (see Section 4.1.2.5)
d. erecting bunding/planting trees around the perimeter of the site.

Applicability
Synthetic covers are typically used to control VOC emissions from excavated soil in short term storage piles. Synthetic covers are also widely used to control VOC emissions during transport by rail or road.

There are severe limitations that limit the use of complete enclosures to the few sites where other control options are not acceptable. Air temperatures within the structure may be high enough to affect worker productivity and safety. The additional safety requirements, along with the additional time required for trucks getting in and out of the structure, will likely lengthen the time needed to complete the excavation and will thereby increase the costs.

For large working areas, fencing is less practical. VOC (and PM) emissions from storage piles can be minimised by controlling the placement and shape of the piles. When feasible, the piles can be placed in areas shielded from the prevailing winds at the site. The amount of surface area can be minimised for the given volume of soil by shaping the pile. The orientation of the pile will affect the wind velocity across the pile, with the lowest wind speed occurring when the length of the pile is perpendicular to the prevailing wind direction.
The selection of a VOC abatement technique to be applied depends mainly on the properties of the VOC. Moreover, these techniques are particularly sensitive to flowrates and concentration.

Economics
The capital cost of the structure for total enclosure is relatively high. Operating costs also can be very high if large volumes of air must be treated and exhausted to keep the concentrations of contaminants in the internal air within the dome at levels that are safe for workers health.

Emission control technique	Material cost (USD/m^2 except if otherwise noted)	Comments
Clay	4.15	Covers, mat and membrane
Soil	1.33	Assume 15 cm deep; does not include soil transport
Wood chips, plastic net	0.50	Chip costs vary with site
Synthetic Cover	4.40	Assume 1.14 mm thickness
Short-term foam	0.04	Assume 6 cm thick, USD 0.7/m^3 foam
Long-term foam	0.13	Assume 3.8 cm thick, USD 3.3/m^3 foam
Wind screen	40/m	Per linear metre

Table 4.45: Summary of emission control costs for area sources applied to excavation and removal [30, Eklund, et al., 1997]

Example plants
The majority of chemical plants have an air extraction and scrubbing system for the main processing tanks and for any pretreatment operations that could produce a toxic gaseous discharge to the air. Most WT plants have some abatement systems in place to control emissions to the air, but the type and level of control varies widely.

Reference literature
[30, Eklund, et al., 1997], [50, Scori, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [132, UBA, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.6.2 Leak detection and repair programme

Description
A leak detection and repair (LDAR) programme for installations handling solvents and similar volatile materials may include:

a. identifying, and where possible, quantifying significant fugitive emissions to air from all relevant sources, estimating the proportion of total emissions which are attributable to fugitive releases for each substance
b. using non-intrusive tank volume measurements
c. replacing filter pot lids when cleaning filters
d. storing filter slops in sealed drums
e. storing contaminated waters which have a potential for odours in covered tanks
f. using drum storage (see Section 4.1.4.2)
g. ensuring that regular cleaning/desludging of tanks is carried out, using maintenance schedules to avoid large scale decontamination activities

h. tanker washing if the load is likely to give rise to odour. The wash-water/aqueous waste from the washing needs to be directly discharged to abated storage systems before opening the tankers. Open tankers for the least amount of time possible
i. direct monitoring of valves, pump seals, etc. using a portable organic vapour analysing instrument to check for leaks
j. undertaking maintenance activities for fixing any detected leaks, e.g. replacing valve packing.

Achieved environmental benefits
Detects leaks of VOCs from valves, pumps and other piping components.

Applicability
Suitable for sites that contain a large number of piping components (e.g. valves) and that process a significant amount of lighter hydrocarbons (e.g. solvents).

Economics
The cost of a leak detection survey and associated repairs can be partially offset by savings from reduced material losses to the air. Savings are dependent upon the value of the material being lost.

Reference literature
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [116, Irish EPA, 2003], [150, TWG, 2004]

4.6.3 Cyclones

Description
In all types of cyclones, centrifugal forces are used to separate solid particles or liquid droplets from flue-gases. Cyclone filters are used to remove heavier particulates which ‘fall out’ as the flue-gases are forced into a rotating motion before they leave the separator again. Two forms exist, e.g. a cyclone or multi-cyclone. The latter separates finer dusts.

Achieved environmental benefits
Cyclones are effective for abating particles of sizes >10 µm. They are not effective against particle sizes <10 µm, which may thus require additional measures, e.g. fabric filters. Some benefits of using a cyclone include:

- efficient over a large concentration range
- collected dust may be re-used in the process.

Cross-media effects
Cyclones create a pressure drop in the gas flow requiring a higher energy consumption to overcome this drop and, therefore, lead to higher overall emissions. High wear with abrasive dust.

Operational data
Cyclones are relatively reliable. Operational conditions include:

- monitoring of pH, flowrate and the level of scrubber liquors and scrubber pressure drop (pressure drop monitoring with alarm)
- exit concentrations needing to be periodically monitored under different operating conditions.

Applicability
This technique may be only used in combination with a bag filter. It is not efficient at separating small particles.

Economics
Cyclones are relatively cheap.

Example plants
Cyclones are used in hazardous waste fuel preparation, where these are used in the mixing vessel as part of the stabilisation process. They are also used for the treatment of the exhaust gases of Ph-c plants.

Reference literature
[55, UK EA, 2001], [122, Eucopro, 2003], [126, Pretz, et al., 2003]

4.6.4 Electrostatic precipitators (ESP)

Description
Electrostatic precipitators use high voltages to attract and remove particulate matter from the flue-gases. There are two different kinds of operation; e.g. dry, which involves the collection of dust on electrodes under the influence of an electric field and wet, which is the same except the electrodes are cleaned to increase effectiveness.

Achieved environmental benefits
Reduces particulate emissions. High collection efficiency for both coarse and small particles. Efficient at high temperatures and efficient for the collection of liquid particles.

Applicability
This technique is not suitable for organic particles due to the high explosion risk they present.

Example plants
It is used for the treatment of the exhaust gases of Ph-c plants.

Reference literature
[122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004]

4.6.5 Fabric filters

Description
The creation of a barrier separates the dust from the flue-gases. Solid particles are trapped by a woven fabric while the gas flow can pass through it. Filter efficiency may be enhanced by pre-coating the filter cloth prior to being brought online.

Achieved environmental benefits
- high collection efficiency for both coarse and small particles
- efficient with a large concentration range
- collected dust may be re-used in the process
- high collection efficiency at high temperatures, if special materials, e.g. teflon, are used.

Characteristics	Fabric filter
Input flow range (m^3/hour)	1000 to 50000
Input concentration (mg/Nm^3)	100 to 5000
Output concentration (mg/Nm^3)	<10
Risks	Explosion
Consumption (per tonne waste fuel produced)	
Electricity (kWh)	2.5 to 3.5
Fuel/gas (litre)	-
Reactant (nature and kg)	-
Residues	-
Costs (EUR/t waste fuel produced per year)	
Investment cost	Up to 4
Operation cost	0.15
Maintenance cost	0.1

Table 4.46: Dust filtration by a fabric filter
[122, Eucopro, 2003]

Cross-media effects

Cyclones and fabric filters create a pressure drop in the gasflow requiring a higher energy consumption to overcome this drop and therefore this leads to higher overall emissions. A major source of hazardous waste at a number of industries is the dust emanating from air pollution control equipment (e.g. from a baghouse). As with sewerage systems, common dust collectors are utilised in different production areas resulting in a mixing of different types of dust and, thereby, precluding recycling. In some cases, modifications can be made to dust collectors so that each different source of waste goes to a different compartment, thereby, preventing the mixing of different waste types and increasing the recycling potential.

Operational data

Insitu cleaning can be achieved by air pulse, counter flow air or mechanical tapping. The reliability highly depends on the filter material. Fabric filters may create a risk of explosion. Fabric filters are equipped with pressure drop monitoring, including alarms and often, with measurement of inlet and exit concentrations. Pressure is often used as an instantaneous surrogate for concentration analysis. From time to time, however, a laboratory control is carried out on the exit concentration in order to quantify the emissions. An opacity meter or particle impingement detector can be used to monitor performance. There need to be a programme in place for the regular cleaning of physical filters.

Applicability

Applied for both fugitive emissions and point source emissions to air. Fabric filters are typically used as secondary or tertiary gas cleaning devices in combination with a cyclone or a dry scrubber located upstream. Fabric filters are not generally suitable for use in moisture laden streams or those with acidic, tarry or sticky characteristics. This is due to the adverse effects of fabric ‘blinding’ and adherence problems.

Example plants

Bag filters are used in the preparation of waste fuel. They are also used in the mixing vessel in the stabilisation process in the production of aerosol cans (e.g. for the removal of dust) and for the treatment of the exhaust gases of Ph-c plants.

Reference literature

[53, LaGrega, et al., 1994], [55, UK EA, 2001], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004]

4.6.6 Lamella separators

Description

In lamella separators, the air stream flows through several parallel plates which have hooked bumps, which force the air stream to change its direction. Because of the inertia of the particles, they are separated in the dust trap and split from the air stream.

Achieved environmental benefits

Reduces particulate emissions.

Applicability

Lamella separators are only applied for the separation of rough dust particles.

Reference literature

[126, Pretz, et al., 2003]

4.6.7 Adsorption

Description

In adsorption processes, the pollutant is removed from the waste gas flow and specifically adsorbed to the adsorbent. Exhaust air purification by adsorption basically consists of two treatment steps:

a. reduction of the pollutant by adsorption and accumulation in an adsorbent
b. regeneration of the adsorbent.

The pollutants from the waste gas stream accumulate in the adsorber. When the charging capacity of the adsorbent is reached, the adsorbed pollutants are desorbed in order to allow for a re-use of the adsorbent. Desorption is usually carried out with a hot air stream, the volume of which is considerably less than the waste gas stream. The concentrated desorbed harmful gas is eliminated in a further treatment step.

Adsorption is based on the principle of active centres in a porous matrix. Different adsorbents can be distinguished mainly by their ability to adsorb water. Thus they can be divided into hydrophilic and hydrophobic adsorbents.

Recently, plants for the treatment of gases with a low content of solvents have been developed. These, are based on new adsorbing materials presenting high chemical and mechanical stability and able to adsorb at low temperatures and desorb at a set temperature. The concentrated solvents can then be burned without fuel addition *in situ*.

Although activated carbon is the most widely used adsorption material, other alternatives include silica gel, alumina and zeolites. In waste gas treatment, adsorption is carried out using an activated carbon filter. Activated carbon has a large volume of very small pores which create a large surface area. Typical activated carbons have surface areas from 600 to 1200 m^2/g. The exhaust gas can be purified by an activated carbon fill or by an injection of activated carbon into the air stream followed by a downstream separation by a textile filter.

Achieved environmental benefits

Some benefits of this technique are:

- applicable for a wide range of components
- the used activated carbon can be recovered several times or may be used as fuel
- adsorption on activated carbon presents similar efficiencies to those of thermal oxidisers but less risk of flash fire, back into the vehicles being loaded/unloaded.

Characteristics	Level
Input flow range (Nm^3/h)	<50000
Input VOC concentration (g/Nm^3)	<0.5
Output VOC concentration (mg/Nm^3)	40 – 110
Need for preliminary de-dusting	yes
Risks	Quick saturation
Residues	
Consumption (per tonne waste fuel produced)	
Electricity (kWh)	25 – 75
Fuel/gas (kWh)	-
Other fuels or biogas	
Reactant (kg)	0.1 – 0.5 g/VOC (for activated carbon)
Costs	
Investment costs (EUR/t capacity)	10 – 30
Operational costs (EUR/t waste fuel produced)	1.65
Electricity	1 – 3
Fuel/gas	0
Others	
Maintenance costs (EUR/t waste fuel produced)	0.5

Table 4.47: Techno-economic data for adsorption
[122, Eucopro, 2003]

Emissions of VOCs from the carbon trap (chlorinated solvents) are 8 – 32 mg/Nm^3 or 215 kg/yr, when cleaning used oils.

Cross-media effects
Limited performance because of incomplete capture of some organic molecules. May also present fire and explosion risks. This method captures but does not destroy organic compounds. Saturated carbon filters need further treatment.

Operational data
The abatement can easily become overloaded and thus ineffective. The use of activated carbon is efficient for the capture of the VOCs, which mainly arise from storage facilities. The absorption capacity of the activated carbon depends on the nature of the particular VOCs, but is limited to a maximum 300 g/kg activated carbon. Some points to note are:

- simple design
- stability over time
- acceptance of high spot concentrations
- that at some (high) VOC concentrations, the adsorption is exothermic and needs to be controlled in order to avoid fire/explosions.

The lifetime of the carbon used in abatement for storage at waste oil treatment facilities is expected to be long. This is because in this application it will only be catering for breathing rather than displacement losses.

If an activated carbon filter is applied, the exhaust air has to be purified of dust first, as the dust can cause clogging and can lead to an increasing pressure gradient.

The charging capacity of the adsorbents is influence by a number of factors:

- physico-chemical properties of the substances that are to be adsorbed (especially the boiling point)
- concentration of the substance
- competing adsorption of other substances
- co-adsorption of water
- adsorption temperature
- pore structure and size of the inner surfaces of the adsorbent.

Applicability
Carbon adsorption is used for the reduction of VOCs, odour and fugitive emissions. Carbon adsorption is commonly used as an abatement technique for local extraction points e.g. at bulking up and sampling points. Care must be taken to avoid the air steam becoming moist as the polar nature of the common adsorbents will preferentially adsorb water vapour. For this reason carbon adsorption is not suitable for the abatement of air emissions from an oil re-processing heating vessel.

There are several different applications for activated carbon, for instance activated carbon is applied for the purification and removal of trace organic contaminants from liquid and vapour streams.

Carbon adsorption systems are often used in soil vapour extraction, but they may be costly to implement and are generally not acceptable for high humidity gas streams. They are also common in the treatment of air emissions from soil washing, soil solvent extraction, from soil flushing, aerosol can treatment, biological treatment plants and Ph-c plants (e.g. for the adsorption of the volatile components).

Carbon adsorption is not suitable for high concentrations or small molecules, or if dust is present. Also, carbon adsorption cannot be adapted to some molecules, e.g. acetone.

Economics
Some points to note are:

- this offers low operating costs for low concentrations of VOC
- there is an additional cost for the renewal of the activated carbon.

The following two tables (Table 4.48 and Table 4.49) show cost data for adsorption.

Treatment	Maximum flow (Nm^3/h)	Capital Cost (USD)
Carbon adsorption (regenerative)	170	20000[a]
	400	24000[a]
	800	33000[a]
	1770	12000[b]
Carbon canisters	160	700
	800	8000[c]
	1600	6000
	6400	23000[c]
	160	50000

[a] Includes blowers, demisters, controls, gauges, valves, and flow ammeters
[b] Includes blowers, flexible connectors, and dampers
[c] Deep bed units

Table 4.48: Capital costs to control VOC emissions from soil venting extraction systems [30, Eklund, et al., 1997]

Technical specification		
Capacity Oil types Process operation Waste gas flow Age of plant Age of pollution control equipment	10000 t/yr Used lubricating oils Batch 0 – 50 Nm^3/hr 10 years old 2 years old	
Possible Control Techniques	**Capital cost**	**Operating cost (GBP)**
Activated carbon drums*	Low	1100
*Assumes three 60 kg drums on site requiring replacement three times a year.		

Table 4.49: Cost of controlling releases to air from a typical oil recycling plant
[42, UK, 1995]

Example plants

Preparation of waste fuel from hazardous waste. Operational experience from biological treatment plants (MBT) is currently not available.

Reference literature

[30, Eklund, et al., 1997], [42, UK, 1995], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [132, UBA, 2003], [150, TWG, 2004]

4.6.8 Condensation

Description

VOCs can be removed by condensation with liquid nitrogen or other cooling agents (e.g. cooling water). The condenser is a vessel incorporating a heat-exchanger where a gas is cooled to change to the liquid phase (i.e. condensation). VOC recovery by nitrogen cryogenic condensation in solvent (-130 ºC). More information on this issue can be found in the BREFs on Large Volume Organic Chemicals (LVOC) and on Common Waste Water and Waste Gas Treatment (CWW).

Achieved environmental benefits

The condensed VOCs can be recovered. VOC emissions achievable can be as little as 10 to 50 g/h. Efficiencies of 99.3 % can be achieved. Chloroform emissions can be as little as 20 mg/Nm^3. Nitrogen is re-usable for other means in the plant.

Characteristics	Value
Input flow range (Nm^3/h)	<100
Input VOC concentration (g/Nm^3)	2 – 500
Efficiency (%)	>95
Need for preliminary de-dusting	no
Residues	no
Consumption (per tonne waste fuel produced)	
Electricity (kWh)	25
Fuel/gas (kWh)	-
Other fuels or biogas	
Reactant (kg)	Nitrogen
Costs	
Investment cost (EUR/t capacity)	20 to 60
Operational costs (EUR/t waste fuel produced)	2 to 6
Maintenance costs (EUR/t waste fuel produced)	<0.5

Table 4.50: Data on liquid nitrogen condensation
[122, Eucopro, 2003]

Cross-media effects

Consumption of nitrogen and electricity. Direct discharge of nitrogen contaminated with other compounds may occur.

Operational data

Sensitivity to water presence. The presence of water vapour in the air can block the system and the water condenses to ice, which could then frost or ice up the flow systems. A defrosting period is then necessary. Consumption of nitrogen of 18 kg/t solvent recovered. Elimination of the security risks. Temperature and pressure controls are simple.

Applicability

Used in cases where only relatively small volumes or low flows need to be treated, and when liquid nitrogen is available and the concentration of VOC is quite high. This technology is available for stable volumes and compositions. Applications typically include treating the emissions from oil reprocessing heating vessels, which also incorporates a recovery of the oil components. Condensation can be used as a pretreatment for thermal oxidation, reducing the fuel requirement and the overall size of the oxidiser required. Applicable to flows of between 50 - 100 Nm^3/h and loads from 1 to 10 kg/h. It is easily applicable to existing plants and it is very flexible to adapt to changes in flow and concentration.

In Ph-c plants, the volatile components are cooled and condensed for their treatment.

Economics

Typically high operating cost. Operational cost of EUR 2/t solvent treated for a liquid nitrogen condensator.

Technical specification		
Capacity	10000 t/yr	
Oil types	Used lubricating oils	
Process operation	Batch	
Waste gas flow	0 – 50 Nm^3/hr	
Age of plant	10 years old	
Age of pollution control equipment	2 years old	
Possible Control Techniques	**Capital Cost (GBP)**	**Operating Cost (GBP)**
Glycol chiller	30000	8000

Table 4.51: Cost of controlling releases to air from a typical oil recycling plant
[42, UK, 1995]

Driving force for implementation

Safety regulations.

Example plants

Preparation of waste fuel from hazardous waste and solvent recovery. At an example waste oil re-refining plant, the dehydration and defuelling units use air-cooled, condensing heat-exchangers for vapour recovery. The vacuum-distillation vapour recovery uses oil and cooling-water condensers. Vapour and non-condensable streams are then routed to the process heater for destruction of the organics and any odorous substances that may be present. There are at least eight plants in the EU.

Reference literature

[42, UK, 1995], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [66, TWG, 2003], [122, Eucopro, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.6.9 Temporary and long term foams

Description
At least six types of foam products are available. The foams vary in their compatibility and effectiveness for various classes of contaminants. Specialised equipment is available for applying foams over large areas. The foam is applied to a depth of 15 – 76 cm, at coverage rates of up to 100 m^2/min. The liquid foam concentrate is applied via an air-aspirating nozzle or chute. The degree of expansion (i.e. the number of litres of foam produced from one litre of liquid concentrate) can be classed as high (250:1), low (20:1), or medium.

Two general types of foams are used: temporary or long term. Temporary foams provide coverage for up to an hour, at which time 25 % or more of the liquid incorporated in the foam will have been released. Long term foams contain a stabilising additive to extend the useful life of the foam to days or even weeks.

Achieved environmental benefits
Reduction of VOC emissions. The effectiveness of foams is quite high for the areas that are covered. Short term emission reductions of 75 to 95 % for total paraffin and total aromatics, respectively have been measured in the field over 20 minute time periods. Emission reductions for total VOCs of 99 to 100 % using stabilised foam have been measured in the field over 24-hour time periods.

The two primary advantages of foams are that they can be highly effective and they can be applied directly to the backhoe bucket and the exposed contaminated soil.

Cross-media effects
There are several disadvantages of foams to consider. The thick layers of foam required for the control of emissions can be applied more effectively to horizontal surfaces than to vertical surfaces such as the sides of the excavation pit. Incomplete coverage of the emitting surfaces will markedly decrease the effectiveness of the controls. As foam concentrates are usually over 90 % water, the addition of this water to the soil increases the weight of the soil, making it more difficult to handle, and making it less amenable to thermal treatment. The foam is difficult to apply on windy days and, under any conditions, frequent application or re-application of the foam may be necessary.

Applicability
Modified fire-fighting foams are commonly used to control VOC emissions during the remediation of hazardous waste sites containing volatile toxic compounds.

Reference literature
[30, Eklund, et al., 1997]

4.6.10 Biofilters

Description
'Biofilter' is the generic term covering all biological oxidation processes taking place in a packed system. This includes conventional trickling filters, bioscrubbers (microbial population supported in scrubber liquor) or biobeds (packed system using soil, peat and bark).

The biofilter consists of an apparatus filled with decomposable material such as compost, bark or a mixture of turf and heather, etc. Micro-organisms (fungi, bacteria, viruses and algae) are resident on the material. The exhaust airflows through the material while the micro-organisms decompose the harmful substances. Water and airflow normally run countercurrently. A biofilter is not a filter in the mechanical sense (i.e. it does not lead to a separation of particles), but it is a reactor where a certain range of harmful substances are metabolised to harmless substances. The desired qualities of a biofilter are outlined in Table 4.52.

Characteristic	Description
Filter media	Biologically active, but reasonably stable
	Organic matter content >60 %
	Porous and friable with 75 – 90 % void volume
	Resistant to water logging and compaction
	Relatively low fines content to reduce gas headloss
	Relatively free of residual odour
	Specifically designed mixtures of materials may be desirable to achieve the above characteristics
Moisture content	50 – 80 % by weight
	Provisions must be made to add water and remove bed drainage
Nutrients	Must be adequate to avoid limitations
	Usually not a problem with aerobic digestion gases because of the high NH_3 content
pH	7 to 8.5
Temperature	Near ambient, 15 – 35 or 40 °C
Gas pretreatment	Humidification could prove to be useful in order to achieve near 100 % inlet gas humidity
	Dust and aerosols may be removed to avoid media plugging, but for most biofilters this is not a problem (unless they have a tissue layer in the bottom)
Gas loading rate	<100 $m^3/h\text{-}m^3$, unless testing supports higher loadings
Gas residence time	30 - 60 seconds, unless testing supports shorter residence time
Media depth	>1m, <2 m
Elimination capacity	Depends on media and compound (typically in the range 10 – 160 $g.m^{-3}.h^{-1}$)
Gas distribution	The manifold must be properly designed to present a uniform gas flow to the media

Table 4.52: Qualities of biofilter media
[59, Hogg, et al., 2002]

In contrast to the biofilter, in bioscrubbers the micro-organisms are not fixed in the bioscrubber on organic materials. The biomass swims quasi free in the suspension, which is sprayed on the exhaust gas in a countercurrent flow. The principal difference this brings about is that the absorption of the harmful substances is local and is separated from the metabolism.

In an aerosol can treatment facility, the exhaust air from the different operational parts is led through an air-permeable filter layer by means of ventilators. While the airflows through the filter layer, the degradable contents are decomposed by micro-organisms that populate the filter. In order to ensure that the filter layer remains air-permeable, which is essential for the supply of air oxygen to the micro-organisms, the exhaust air is cleaned beforehand so that solids (dusts) are removed. Simultaneously, cleaning moisturises the exhaust air, which is necessary to prevent drying of the filter layer. The biofilter, thus, represents an aerobic fixed bed reactor for the biochemical decomposition of organic substances. The biofilter, e.g. with an area of 1800 m^2, can treat an exhaust air stream of approximately 200000 m^3/h, which results in a specific filter load area of 111 $m^3/m^2/h$. Below the biofilter, there are supply areas that are utilised by the different treatment facilities (provision for treatment and dispatch). This area is designed as a collection tray. Moreover, a stationary foam extinguishing installation is present.

Achieved environmental benefits
Reduces odour and VOC emissions from natural compounds and from the synthesis of inorganic compounds (e.g. H_2S and NH_3), aromatic and aliphatic compounds (e.g. acids, alcohols, hydrocarbons). Other compounds that may be degraded are non-chlorinated solvents, mercaptans, amines, amides, aldehydes and ketones. The treatment capacity ranges from 50 - 150 $Nm^3/h/m^2$ depending on the type of pollutant.

Substance (group)	Input concentration (mg/Nm^3)	Output concentration (mg/Nm^3)	Biofilter efficiency (%)
Aldehydes, alkanes			75
Alcohols			90
AOX, aromatic hydrocarbons (benzene)			40
Aromatic hydrocarbons (toluene, xylene)			80
NMVOC			83
PCDD/F			40
Odour			95 – 99
NMVOC (Values in total carbon)	30 – 70	10 – 40	80

Table 4.53: Biofilter efficiency in MBT waste gas treatment
[81, VDI and Dechema, 2002]

The removal efficiency of a biofilter is determined by the gas residence time in the media bed. Effective residence times typically range from 30 to 60 seconds for most aerobic digestion applications. Studies have reported high removal efficiencies for specific compounds such as H_2S (>99 %), methyl mercaptan, dimethyl disulphide, dimethyl sulphide (>90 %) and various terpenes (>98 %).

Environmental benefits include low energy requirements and the avoidance of potential cross-media transfer of pollutants. Measurements in the practical application of biofilters in physico-chemical treatment plants have shown results of approx. 95 to 98 % degradation for organic solvents, with concentrations in exhaust air to be purified from 400 to 1600 mg/Nm^3.

In biological treatment plants, malodorous gases will be fed through a scrubber (e.g. acidic wet scrubber), which reduces the ammonia content to an acceptable level for the biofilter. The biofilter removes odours and any remaining ammonia. The filtering process does not create any compounds that are harmful to the environment and after use, the filter can be treated by composting and additional waste will not be generated. The levels of ammonia and odour after treatment are <1 mg/m^3 and 1000 – 6000 ouE/m^3 (90 % reduction), respectively.

Table 4.54 and Table 4.55 show the effectiveness of biofilters applied to MBTs.

Parameter	Concentration (μg/m^3) min – max	Effectiveness (%) min – max	Concentration (μg/m^3) min – max	Effectiveness (%) min – max	Concentration (μg/m^3) min – max	Effectiveness (%) min – max
Acetaldeyde	2100 – 2500	78 – 89	46 – 740	89 – 96	4900 – 6100	99
n-Butylacetate	150 – 425	97 – 99	30 – 120	83 – 96	170 – 980	73 – 99
Ethylbenzene	250 – 310	12 – 42	60 – 190	27 – 61	250 – 740	16 – 43
2-Ethyltoluene	180 – 220	33 – 41	25 – 105	14 – 89	80 – 270	25 – 55
3,4-Ethyltoluene	480 – 640	23 – 45	70 – 260	38 – 96	230 – 1000	48 – 77
Limonane	1700 – 4300	29 – 40	810 – 2200	94 – 98	1300 – 3700	30 – 63
Toluene	490 – 550	16 – 39	130 – 280		460 – 1000	7 – 36
m/p-Xylene	850 – 1400	9 – 42	280 – 620	30 – 71	720 – 2000	19 – 45
o-Xylene	260 – 290	23 – 41	60 – 150	7 – 63	160 – 650	20 – 45
Acetone	2450 – 2900	99 – 100	1200 – 2800	99 – 100	4700 – 8200	93 – 97
2-Butanone	960 – 2800	99 – 100	80 – 770	94 – 99	370 – 11000	95 – 100
Ethanol	5200 – 5300	100	88 – 750	94 – 99	14000 – 18000	100
α-Pinene	370 – 700	8 – 44	280 – 790	53 – 83	560 – 930	5 – 39
β-Pinene	330 – 800	12 – 44	120 – 300	53 – 81	230 – 490	38 – 49

Table 4.54: Concentration ranges for some parameters of the exhaust air from MBTs, showing the retention efficiency of the biofilter for these compounds
[132, UBA, 2003], [150, TWG, 2004]

Biological exhaust gas purification processes are able to reduce the exhaust air/exhaust gas contents from municipal waste treatment plants only to a limited extent (typically NMVOC of more than 300 g/t waste). Table 4.55 shows some measurement results from well maintained biofilters with upstream air humidifiers.

Compounds of the exhaust air	Separation efficiency (%)		
	Facility A	Facility B	Facility C
Acetaldehyde	-18 to -99	99	99
n-Butylacetate	83 – 96	73 – 99	97 – 99
Camphor	60 – 88	60 – 90	88 – 91
Dichloromethane	-53 to -80	-300 to -33	43 – 62
Dimethyldisulphide	44 – 78	-55 to -89	10 – 31
2-Hexanone	75 – 80	-	80 – 82
Naphthalene	50 – 75	38 – 93	58 – 82
Phenol	-25 to - 79	75 – 88	47 – 94
1,4-Dichlorbenzene	0 – 73	-1900 to -89	-130 to -13
Ethyl benzene	27 – 61	16 – 43	12 – 42
2-Ethyl toluene	14 – 89	25 – 55	33 – 41
3/4-Ethyl toluene	38 – 96	45 – 77	23 – 45
Limonene	94 – 98	30 – 63	29 – 40
Styrene	64 – 89	44 – 66	21 – 50
Toluene	29 – 50	7 – 36	16 – 39
m/p-Xylene	30 – 71	19 – 45	9 – 42
o-Xylene	7 – 63	20 – 45	23 – 41
Acetone	99 – 100	93 – 97	94 – 97
2-Butanone	94 – 99	95 – 100	99 – 100
Ethanol	94 – 99	100	100
Ethylacetate	74 – 93	82	97 – 99
α-Pinene	59 – 83	5 – 39	8 – 44
β- Pinene	53 – 81	38 – 49	12 – 44
Benzene	0 – 17	-	0 – 20
Trichlorethene	-108 to -3	67 – 90	20 – 46
Combinations of air humidifiers and biofilters may provide varying purification power for organic substances of the first and second group			

Table 4.55: Separation efficiency of organic compounds in the biofilter
[132, UBA, 2003]

Table 4.56 gives a summary of current measurement results from the biofilter of an aerosol can treatment facility. Note that other parts of the exhaust air of the treatment process are treated by the in-house high temperature incineration facility.

Component	Average concentration of raw gas	Average concentration of cleaned gas
Total carbon (FID)	206	49
CHC/CFC	9.69	8.17
Benzene	1.07	0.35
Aromatic compounds	35.4	8.07
Ester, alcohols	80.8	0.57
Results from 2003 and data in mg/m^3		

Table 4.56: Raw gas and treated gas by a biofilter in an aerosol can treatment facility
[157, UBA, 2004]

Cross-media effects

N_2O and NO emissions are typically increased. However, it has been demonstrated that the use of an acid scrubber for ammonia (NH_3) removal prior to biofiltration can reduce potential N_2O and NO emissions. Methane is neither biodegradated nor produced by the biofilter. Terpenes are produced by the biofilter itself and arise from the degradation of any wooden materials in the biofiltering media. Some references question whether biofilters really decrease VOCs since, they claim, VOCs are actually produced by the biofilter itself.

The degrees of decomposition of the studied biofilters in MBT plants for single compounds are not as high as for several special applications in industry (80 % or >90 %). For non-methane TOC (NMTOC) they achieve on average an efficiency rate of only 40 – 70 %. For methane, the efficiency is close to 0 %. The decomposition efficiency for single compounds in the exhaust gas of MBT plants exhibit good values for NMTOC (e.g. acetone, acetaldehyde, limonene and ethanol), moderate values for BTEX and no reduction for CFCs.

The partly low degradation efficiencies for NH_3 also with a potential inhibition of carbon decomposition, may be improved by the use of acid scrubbers (e.g. sulphuric acid for the absorption of ammonia) instead of neutral scrubbers. The NH_3 emissions will be minimised not only because they are odorous but also because, in the biofilter, close C/N relations of the MBT exhaust air may lead to the formation of NO and N_2O.

Operational data

Biofilters are typically one metre thick of porous material. The material used in the biofilter is usually a mix of green compost typically mounted over a certain structure. These systems are very easy to be built and maintained. High porosity (80 – 90 %), the humidity (60 – 70 %), pH, temperature, and the contact time between the nutrients need to be controlled for good biofilter performance. The humidity in the biofilter can be maintained with a special water system or by humidifying the gas to be purified before it is passed pass through the biofilter.

The NMVOC removal in biofilters strongly depends on the temperature (e.g. weather conditions), which can reduce the efficiency of the biofilter.

In some cases, the materials used for the biofilter media may not be able to fully satisfy the demands for all the essential nutrients of the micro organisms in the biofilter for a longer time. In these cases supplying additional nutrients can significantly increase the efficiency of the biofilter.

The pressure drop is less than 50 mm H_2O. The surface load per unit area of the biofilters should not exceed approx. 80 Nm^3/m^2 x h.

Some issues to consider include:

- incoming air must have a relative humidity of >90 % (this may require the use of a humidifier)
- particulates must be removed
- hot gases may need to be cooled closer to the optimal activity temperature for aerobic micro-organisms, generally 25 to 35 °C and the potential temperature rise across the bed of up to 20 °C needs to be taken into account
- the major operating parameters, such as the off-gas temperature and the back-pressure, need to be checked daily
- the moisture content in the filters needs to be monitored regularly
- a low temperature alarm needs to be fitted to warn of freezing, which can damage the filter and could affect the growth of the microbes
- the packing media must be supported to allow a fast, even airflow without any pressure drop
- the media needs to be removed when it starts to disintegrate, thus affecting the airflow (bark is less resistant than, for example, heather)
- the choice of media and supporting system affects the power requirement for maintaining the airflow, with the power needed to overcome the bed resistance being the largest operational cost
- consideration needs to be given to the effect of a loss of biomass due to the introduction of toxic compounds and a stand-by procedure needs to be developed for such an event.

Even in the case of optimisations (combinations with bio-scrubbers instead of water scrubbers) a low and reliable emission cannot be permanently achieved. For the odorous emissions, a strong reduction can be achieved (with only the filter's innate smell remaining) if an appropriate conditioning of the exhaust air is carried out.

In the case of flue-gas treatment from aerobic digestion of the digestate generated in anaerobic treatments, the concentration of ammonia is rather high (>30 mg/Nm^3) being in this case necessary to chemically pretreat the flue-gas before it is guided to the biofilter.

Applicability

Biofilters are applied for great volumes of exhaust gas streams which carry low organic loads in the particular exhaust gases but which have intensive odours. Concentrations of components to be treated need to be relatively stable for a good performance. Biobeds have been installed on waste treatment sites for the abatement of odorous emissions. Applicable to all types of WWTP.

Biofilters are used for the treatment of exhaust gases in aerosol can treatment facilities, thermal distillative drying of sludge, biological treatment (MBT) plants and Ph-c plants. In Ph-c plants, biofilters are used for the adsorption of the volatile components to compost material and for the biological decomposition of the adsorbed components by micro-organisms in the compost material. If the biofilter is in danger of desiccating, the exhaust air that is to be cleaned has to be moisturised.

Biofilters are suitable only for low polluted exhaust gas streams and are thus only used for the purification of the hall exhaust air streams. Flue-gas cleaning by biofilters or biological cleaning generated in anaerobic digestion plants has been proven to be of value.

Economics

Biofiltration and bioscrubbing have lower operating costs than many other air pollution control technologies for treating low concentrations of biodegradable organic pollutants. Bioscrubbers have the higher maintenance cost of the two. Treatment gas flows of more than 1500 Nm^3/h are considered cost-effective. Investment cost of EUR 550000 for a biofilter applied to treatment of WWTP odours with a flow of 1800 Nm^3/h.

Characteristics	Value
Input flow range (Nm^3/h)	<100000
Input VOC concentration (g/Nm^3)	<1
Efficiency (%)	<90 %
Need for preliminary de-dusting	No
Risks	Destruction of micro-organism
Residues	Yes
Consumption (per tonne waste fuel produced)	
Electricity (kWh)	15
Fuel/gas (kWh)	-
Alternative fuel or biogas	
Reactant (kg)	Barks
Costs	
Investment costs (EUR/t capacity)	10 to 20
Operational costs (EUR/t waste fuel produced)	<1
Maintenance costs (EUR/t waste fuel produced)	<0.25

Table 4.57: Consumptions and costs of biofilters
[122, Eucopro, 2003]

Driving force for implementation

Reduction of odour emissions. The German and Austrian Governments have set limit values for MBT facilities for odour emissions with 500 GE/Nm³ and for VOCs (Austria: 100 g/t treated waste, Germany: 55 g/t treated waste). Furthermore, such systems cannot achieve the TOC emission limit values demanded by some German standards (e.g. less than 55g TOC per tonne of MBT input and a TOC concentration of less than 20 mg/Nm^3).

Example plants

Widely used in the sector. Applied in the treatment of flue-gases from biological treatment plants and from physico-chemical treatment of waste waters and immobilisation. It is also commonly used in other industrial sectors, such as in the chemical, iron and steel, and food industries and in waste water treatment plants. Many examples of the use of biofilters exist in the EU.

Reference literature

[52, Ecodeco, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [66, TWG, 2003], [81, VDI and Dechema, 2002], [121, Schmidt and Institute for environmental and waste management, 2002], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [132, UBA, 2003], [135, UBA, 2003], [150, TWG, 2004], [157, UBA, 2004]

4.6.11 Scrubbing

Description

Absorption techniques are typically called scrubbers. Some techniques include:

a. having in place a scrubber system for the major inorganic gaseous releases (e.g. Cl_2, ClCN, HCl, H_2S, NH_3, NO_x), organic compounds (e.g. VOC) and odour from some unit operations treating certain types of waste (containing these volatile compounds), which have a point discharge for process emissions. In circumstances of highly variable emissions, the installation of a secondary scrubber unit to certain pretreatment systems may be a solution if the discharge is incompatible, or too concentrated for the main scrubbers
b. correctly operating and maintaining the abatement equipment, including the handling and disposal of spent scrubber medium.

Water sprays are a commonly used control method for particulate matter emissions. The addition of dust control chemicals such as polymers or acrylics to the water increases the effectiveness of the spraying.

Achieved environmental benefits

Reduces emissions to air of VOC, acids, ammonia, particulates, etc. Increases the efficiency of pollutant adsorption, due to the particle-gas contact (particularly relevant for the removal of acid gases by basic particles injected at the scrubber, if applicable).

Cross-media effects

This technique generates liquid effluents and sludge that require further treatment.

Wet scrubbers generate steam plumes. Releases from wet scrubber vents need to be hot enough to avoid visible plume formation in the vicinity of the vent. This is to prevent the condensation or adsorption of environmentally harmful substances by the condensing water vapour. Exhaust gases from a wet scrubber can be heated by the use of waste heat to raise the temperature of the exhaust gases and to prevent immediate condensation on the exit from the vent. This procedure also aids the thermal buoyancy of the plume.

Operational data

Usually some level of air monitoring will be carried out, either at the scrubber discharge or at the site boundary. Typically the monitoring of the exit gases from the scrubber systems/filter systems is spasmodic. The assumption is that the abatement systems are fit for this purpose and will reduce the emission to an acceptable background release. Discharge points may be monitored on a quarterly or monthly basis for those acid gases that are expected to be collected.

Water supply and effluent disposal facilities must be available. Monitoring provisions include:

- pH, flowrate and level of scrubber liquors and scrubber pressure drop
- pressure drop monitoring with alarms
- periodically monitoring the exit concentrations under different operating conditions.

There also needs to be a programme in place for the regular changing of absorbent in the absorption units.

Applicability

Suitable for high flow, low concentrations (e.g. 1 – 200 mg/Nm^3 VOC), low temperature gas streams and when the pollutant is chemically reactive (or soluble in the case of VOC contaminants).

These techniques are typically applied to point source emissions related to those compounds which result from the collection of gas from a vessel or area and which are passed on either via abatement or direct to a stack or vent. This technique can be used for the treatments of off-gases generated during the loading of storage tanks.

Acid scrubbers are applied to capture the ammonia emissions liberated during the acidic treatment in the re-refining of waste oils. Mineral oil scrubbers are also used to trap VOCs and odours in waste oil treatment facilities.

Hypochlorite or hydrogen peroxide may be used for cyanide scrubbing and odour control. A two-stage system could be utilised, e.g. alkali and oxidiser scrubbers in series. Water supply and effluent disposal facilities need to be available to run these systems. There needs to be a programme for the regular changing of absorbent in the absorption units.

Alkaline potassium permanganate or hypochlorite can be used as oxidisers for the treatment of cyanide compounds.

Economics

Table 4.58 below shows a summary of scrubbing costs for emission controls for area sources applied to excavation and removal.

Emission control technique	Material cost (USD/m^2)	Comments
Water spray	0.001 (varies)	Assuming municipal water cost of 1 USD/1000 litres. Water requires constant re-application. Water truck rental: 500 USD/week.
Additives:		Costs vary with chemical use
Surfactant	0.65	
Hygro salt	2.58	
Bitumen/adhesives	0.02	

Table 4.58: Summary of costs for emission controls for area sources applied to excavation and removal
[30, Eklund, et al., 1997]

Example plants

A common use is the treatment of extracted air from the reactor vessel with a scrubber liquor, typically a caustic solution. The process is extensively applied in Ph-c plants (e.g. wet scrubbing). Used as a pretreatment, e.g. before biofilters, for the treatment of the exhaust gases of biological treatment plants.

Pretreatment processes capable of liberating toxic gases tend to have their own scrubbing systems, with the scrubber vent leading into the main site exhaust system, and with the aqueous liquors being treated in the plant.

All of the oxidation systems seen in the UK have their own local scrubber systems, and the residues from both the oxidation and the scrubber solutions are treated in the main plant. Where the plant has a total exhaust system for the site, the exhaust from the oxidation scrubbers typically goes through the main plant exhaust scrubbing system prior to discharge to the air.

Caustic scrubbing is employed to strip hydrogen sulphide in plants treating waste oil.

Reference literature

[30, Eklund, et al., 1997], [42, UK, 1995], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004]

4.6.12 Chemical scrubbing

Description

Chemical exhaust gas treatment can be one-step or multi-step scrubbing with chemical scrubbers. Up to now, plants of this type have been produced, e.g. as one-step or multi-step carrier material cleaners with controlled pH values in each step or with an addition of oxidants.

Achieved environmental benefits

Scrubbers of this type are well suitable for removing single components (e.g. ammonia).

Cross-media effects

This scrubber is required for the reduction of N-compounds prior to the subsequent treatment. Multistage exhaust air scrubbers (acid-alkaline), or scrubbing with H_2O_2, can only reduce the concentration of certain components (e.g. VOCs) due to the high crude gas concentrations generated especially by recirculating treatments.

Applicability
A state-of-the-art technique in biological treatment (MBT) plants is a combination of acid scrubbers and thermal regenerative exhaust gas treatment. The release of the treated exhaust air is carried out via a stack.

Driving force for implementation
It is reported that scrubbed gas concentrations required by a German regulation cannot be reached by these systems alone.

Example plants
Currently no information is available on its use as an independent treatment step in biological treatment (MBT) plants. All information in this section corresponds to experiences in other types of plants.

Reference literature
[132, UBA, 2003], [150, TWG, 2004]

4.6.13 Low oxidative processes

Description
Among the low oxidative processes commonly used are ionisation and UV processes. These are based on the principle that sometimes the adsorption of a single O or OH radical can significantly reduce the odorous properties of a substance.

Achieved environmental benefits
The effect of the low oxidative processes is very substance-group specific and can be impaired considerably by the presence of certain noxious gases (e.g. formation of amines in the presence of ammonia).

Cross-media effects
This treatment however does not lead to a significant decomposition of organically bound carbon. According to experiences gained so far, there is often only a partial oxidation and no break-up of the ring of aromatic hydrocarbons. Styrole may be polymerised. Methane is only slightly reduced.

Operational data
The specific energy demand is usually below 1 kW/1000 Nm^3 of air.

Applicability
These processes are often used for odour neutralisation in different areas.

Example plants
Used in biological treatment plants, nevertheless, operational experience is not available.

Reference literature
[132, UBA, 2003]

4.6.14 Incineration

Description

In the decontamination of thermal exhaust air, the exhaust air is treated in a combustion chamber at temperatures of up to 850 ºC and for a minimum residence time of at least 2 seconds. Within this space of time, the harmful substances will be totally oxidised and the cleaned gas can then be released to the air.

In biological treatment plants, incineration can be differentiated into post-combustion, with or without heat recovery. As in thermal post-combustion, the carbohydrates are oxidised to carbon dioxide and water in a combustion chamber.

Achieved environmental benefits

Used for VOC control and will usually require the addition of supplementary fuel to support the combustion process. The operator can offset the cost of the supplementary fuel when there is a requirement elsewhere on site for the waste heat that is generated. Values of less than 50 g of VOC per tonne of waste can be achieved with this technique.

In biological treatment plants, by using special heat-exchangers, high quality heat recovery of up to 98 % may be achieved. These high rates of heat recovery are based on the use of special ceramic heat-exchangers, which combine a high mass and a large surface area in an ideal way.

Operational data

Usually requires the addition of supplementary fuel to support the combustion process. The flowrate is 1500 Nm^3/h and the operating temperature is 1050 – 1200 ºC. The specification of 850 ºC with 2 seconds residence time may be justified in waste incineration when a complete flue-gas treatment installation achieves the full removal of residual contaminants. The burning conditions are more extreme (e.g. 1100 ºC with 2 seconds residence time) to completely destroy some odorous and VOC components as well as destroy dioxins and dioxin pre-cursors.

Table 4.59 shows the energy requirements of incineration for different hydrocarbon concentrations in the gas.

Parameter				
Hydrocarbon concentration in the gas (g/Nm^3)	0.5	1.5	3	6
Incineration	9	8	6.2	3.2
Heating energy in kWh required for the treatment of 100 Nm^3/h of gas contaminated with VOCs The flows that have been treated range from 500 Nm^3/h up to 11000 Nm^3/h				

Table 4.59: Energy requirements of incineration for different hydrocarbon concentrations in the gas
[30, Eklund, et al., 1997]

Applicability

There are no limits for its application.

Economics
The following two tables (Table 4.60 and Table 4.61) show cost data for incineration.

Treatment	Maximum flow (Nm^3/h)	Capital cost (USD)
Incineration	110	13000[1]
	160	25000[1]
	915	44000[1]
Internal combustion engine	96	62000
	160	50000
[1] The cost includes blower, sampling valves, and controls. Heat recovery systems are not included		

Table 4.60: Capital costs for controlling VOC emissions from soil venting extraction systems [30, Eklund, et al., 1997]

Capital cost (GBP)	Operating cost (GBP)
30000	3000
Incineration of 2.5 kg fuel oil/hour @ GBP 0.13p/litre Capacity: 10000 t/yr Oil types: used lubricating oils Process operation: batch Waste gas flow: 0 – 50 Nm^3/hr Age of plant: 10 years old Age of pollution control equipment: 2 years old	

Table 4.61: Cost of controlling releases for air from a typical oil recycling plant using incineration [42, UK, 1995]

In biological treatment plants, cost-efficiency of the operation is determined by the size of the volume flow to be treated and by the pollutant concentrations. The ideal conditions are autothermal operation, where the amount of energy released by the combustion of the pollutants exactly corresponds to the energy demand for maintaining the combustion temperature. The necessary heating energy can, in this case, be gained completely from the combustion of the carbohydrates. This energy demand is directly dependent on the degree of heat recovery. Pollutant concentrations are low making heat supply necessary and, consequently, generating high operation costs.

Driving force for implementation
Waste Incineration Directive (2000/76/EC).

Example plants
At least two waste oil treatment plants use such a system. Used in biological treatment plants.

Reference literature
[30, Eklund, et al., 1997], [42, UK, 1995], [66, TWG, 2003], [86, TWG, 2003], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [132, UBA, 2003], [150, TWG, 2004]

4.6.15 Combined combustion

Description

In some plants where combustion takes place, it is possible to inject polluted air collected in the workshop directly into the secondary air circuit of the burner or into the primary air that goes into the burner. This might require a specific adaptation of the combustion process (modification of gas cleaning and stability of combustion).

Achieved environmental benefits

- synergy with existing combustion facilities
- allows an energy recovery from burning the VOCs in the combustion.

Table 4.62 shows VOC removal data using combined combustion.

Characteristics	Value
Input flow range (Nm^3/h)	<50000
Input VOC concentration (g/Nm^3)	~ 3 <explosion limit of the compounds
Output VOC concentration (mg/Nm^3)	10 – 50
Need for preliminary de-dusting	no
Residues	no
Consumption (per tonne waste fuel produced)	
Electricity (kWh)	*
Fuel/gas (kWh)	*
Costs	
Investment cost (EUR/t capacity)	*
Operational costs (EUR/t waste fuel produced)	*
Maintenance costs (EUR/t waste fuel produced)	*
*depends on each case	

Table 4.62: VOC removal using combined combustion
[122, Eucopro, 2003]

Cross-media effects

- not available during maintenance of the burner
- specific instrumentation and valves must be installed to prevent a ‘domino effect’ between each process
- fluctuations in quality or quantity of the VOC could cause some trouble in the combustion system.

Applicability

Needs prior dilution with air when an explosive concentration may be reached.

Economics

Adaptation costs can be high. The operator can offset the cost of the supplementary fuel when there is a requirement elsewhere on site for the waste heat that is generated.

Driving force for implementation

Waste Incineration Directive (2000/76/EC).

Example plants

Used for the preparation of waste fuel from hazardous waste and laundering of waste oils.

Reference literature

[30, Eklund, et al., 1997], [42, UK, 1995], [66, TWG, 2003], [86, TWG, 2003], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004]

4.6.16 Catalytic combustion

Description

The polluted air is burned but, in this technique, the combustion temperature is reduced by the use of a catalyst. The catalyst allows the same destruction efficiency of the VOC at a lower temperature.

In biological treatment plants, catalytic combustion may be used to remove TOC from the exhaust gas. The pollutants are oxidised at temperatures between 200 and 500 ºC using noble-metal or metal oxide catalysts.

Achieved environmental benefits

- low fuel consumption
- complete destruction of VOC
- efficiencies range from 95 to 99.9 %
- output concentrations of 5 – 50 mg C/Nm^3 are achievable. The actual range depends on the type of compound and the input concentration.

Table 4.63 shows VOC removal data using catalytic combustion.

Characteristics	Value
Input flow range (Nm^3/h)	20000 – 50000
Input VOC concentration (g/Nm^3)	1 – 3
Output VOC concentration (mg/Nm^3)	10 – 50
Need for preliminary de-dusting	Yes
Risks	Catalyst poisoning
Residues	no
Consumption (per tonne waste fuel produced)	
Electricity (kWh)	25 – 75
Fuel/gas (kWh)	70 – 140
Reactant (kg)	Catalyst
Costs	
Investment costs (EUR/t capacity)	20 – 30
Operational costs (EUR/tonne waste fuel produced) Electricity Fuel/gas	 1 – 3 1 – 2
Maintenance costs (EUR/t waste fuel produced)	<1

Table 4.63: VOC removal using catalytic combustion
[122, Eucopro, 2003]

In biological treatment plants, purification efficiencies of more than 99 % can be achieved.

Cross-media effects

The catalyst is sensitive to some compounds (e.g. metal and organic), and their build up may progressively decrease their efficiency.

In biological treatment plants, among the disrupting substances are catalyst toxins, such as organometallic compounds, organic silicon compounds and arsenic compounds. The treatment of halogenated compounds, organic sulphur compounds and organic nitrogen compounds is possible only to a limited degree. Methane can be catalytically reduced to CO_2 only under certain conditions. High temperatures of over 600 ºC are necessary for the catalytic oxidation of methane. The energy use of a thermal treatment without heat recovery is very high. The catalytic-thermal oxidation in biological treatment (MBT) is, therefore, questioned under both an economical and environmental point of view.

Operational data

- needs a gas pretreatment in some cases (e.g. ESP, bagfilters and gas scrubber)
- needs prior dilution with air when explosive concentrations are reached
- the energy consumption is lower than for incineration.

Table 4.64 shows the energy requirements of catalytic combustion for different hydrocarbon concentrations in the gas.

Parameter				
Hydrocarbon concentration in the gas (g/Nm^3)	0.5	1.5	3	6
Catalytic combustion	2	1.2	0	0
Heating energy in kWh required for the treatment of 100 Nm^3/h of gas contaminated with VOCs. The flows that have been treated range from 500 Nm^3/h up to 11000 Nm^3/h				

Table 4.64: Energy requirements with catalytic combustion for different hydrocarbon concentrations in the gas
[122, Eucopro, 2003]

In biological treatment plants, the operating life of such catalysts may be more than 30000 operating hours, depending on the operating temperature and on the disrupting substances in the process gas.

Applicability

Given the numerous interfering factors, the practical applicability of catalytic oxidation in biological treatment plants seems problematic. Furthermore, operational experience from biological treatment (MBT) plants is not available.

Economics

The cost of investment is relatively high. Table 4.65 shows the capital costs for controlling VOC emissions from soil venting extraction systems.

Treatment	Maximum flow (Nm^3/h)	Capital cost (USD)
Internal combustion engine	96	62000
	160	50000
Catalytic oxidation	160	25000[a]
	320	31000 – 69000[a]
	800	44000 – 86000[a]
	1600	77000[b]
	8000	140000
[a] Includes burner, blower, flame arrestor, gauges, filters, knockout pot, sampling port, controls, and skid mounting [b] Dilution system available for an additional 22000 USD.		

Table 4.65: Capital costs for controlling VOC emissions from soil venting extraction systems
[30, Eklund, et al., 1997]

Driving force for implementation

Waste Incineration Directive (2000/76/EC).

Reference literature

[30, Eklund, et al., 1997], [42, UK, 1995], [66, TWG, 2003], [86, TWG, 2003], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [132, UBA, 2003], [150, TWG, 2004]

4.6.17 Regenerative catalytic oxidiser

Description

VOCs are burned in combustion chambers at a temperature ranging from 750 to 950 °C. The energy produced by the combustion of the VOCs is used to preheat the polluted air on the ceramic bed before combustion. The combustion temperature can be adapted according to the VOC concentration. The polluted process air is heated to the necessary reaction temperature by a heating system and then guided over a combined catalyst and heat accumulating bed reactor. In this reactor, the process air is decomposed to CO_2 and water. The heat from this reactor is then guided over a second combined bed reactor and accumulated there. After this reactor's accumulator bed has been heated, the process air stream is switched so that it enters the second reactor. The heat from the second reactor is then used to preheat the process air, whilst the pollutant oxidation takes place in the first reactor. During further operation, the unit is switched cyclically between the two stages described above.

Achieved environmental benefits

- high VOC destruction rate (>99 %)
- reduced use of fossil fuel or waste fuel (high energy efficiency)
- at high VOC concentrations (>3 g TOC/Nm^3), it is possible to operate in an autothermal zone. This means that minimum external energy is needed to be added to sustain the reaction.

Table 4.66 shows VOC removal data using regenerative catalytic oxidation.

Characteristic	Value
Input flow range (Nm^3/h)	20000 – 80000
Input VOC concentration (g/Nm^3)	2 – 4 with peaks of up to 10
Output VOC concentration (mg/Nm^3)	15 – 50
Efficiency (%)	>99 %
Need for preliminary de-dusting	Yes
Risks	
Residues	No
Consumption (per tonne waste fuel produced)	
Electricity (kWh)	10 – 50
Fuel/gas (kWh)	50 – 200*
Alternative fuel or biogas	Yes
Reactant (kg)	-
Costs	
Investment costs (EUR/t capacity)	10 – 25
Operational costs (EUR/t waste fuel produced)	
Electricity	1 – 3
Fuel/gas	2 – 6
Maintenance costs (EUR/t waste fuel produced)	<1
*according to the VOC concentration	

Table 4.66: VOC removal using regenerative catalytic oxidation
[122, Eucopro, 2003]

Cross-media effects

High energy consumption if there is only a low VOC concentration.

Operational data

- accepts fluctuations of VOC concentrations
- needs prior dilution with air when an explosive concentration may be reached
- needs a de-dusting when dust concentration inlet is higher than 20 mg/Nm^3.

Table 4.67 shows the energy requirements of regenerative catalytic oxidation for different hydrocarbon concentrations in the gas.

Parameter				
Hydrocarbon concentration in the gas (g/Nm^3)	0.5	1.5	3	6
Regenerative catalytic oxidation	0	0	0	0
Heating energy in kWh required for the treatment of 100 Nm^3/h of gas contaminated with VOCs. The flows that have been treated range from 500 Nm^3/h up to 11000 Nm^3/h				

Table 4.67: Energy requirements with regenerative catalytic oxidation for different hydrocarbon concentrations in the gas
[122, Eucopro, 2003]

Applicability
It is designed for low to medium VOC concentrations because of its low energy costs.

Economics
Low operation costs and high investment cost.

Driving force for implementation
Waste Incineration Directive (2000/76/EC).

Reference literature
[30, Eklund, et al., 1997], [42, UK, 1995], [66, TWG, 2003], [86, TWG, 2003], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004]

4.6.18 Regenerative thermal oxidiser

Description
The aim of a regenerative thermal oxidiser is the permanent and high quality recovery of a large part of the heat energy that is necessary for heating the waste gas stream to the required oxidation temperatures for treatment.

This heat energy is stored in flow-through heat-exchangers. Such heat-exchangers consist either of a ceramics fill material or are fin heat exchangers. The performance of this recuperative process is expressed by the degree of heat recovery achieved, which is defined as follows:

$$\text{Performance} = 1 - \frac{T_{\text{scrubbed gas}} - T_{\text{crude gas}}}{T_{\text{combustion chamber}}} \qquad T = \text{temperature}$$

The incoming exhaust air is heated up in the 'hot' heat-exchanger bed. The air is heated up to a temperature a few degrees below that of the combustion chamber, depending on the heat storage capacity. In the combustion chamber, oxidation takes place. In the case of low pollutant concentrations in the process air, the missing energy has to be brought in by primary energy sources. After passage through the combustion chamber the exhaust gas, which is now at the reaction temperature, gives off its heat to a 'cold' heat-exchanger bed.

Due to the high energy demand for heating up the exhaust gas and due to the optimal heat exchange the greatest part of the heat stored in the 'hot' heat-exchanger bed is given off to the exhaust gas after appox. 120 seconds. Conversely the hot exhaust gas heats up the 'cold' heat-exchanger bed.

Achieved environmental benefits

The realised heat recovery rates vary between 90 and 98 % depending on the pollutant content of the exhaust gas. An additional supply of energy in this case is not necessary. With regards to the required values for the scrubbed gas, the systems currently available on the market differ in the technical method utilised for ensuring the lowest scrubber gas values. This is necessary because at the stream reversal point, remnants of the crude gas may pollute the scrubbed gas. Systems optimised with respect to this problem can achieve scrubbed gas concentrations of less than 10 mg/Nm^3.

Operational data

In order to maintain permanent operation, the stream direction has to be controlled in such a way that the heat-exchanger bed when heated up at a given time can be used for heating up the waste gas. This results in an alternating heating and cooling of the respective heat-exchanger beds.

Also crucial for the design of the plant is the amount of the enthalpy chemically bound in the pollutants that are to be oxidised. The operation is autothermic if the sum of the heat stored in the heat-exchanger beds and the reaction enthalpy released is sufficient to maintain the necessary temperature in the combustion chamber.

If the enthalpy bound in the pollutants is not sufficient to reach oxidation temperature, this has to be achieved and ensured by the use of an external energy supply. Some individual providers realise this by the installation of controlled burners in the combustion chamber, others enrich the exhaust gas with the additional combustibles so that the system can be kept in autothermic conditions. In this case, the plant can be operated flamelessly. In energy-optimised plants, an energy consumption of 8 kWh heat output per 1000 Nm^3 of waste gas can be expected.

For the starting period until reaching operational temperature and during operation with low organic substance concentrations (<2 g C/Nm^3), an external energy supply is necessary due to the as yet insufficient energy storage in the heat-exchanger beds. In the starting phase of flameless systems electrical heating is usually used, otherwise the heat energy can be brought in by natural gas or propane gas burners.

For operation with gaseous waste fuels such as landfill gas or biogas, it needs to be taken into account that these gases may be contaminated by pollutants. For starting an operation that has not yet reached the required combustion chamber temperatures, these gases should not be used. This can only be done with conventional fuels such as natural gas or propane gas. Additionally it has to be ensured in the safety chain that in the event of any service interruption and the resulting decrease of the temperature in the combustion chamber, the supply of the waste fuels is regulated and thus always available.

Applicability

In the context of research projects and for plant operation, combinations of acid scrubbers and regenerative thermal oxidisers have proven valuable. This process combination has advantages in terms of cleaning capacity as well as in terms of operational costs.

Example plants

In practice, there are several different designs of regenerative thermal oxidisers, which differ primarily in the design of the individual heat-exchanger beds and in the selection of the heat-exchanger material. For low concentrations, these processes have become widely used in post-combustion with heat recovery.

Regenerative thermal oxidisers have been used in Germany for several years for the purification of biological treatment (MBT) plants' exhaust gas. In Austria, an MBT plant has also recently installed and started operation of these types of systems.

Reference literature

[132, UBA, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.6.19 Oxidation treatments

The type of oxidation treatment related to the following two tables (Table 4.68 and Table 4.69) has not been specified. It could be any of the four techniques described in Sections 4.6.14 to 4.6.17. These tables show air emissions data after treatment.

Air emission parameter	Value	Units
Fume temperature	140	ºC
PM	10 – 27	mg/Nm^3
Heavy metals	0.03	mg/Nm^3
TOC	8	mg/Nm^3
SO_x	10	mg/Nm^3
NO_x	350	mg/Nm^3
HCl	2.3 – 10	mg/Nm^3
HF	<0.1	mg/Nm^3
HBr	<0.1	mg/Nm^3
HCN	<0.1	mg/Nm^3
P	0.019	mg/Nm^3
$CO_2/(CO+CO_2)$	<1	mg/Nm^3
CO_2	9.5	%
CO	50	mg/Nm^3
PAH	<0.1	ng/Nm^3
PCDD + PCDF	<0.01	ng/Nm^3
TCDD + TCDF	<0.01	ng/Nm^3
PCB + PCN + PCT	<1	ng/Nm^3
Values referred to 10 % O_2 in the fumes		

Table 4.68: Air emissions from off-gas thermal destruction plants from several waste oil treatment plants
[42, UK, 1995], [66, TWG, 2003], [86, TWG, 2003]

Air parameter	Units	INPUT streams		OUTPUT
		Off-gas from process plants	Off-gas from tanks blanketing	
Flow	Nm^3/h	101	1400	2700[1]
Temperature	°C	18	27	146
Dust	mg/Nm^3	58.6	1.1	28.4
H_2S	mg/Nm^3	101600	<1	<0.1
Mercaptans	mg/Nm^3	2153	1.7	0.7
SO_x	mg/Nm^3	30000	1.3	3
HCl	mg/Nm^3	308	0.9	0.8
VOC	mg/Nm^3			3
NO_x	mg/Nm^3			181
PAH	mg/Nm^3			<0.1
[1]Combustion air included				

Table 4.69: Thermal treatment of contaminated streams
[66, TWG, 2003]

4.6.20 Non-thermal plasma treatment

Description

The non-thermal plasma technique is one of the highly oxidative processes. It is a physical process that activates the molecules in a changing electric field and thus facilitates attack by a radical reaction. Non-thermal plasma denotes a condition of atoms and molecules which are activated by electric fields and which are thus subject to dissipation of the electrons or a shift of the electrical charge to energy-richer orbits. Thereby energy potentials, whose energy level corresponds to temperature equivalents of up to 100000 °C of thermal activated plasma can be reached.

Achieved environmental benefits

Organically bound carbon can be degraded to a high extent. The advantage of non-thermal plasma is that with sufficiently high field strengths and a precise energy supply, dosing can cause a reaction within fractions of seconds. Hereby increased quantities of different radicals are produced, which due to their high oxidative capacity are able to attack organic molecules and to break up compounds.

Cross-media effects

Due to the radical reaction in the reactor, ozone is released at rates of several grams per hour. The plant concept, therefore, has to ensure elimination of this ozone. For this special metal, a catalyst or activated carbon is suitable. When choosing the catalyst it needs to be ensured that there are no secondary odorous emissions from unfinished catalytic processes. The danger of self-ignition of the activated carbon in reactions with ozone has to be taken into account. Moreover it also needs to be taken into account that N_2O is produced to a greater extent.

Example plants

Used in biological treatment plants, nevertheless, operational experience is not available.

Reference literature

[132, UBA, 2003]

4.6.21 NO_x abatement techniques

Description

More information can be found in the Common Waste Water and Waste Gas Treatment (CWW) and waste incineration BREFs. Some techniques include:

a. good process control, which can prevent the actual emission of NO_x
b. good combustion chamber design
c. low NO_x burners
d. SCR
e. SNCR
f. internal flue-gas recirculation
g. oscillating combustion
h. chemical scrubbing (see Section 4.6.12).

Achieved environmental benefits

Reduces NO_x emissions to air.

Cross-media effects

The injection of ammonia or urea in the flue-gas when using SCR or SNCR stream induces the risk of NO_x formation rather than removal, if the temperature is too high and there is excess oxygen present.

Applicability

Basis for the benchmark	Activity
Using sound process control to prevent the emission of NO_x	Waste acid treatment
Using a good combustion chamber design	Combustion plant
Using low NO_x burners	Combustion plants

Economics
SCR and SNCR have higher operational costs than other techniques such as good process control and low NO_x burners.

Reference literature
[55, UK EA, 2001], [86, TWG, 2003], [150, TWG, 2004]

4.6.22 Odour reduction techniques

More information can be found in Section 4.6.23.

Description
In designing and implementing a structured odour management plan, the plan needs to:

g. describe the main activities which generate odour and/or the sources of odour, also covering any relevant environmental surveys which have been undertaken and the technical choices available for controlling odorous emissions
h. initiate or further develop an inventory of the odorous materials used or generated, covering also all intentional and fugitive (unintentional) release points
i. detail any routine monitoring undertaken to assess the odour exposure of receptors
j. provide a system for reporting the results of monitoring and for recording any complaints received
k. identify the actions needed to be taken in the event of abnormal events occurring or conditions which might lead to odour, or potential odour problems
l. cover the maintenance requirements of the containment and the management of the operations where odour can be contained, for example within buildings
m. place emphasis on pre-acceptance screening (see Section 4.1.1.2) and on the rejection of specific wastes. For example, and particularly for odorous materials, they need to be handled in dedicated sealed handling areas which incorporate an extraction to abatement equipment
n. take into account the scrubber liquors to ensure that they are also closely monitored to ensure optimum performance, i.e. with respect to correct pH, on-time replenishment and replacement
o. cover the vacuum extraction requirements for installations causing odours
p. cover the enclosure requirements within buildings zones where VOC emissions are high and may provoke high odours.

Achieved environmental benefits
Prevents the emissions of those odorous releases that may be offensive and detectable beyond the boundaries of the site.

Applicability
For complex installations, for example where there are a number of potential sources of odorous releases or where there is an extensive programme of improvements being put in place to bring odour under control, an odour management plan will typically be maintained.

Reference literature
[50, Scori, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [81, VDI and Dechema, 2002], [86, TWG, 2003], [116, Irish EPA, 2003], [120, Prantner, 2002]

4.6.23 Odour management in biological treatment plants

More information can be found in Section 4.6.22.

Description

Effective operational management can help control the formation of odours. This includes:

a. processing incoming feedstock as soon as possible
b. ensuring proper stabilisation of the biomass within the retention time in enclosed buildings, so as to ensure only odourless materials are present in the open curing stage
c. avoiding an early refining step to reduce the particle size too far, which would hinder the diffusion of air through the material that still has to complete its biochemical transformation (a smaller particle size could cause the aerobic digestion to lose structure and make anaerobic decomposition more likely)
d. preventing the formation of leakage puddles (e.g. ensuring proper slopes to paved surfaces)
e. avoiding the external stockpiling of coarse rejects from pre-process screening steps, as these would also contain a certain percentage of fermentable materials
f. withdrawing the exhaust air from the odorous sections of the process (tipping, deep bunkers storage of input fermentable materials, pretreatment, early process steps. Sometimes also the curing section can be enclosed and exhaust air treated)
g. designing the withdrawal system to prevent any loss of exhaust air from windows, doors, etc.
h. fitting the facility with properly dimensioned abatement systems
i. ensuring proper maintenance of odour abatement technologies is carried out
j. using surfactant reagents
k. providing enclosed leachate collection/storage tank(s), to minimise odour emissions while holding liquor prior to recirculation and/or off-site disposal
l. providing stored leachate treatment, such as aeration, to prevent septic conditions causing odour
m. providing odour abatement, to control emissions from specific sources, such as odour masking atomisers
n. designing the enclosed buildings in such a way so as to have a negative air pressure, to prevent odour emissions from doorways.

Achieved environmental benefits

Prevents or decreases odour emissions.

Cross-media effects

The use of surfactant reagents will not completely eliminate odour, especially if the choice of reagent is based on a characterisation of the compounds in the odour-causing aerosol.

Operational data

When applying technique ‘n’ (see Description section above), the airflow to maintain a negative air pressure, is sometimes given in how many hours are necessary to exchange the air inside the building. The high this value is, the higher the odour concentrations are achieved inside.

Applicability

Besides prevention, often aerobic facilities have to tackle odour issues through the treatment of the exhaust air, above all where they feature high capacities and/or involve short distances from dwellings.

Example plants

A good number of facilities across Europe are currently employing technologies that help in the running of aerobic digestion activities even in most crowded areas, provided design and management of the plant consider odour problems with the proper care.

Reference literature

[59, Hogg, et al., 2002], [116, Irish EPA, 2003], [150, TWG, 2004]

4.6.24 Some examples of waste gas treatment applied to different waste treatments

Table 4.70 lists some examples of waste gas treatment applications in different waste treatment processes. Typically, the type of waste gas abatement applicable to each case is a combination of techniques; some of them may not be mentioned in the examples below. Some examples are shown in Section 4.6.25.

Waste treatment activity/process	Technique applied
Thermal desorption	Condensers Incineration Carbon adsorption Cyclones Venturi scrubbers Fabric filters HEPA filters Wet scrubbers Dry scrubbers
Vapour extraction from excavated soil	Carbon adsorption Catalytic incineration Incineration Internal combustion engines
Ex-situ bioremediation	Carbon adsorption
Soil washing	Carbon adsorption
Solvent extraction	Incineration
Bioventing	Activated carbon Catalytic oxidation Internal combustion engines Biofilters
Physico-chemical treatment of waste waters	Wet scrubbers Evaporation Stripping distillation
Preparation of waste fuel	Extraction Condensers Carbon adsorption Biofilters Thermal oxidation Incineration Scrubbing
Stabilisation	Absorption Adsorption Fabric filters Thermal oxidation Cyclones
Waste oil treatment	Condensation Thermal oxidation Biological oxidation
Drum crushing and shredding	Adsorption Absorption Thermal oxidation

Table 4.70: Applicability of waste gas treatments
[30, Eklund, et al., 1997], [55, UK EA, 2001], [121, Schmidt and Institute for environmental and waste management, 2002], [135, UBA, 2003], [150, TWG, 2004]

4.6.25 Some examples of combined treatment of exhaust air

This section shows some examples of the application of combined waste gas treatments in different waste treatment processes. Typically, the type of waste gas abatement applicable to each case is a combination of techniques; some of them may not be mentioned in the examples below.

Attached operational facilities	Production halls, tank farms, barrel treatment
Emission limit values	Organic contents according to the German TA-Luft
Size of building	940 m^2
Facility consists of	Activated carbon pre-filter (smoothing out emission peaks of the raw gas), two-fold
	Regenerative main filter, activated carbon (two-fold)
	High scrubber for emissions from tank farms and from loading processes, two-fold
	Strippers for the extraction of solvents from water (gas extraction with air), two-fold
	Biological water treatment for condensates from high scrubber and activated carbon step
	Cooling towers (outside of the building)
Technology	Adsorption to activated carbon
	Physical absorption to wash with recovery of solvents
Emission control	Online analysis of total carbon, perchloroethylene, methylene dichloride, trichloroethylene, glycols, BTX-aromates
Input materials	Exhaust air streams contaminated with solvents (VbF, CHC and others)
Operational capacity	6000 m^3/h lightly polluted exhaust air from production halls
	400 m^3/h highly polluted exhaust air from tank farm and loading processes
Emission achieved values	With regard to organic substances contained in waste gas, except organic particle matter, a total mass flow of <57 kg/yr or a total mass concentration of <3.6 mg TOC/Nm^3 are achievable each of which to be indicated as total carbon

Table 4.71: Exhaust air treatment facility of a waste solvent treatment plant [130, UBA, 2003]

Abatement treatment composed of	a. collection of contaminated air with a network under depression b. group of cyclones and filters used in order to reduce the particulate concentration c. regenerative thermal oxidation system
Achieved environmental benefits	The regenerative thermal oxidation system is a non-burning system and has no combustion chamber. As a consequence it does not generate NO_x. Because the pollutants are degraded at high temperature (950 °C), they can achieve VOC concentrations in the outlet of less than 50 mg/Nm^3
Operational data	Electrical power is needed to maintain the high temperature and natural gas is necessary to run the process
Example plant	One plant in France

Table 4.72: Combined abatement of particulates and VOCs in a hazardous waste treatment plant [50, Scori, 2002]

4.6.26 Some examples of abatement techniques comparisons applied to the preparation of waste fuel from hazardous waste

Table 4.73 and Table 4.74 compare some abatement techniques when applied to one specific waste treatment.

Criteria	Bag filter	Wet scrubber
Dust treatment performance	+	-
Flexibility	+	+
Consumption	++	-
Costs	++	-
Risks (fire, explosion, etc)	+	++
Cross-media effects	+	-
Note: (-) poor, (+) acceptable and (++) well adapted		

Table 4.73: Comparison of bag filters and wet scrubbers for the abatement of dust emissions [122, Eucopro, 2003]

Criteria	Nitrogen trap	Biological treatment	Activated carbon	Combined combustion	Catalytic combustion	Regenerative thermal oxidiser
VOC performance	++	-	-/+	+	+	++
Consumption	-	++	++/ -	++	+	+
Costs	+	++	++	++	-	+
Flexibility	-	-	+	+	-	++
Risk (e.g. fire, explosion)	+	+	-	+	+	+
Cross-media effects	-	-	-	+	+	+
Note: (-) poor, (+) acceptable and (++) well adapted						

Table 4.74: Comparison of VOC abatement techniques [122, Eucopro, 2003]

4.7 Waste water management

This section only covers the management of waste water after it has already been contaminated. Prevention techniques to avoid the contamination of water or those techniques to reduce the consumption of water are not covered here and instead are included in Section 4.1.3.6.

This section only covers those techniques most relevant to the waste treatment sector. In general, most common techniques have already been described and analysed in many other BREFs (special reference should be made to the waste water and waste gas BREF [63, EIPPCB, 2002]). For this reason, it is not the intention of this section to give a complete analysis of the different techniques, instead this section focuses only on those issues of particular relevance for the industrial sector covered in this document, as well as giving emission data for what is considered good achievable emission values in the Sector.

The main purpose of waste water treatments is the reduction of the BOD content of liquid effluent (and as a consequence an associated reduction of COD). Treatment typically involves an agitation phase, which not only homogenises the slurry but also promotes the following actions:

- breakdown of solid particles
- desorption of waste from solid particulates
- contact between organic waste and micro-organisms
- oxidation of the slurry by aeration.

Waste water treatments combines chemical, physical and biological treatments. Usually this will include an aerobic stage, where the effluent is aerated in an aeration tank (0.5 - 3 days retention time) to convert soluble organics into micro-organisms (sludge) and a cleaner final effluent. Biological degradation only occurs on organics that are dissolved in water and not on suspended or free-phase organics. In general, the treatment and purification of waste waters from waste treatment plants is an important element of these plants, mostly due to the potentially high pollution loads that may be in the waste water. A distinction can be made between separation and conversion processes.

Separation processes are, for instance:

- mechanical treatment
- evaporation
- adsorption
- filtration
- nano-, ultrafiltration
- reverse osmosis
- centrifugation.

Whereas, conversion processes are, for example:

- wet oxidation using H_2O_2
- ozonisation
- precipitation/neutralisation
- anaerobic and aerobic biological treatments of waste waters.

4.7.1 Management on the waste water within the waste treatment sector

Description

Figure 4.10 shows an effluent management system for a WT installation.

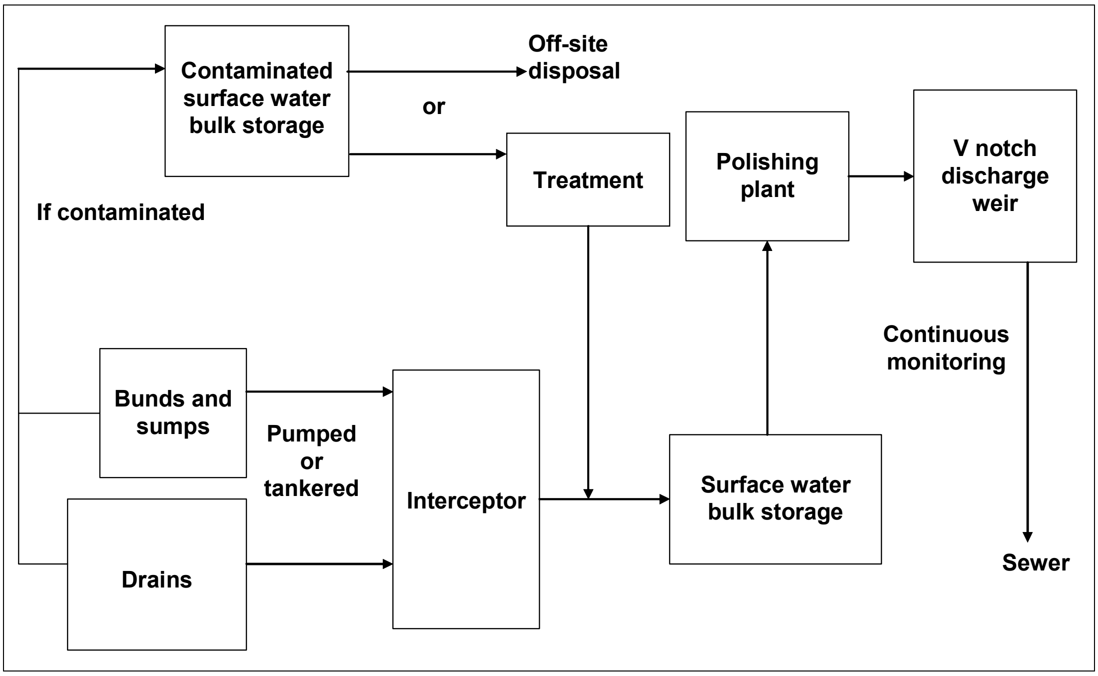


Figure 4.10: Effluent management within a waste treatment installation, which can be classified as shown in Table 4.75 below
[55, UK EA, 2001]

Classification	Objective	Techniques	Section in this document
Screening	To avoid introducing harmful and persistent substances into the system which will be unaffected by treatment	Pre-acceptance and acceptance measures	4.1.1 4.7.2
Primary treatment	Removal or reduction of target substances from wastes		4.7.3
Secondary treatment	Detoxification To convert dissolved substances into solids	Oxidation of cyanide or nitrite Reduction of chromium (VI) Precipitation of metals pH neutralisation COD reduction Settlement	4.7.4
Tertiary treatment	Elimination of biodegradable organic and nitrogen compounds	Biological treatment Settlement Thickening and dewatering	4.7.5
Final treatment	‘Polishing’ of effluent Recovery of substances from effluent	Filtration Membranes Wet air oxidation Adsorption	4.7.6

Table 4.75: Effluent management techniques

Some techniques for effective waste water management include:

a. describing any off site treatment in the overall description of the waste water treatment system (in most cases this maybe an urban waste water treatment facility, such as a sewage works). Where effluent is treated off-site at a sewage treatment works, the waste water producers need to demonstrate that:
    - the treatment provided at the sewage treatment works is as good as would be achieved if the emission was treated on-site, based on the reduction of load (not concentration) of each substance to the receiving water
    - the probability of sewer bypass, via storm/emergency overflows or at intermediate sewage pumping stations, is acceptably low
    - action plans are in place to deal with any bypass occurring, e.g. knowing when the bypass is occurring, and rescheduling activities such as cleaning or even shutting then down while the by-pass is taking place
    - a suitable monitoring programme is in place to check the emissions to sewer, taking into consideration the potential inhibition of any downstream biological processes and actions plan for any such event
b. selecting the appropriate treatment technique for each type of waste water
c. implementing measures to increase the reliability with which the required control and abatement performance can be carried out (for example, optimisating the precipitation of metals)
d. identifying the main chemical constituents of the treated effluent (including the make-up of the COD) and making an informed assessment of the fate of these chemicals in the environment
e. conducting daily checks (where there is daily discharge) on the effluent management system and maintaining a log of all checks having in place a system for monitoring effluent discharge and sludge quality
f. having in place procedures to ensure that the effluent specification is suitable for the on-site effluent treatment system or discharge criteria
g. avoiding effluent by-passing the treatment plant systems
h. having in place and operating an enclosure system whereby rainwater falling on the processing areas is collected along with tanker washings, occasional spillages, drum washings, etc., and returned to the processing plant or collected in a combined interceptor
i. collecting the raining water in a special basin for further treatment in the case it is detected that it is contaminated
j. having a full concrete base, with falls to internal site drainage systems which lead to storage tanks or to interceptors that can collect rainwater and any spillage. Interceptors with an overflow to sewer usually need automatic monitoring systems, such as a pH checks, which can shut down the overflow
k. reusing treated waste waters and rainwater in the process (e.g. cooling water)
l. only discharging the waste water from its storage only after the conclusion of all the treatment measures and a subsequent final inspection
m. use of landfill leachate as water input for the aerobic digestion
n. process and run-off water is handled by means of a closed circulation system
o. partial re-use of the water used for the production of polymer solution
p. displacement methods of treating chemical process waters containing VOC (another specific example is contaminated groundwater), resulting in a lower COD content.

Achieved environmental benefits
These techniques generally minimise emissions to load watercourses. They may also reduce the risk of contamination of process or surface water as well as reduce odour and VOC emissions.

Operational data
The operation particularly relies on a good control of the feedstock to ensure that the waste does not inhibit the treatment process (e.g. biological).

Applicability

Generally applied in most waste treatment facilities. The waste treatment option applied depends on the type of contamination present in the waste water. However, measures for treatment of organic and inorganic contaminants are sometimes common. In some cases, specially for small sites, waste water treatments can be carried out off-site. These off-site central waste water treatments typically treat waste water from many installations, not only from WT installations.

Technique d (see description section above) needs to have in consideration that it is not realistic to perform an environmental impact assessment to all variations of the discharge of the WT installation.

The frequency of technique e (see description section above) is sometimes guided by a risk approach.

Technique k (see description section above) can have restrictions to be applied due to the increase of the concentration of some soluble components that may interfere the waste treatment process.

Technique l (see description section above) may imply to have a further storage tank. This may potentially be costly and space is required especially for large and continuous flows.

Driving force for implementation

Water discharges are regulated by local/regional/national or international regulation.

Example plants

A large proportion of UK sites operate an enclosed system whereby rainwater falling on the processing areas is collected and returned to the processing plant. There are some examples of the re-use of water in immobilisation processes and in waste oil treatment plants after biological treatment. More examples for the re-use of water is in washing and cleaning purposes activities.

Reference literature

[50, Scori, 2002], [51, Inertec, et al., 2002], [52, Ecodeco, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [66, TWG, 2003], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004], [152, TWG, 2004], [153, TWG, 2005]

4.7.2 Parameters to consider before mixing waste waters

Description

Some techniques before mixing waste waters that are to be further treated include:

a. not mixing waste waters that contain adsorbable organically bound halogens (AOX), cyanides, sulphides, aromatic compounds, benzene or hydrocarbons (dissolved, emulsified or undissolved)
b. for the metals, using as mercury, cadmium, lead, copper, nickel and chromium as the classification parameters for the waste water, since like arsenic and zinc, they all occur in waste water partly in dissolved form and partly as suspended sulphides and have to be reduced in waste water treatment plants. These parameters also serve to control the effectiveness of the waste water treatment
c. ensuring that measures are in place to isolate effluents if the test samples indicate a potential breach of specification. Incidents of this nature need to be recorded in the effluent log
d. segregrating the collecting systems for potentially more contaminated waters (e.g. from storage and loading unloading areas) and less contaminated water (e.g. rainwater)
e. to isolate drainage systems from flammable waste storage areas to prevent fire being spread along the drainage system by solvents or other flammable hydrocarbons.

Achieved environmental benefits

Avoids problems in the later treatment and dilution.

Operational data

Wastes and waste waters often contain a mixture of hard and soft COD compounds which may or may not affect BOD content.

Applicability

Technique d is typically carried out in two separated systems. One dedicated to rainwater typically not treated and another one collecting all the rest of aqueous efluents that are typically treated together. In same cases, rainwater coming from storage or loading/unloading areas may become more contaminated.

Example plants

The procedures conducted by Ph-c plants are hydraulically separated into contaminated waste water and uncontaminated rainwater. Ph-c plants have two separate technical dewatering systems.

Related to point e) of the description section, there have been a number of incidents in the UK where fire has been spread from one area of a site to another via the drainage system.

Reference literature

[121, Schmidt and Institute for environmental and waste management, 2002], [134, UBA, 2003], [150, TWG, 2004]

4.7.3 Primary waste water treatments

Description

Some techniques include:

a. ensuring that the effluent is free of visible oil. This cheek needs to include procedures to ensure the correct configuration, operation and maintenance of the oil/water separation plant
b. performing air stripping in the aeration tanks of landfill leachates before it is mixed with waste water from the plant.

Achieved environmental benefits

Removes or reduces target substances from waste water. Related to technique b in the description section above, such a system is designed to remove any excess ammonia and methane from the leachates before these emissions go direct to the air or cause a risk of explosions in the sewer. An estimated discharge of five tonnes ammonia per year has been reported from one site.

Applicability

Air stripping is used to remove halogenated and non-halogenated hydrocarbons from dilute aqueous solution, to allow the residual solution to be processed within the WWTP without affecting effluent discharge standards. The hydrocarbons are recovered in carbon filters. Air stripping is ideally suited for low concentration streams (<200 ppm). The steam stripping process is capable of reducing VOCs in water to very low concentrations (i.e. ppb levels).

Reference literature

[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [150, TWG, 2004]

4.7.4 Secondary waste water treatments

Description
Some techniques include:

a. having an in-house effluent treatment unit which uses vacuum filtration to remove colloidal solids
b. ensuring that the levels of metals in solution are minimised, normally by adjusting the pH to the correct level required to maintain minimum solubility
c. ensuring that the cyanide treatment (oxidation of cyanide) is carried out to completion, normally by maintaining pH >10 and preventing the carry over of NaOCl due to overdosing
d. having in place a pH neutralisation system
e. utilising a flocculation process to create a filter cake, with neutralisation of the filtrate and a discharge to sewer for the handling of latex emulsion waste and contaminated site rainwater. The final cake analysis will have a nitrogen concentration of ~51 mg/kg of cake.

Achieved environmental benefits
Precipitation and flocculation are employed to convert dissolved substances into solids and to concentrate them so that they can be separated by adapting an appropriate pH value.

Precipitation transfers dissolved inorganic and organic substances into the undissolved solid phase through a chemical reaction. During flocculation, physico-chemical processes (destabilisation, creation of micro- and macroflocs) are used to bring fine suspended or colloidal substances into a condition in which they can be separated from the fluid phase by mechanical procedures (e.g. sedimentation, flotation, filtration). In practice, precipitation and flocculation often take place in parallel with adsorption processes.

Operational data
Certain inorganic and organic complexing agents contained in the water can disrupt or inhibit the precipitation reaction.

High concentrations of neutral salts raise the residual solubility in the neutral precipitation of metals. If the requirements regarding the residual metal concentrations are not fulfilled, further treatment steps will be necessary, e.g. additional precipitation as sulphide, filtration, ion exchange, etc.

In order to ensure optimal conditions for precipitation and flocculation pretreatment may be necessary. This may involve a separation of light substances, emulsion splitting, complex destruction or a systematic removal, detoxification or avoidance of substances which may disrupt the reaction or the subsequent separation of solids. This may also possibly lead to a requirement for the separate treatment of wastes and their waste waters.

If the waste water contains surface-active substances which can lead to foaming in the reaction containers, counteractive measures need to be taken.

Applicability
Chemical precipitation is employed mainly to remove metal ions from waste waters and for the chemical elimination of phosphate. Apart from the separation of precipitation products, flocculation also removes suspended solids and higher molecular compounds.

For precipitation and flocculation, the following points may be of importance and should be taken into consideration:

- chemical precipitation should lead to compounds with correspondingly low solubility product
- in order to ensure optimal contact between the reaction partners, good mixing is necessary in the precipitation reactor. Effective flocculation also requires a swift and even distribution of the flocculation agents. Applying stirring allows the creation of flocs that sediment well, although overly large shearing forces should be avoided
- separation of the coagulation phase (compensation of the electrical potential of the colloids) and flocculation phase into two distinct steps is an appropriate way in many cases to achieve a good flocculation result
- refeeding the contact sludge improves the production of compact, heavy flocs and ensures the optimal utilisation of reagents
- a multi-stage precipitation and flocculation process supports the stepwise achievement of the optimal pH-value and the efficient/effective combination of different precipitation and flocculation techniques (e.g. hydroxide precipitation followed by sulphide precipitation).

Reference literature
[55, UK EA, 2001], [134, UBA, 2003]

4.7.5 Tertiary waste water treatments

Description
For the elimination of biodegradable organic compounds and nitrogen compounds biological treatment processes have repeatedly been shown to be effective. In contrast to other treatment techniques biological treatment makes use of micro-organisms 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). Under anaerobic conditions different populations of bacteria evolve which allows for the degradation of a broad range of substances. In the optimal case, degradation proceeds to the point where inorganic substances such as CO_2 and H_2O are created (mineralisation). Some tertiary techniques include:

a. applying a biological treatment for waste water with a high BOD content. Harmful and persistent substances, constituting a proportion of the COD load such as solvents, pesticides, organo-halogens and other organic substances, may be adsorbed onto particulate and colloidal matter and then removed as a solid residue. The treatment process does not determine the efficiency of this and removal is highly variable. As a ‘rule of thumb’, to facilitate biodegradation, the COD/BOD ratio of effluent to sewer should typically not exceed 10:1
b. settlement
c. thickening and dewatering
d. wet air oxidation.

Achieved environmental benefits
Reduces BOD and consequently reduces the COD load of the waste water. At the same time nitrogen and some microelements (e.g. Zn) can be captured by the biological treatment. The degradation of organic compounds is carried out by micro-organisms whose activity depends largely on their environmental conditions, causing some degree of fluctuation in the efficiency of the process.

Parameter	Feed (primary effluent)		Effluent after biological treatment (sequential batch reactor)	
	Minimum (mg/l)	Maximum (mg/l)	Minimum (mg/l)	Maximum (mg/l)
COD	2500	12000	600	1500
NH_4-N [1)]	25	16000	<1	150
Nitrite	10	300	<1	<1
Nitrate	10	1000	<1	<1
Phenoles	10	500	<2	<2
Oil content	--	--	<0.5	--
[1)] Effluent after biological treatment: Often around 20 mg/l				

Table 4.76: Effluent concentration of a Ph-c plant before and after tertiary waste water treatment [150, TWG, 2004]

Cross-media effects

Mineralisation of organic substance and biomass production. Through adsorption processes and bioaccumulation, inorganic and non-degradable organic compounds may accumulate in the biomass.

Operational data

Certain organic and inorganic contents of the waste water may have a toxic effect on the bacteria population. Due to the nutrient demand of biological processes, low phosphorus concentrations can become the limiting factor for the life of bacterial (this problem may possibly be solved by a systematic addition of nutrients). For all biological treatment techniques currently in use, a number of special characteristics and boundary conditions have to be considered:

- for biological degradation, nutrients (nitrogen, phosphorus) and trace elements (metals, etc.) are needed
- optimal pH-ranges (usually pH 6.5 - 8.5) have to be maintained within the reactor
- to keep the process running oxygen contents greater than 1 mg/l are necessary
- activity of the micro-organisms increases with increasing temperature, up to an optimum at around 30 – 35 °C. Below 10 °C the reaction speed usually decreases drastically
- for the functionality of the system the retention of biomass is of particular importance.

Biological plants should be designed with sufficient residence time to achieve an adequate breakdown of the more complex compounds present in the waste water.

The age of the sludge is also important. Optimum operating temperatures can also aid degradation. Some aerobic plants are currently planned to operate at around 30 °C

Applicability

Biological treatment is a very effective technique for the elimination of:

- a large number of biodegradable organic carbon compounds. Even if the analysis of the waste water indicates low biological degradability (relation BOD_5/COD <0.1), 40 – 50 % of the COD can still be eliminated (with only small production of biomass)
- nitrogen compounds. Organic nitrogen and ammonium can be transformed via nitrite to nitrate. Emission values below 10 mg NH_4^+-N/l can be achieved easily, values <1 mg NH_4^+-N/l are common. Nitrate or nitrite can be converted into elementary nitrogen.

Example plants

Widely used in the sector.

Reference literature

[55, UK EA, 2001], [134, UBA, 2003], [150, TWG, 2004]

4.7.6 Final waste water treatments

Description

Final treatment refers to any process that is considered a ‘polishing’ phase typically after the tertiary treatment if exist and which may also encompass the recovery of specific substances. Some techniques are listed in the following Table 4.77:

Technique	Description
Macro-filtration	Sand filtration, mixed media (for example, sand/anthracite blends) or more specialised types of filtration media, such as Granular Activated Carbon (GAC)
Strong reduction	
Wet air oxidation	Wet air oxidation is a destructive physico-chemical treatment method that is used to treat aqueous effluents with high COD levels, which are not suitable to be directly discharged to a WWTP, but that are too expensive to incinerate
Strong reduction with hydrazine	
Ion exchange	Removal of nitrate, metals and concentration of metals

Table 4.77: Final waste water treatments

Achieved environmental benefits

The benefits of these treatments is the final ‘polishing’ of the effluent and the recovery of substances from the effluent before its re-use or its emission to the sewer, surface waters, etc.

There may be some scope for the application of these filtration techniques (including sand filters) to remove particulates in effluent, thereby offering a means to reduce the level of suspended solids in the effluent.

Macro-filtration remove the suspended solids, certain chemicals, taste and odours.

Cross-media effects

Macro-filtration by GAC carbon needs regeneration, which is usually carried out by incineration.

Operational data

Filtration processes need pressure. In some cases, very high pressures are needed (e.g. as is the case with reverse osmosis).

Attempts at using wet air oxidation for some waste treatment has suffered from problems connected with heterogeneous and variable waste feedstock; and as a consequence there are no current applications in waste treatment. Though these are applied in other sectors, as is suitable for dedicated processes with specific waste streams on-site.

Applicability

Adsorption is simple and reliable and batch operation is possible.

Driving force for implementation

The need for these treatments is dictated by three potential factors:

- the requirement to meet the discharge conditions stated in the permits
- to allow recycling of waste water for process water or wash-water
- to aid recovery i.e. of oil from water contaminated with oil by, for example, ultra-filtration.

Filtration systems are currently being utilised by some water utilities for discharges from waste water treatment works, primarily in order to control the pathogens in the waste.

Hydrazine is a hazardous substance and reports state that its use is banned in at least one MS.

Example plants
There is an example plant where 90 % of the Hg emission comes from contamination in the soil, which subsequently leaks into the pipeworks. At Akzo Nobel in Bohus (Sweden), a mercury base chlor-alkali plant, the waste water mercury removal system consists of a mixing unit where hydrazine is added to the waste water, two sedimentation tanks, sand filters, activated carbon filters and ion exchange filters. The treated waste water flow was 7 m^3/h with a mercury content of 3000 - 5000 µg/l in 1997, with a resultant mercury concentration in the waste water of 5 - 8 µg/l, corresponding to an emission of 0.005 g Hg/tonne chlorine capacity. The total mercury emission to water from the site was approximately 0.045 g Hg/tonne chlorine capacity, which meant that about 10 % of the mercury emissions were process emissions with the other 90 % being indirect emissions of deposited mercury which end up in the run-off water.

Reference literature
[41, UK, 1991], [42, UK, 1995], [55, UK EA, 2001], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

4.7.6.1 Evaporation

Description
The aim of the treatment is to concentrate the waste water contents into more manageable volumes.

By splitting the evaporation into several smaller steps and by using a vacuum (in order to lower the boiling temperature), the energy use can be optimised.

Depending on the temperature, the evaporation usually takes place without the chemical conversion of substances. During concentration, phases might be created which favour further separation (e.g. crystallisation).

Achieved environmental benefits
Reduces the amount of waste water to be treated.

Cross-media effects
There is an increased energy consumption. If the materials are not suitable for recovery, the residues from evaporation can be landfilled after an appropriate after-treatment (such as drying, dewatering, conditioning) according to their contents. Since evaporation will only lead to a lightly polluted vapour condensate in the ideal case, the condensate will usually have to be subjected to an after-treatment and purification according to its contents.

Operational data
Limits of the treatment:

- for the selection of input material for the evaporation facility the contents of the waste water need to be taken into account
- if the waste water contains surface-active substances which could lead to foaming during the evaporation process, measures have to be taken to reduce the foam. In addition to the installation of separators, the use of defoamers may be necessary.

Facilities for the mechanical removal of ‘crusts’ or for the discharge of solid substances which accumulate during evaporation need to be available.

Applicability
The treatment is suitable for highly polluted waste waters from which all inorganic and organic contents that are not volatile need to be eliminated. Evaporation is suitable for instance to further concentrate waste waters already thickened by reverse osmosis or ultrafiltration.

Example plants
Physico-chemical treatment of waste waters.

Reference literature
[134, UBA, 2003], [150, TWG, 2004]

4.7.6.2 Adsorption

Description
Adsorption to activated carbon is mainly applied for the separation of organic substances from waste waters. Two different approaches are currently in use:

- adding mostly powdery activated carbon to the waste water that is to be treated
- running the waste water over several adsorption columns arranged in series, and which are filled with granulated activated coal.

Achieved environmental benefits
Reduces of organic substances in the waste water.

Cross-media effects
When using powdery carbon, the carbon must be separated from the waste water after use. Depending on the substances adsorbed, it can be incinerated or disposed of at suitable landfill sites. Granulated carbon is usually recovered in external plants.

Applicability
This treatment process is mainly suitable for removing organic substances from waste waters. If individual pollutants or groups of pollutants (e.g. AOX) are to be removed selectively, the process can be optimised by visiting the special properties of the waste water (type and quantity of substances) and thereby the adsorption can be adapted to individual cases (form and properties of the carbon, adsorption time, column size and arrangement, etc.).

As solids can occupy the surface of the activated carbon and thus block the pores they need to be removed before the treatment with activated carbon.

Example plants
Activated carbon adsorption is frequently used in order to enable the operator to meet the permissible maximum value of AOX ≤ 1 mg/l. Activated carbon adsorption however does not selectively separate the AOX-forming materials, but rather a multitude of other organic substances.

Reference literature
[134, UBA, 2003]

4.7.6.3 Membrane filtration

Description
The separation of substances in membrane processes is brought about by the differential permeabilities of the membrane for different chemical components. There at least one component of the substance mix that is to be separated - usually the solvent – will be able to pass the membrane without resistance, while the other elements are held back to a higher or lesser extent. The fraction that is retained represents the concentrate; the material that passes the membrane is called the permeate.

The following treatment processes, grouped according to their pore sizes, are currently in technical use:

• microfiltration (MF)	(>0.6 µm,	>500000 g/mol)
• ultrafiltration (UF)	(0.1 – 0.01 µm,	1000 – 500000 g/mol)
• nanofiltration (NF)	(0.01 – 0.001 µm,	100 – 1000 g/mol)
• reverse osmosis (RO)	(<0.001 µm,	<100 g/mol)

Some issues to consider include:

a. the pH value in the waste water to be treated can be shifted in order to accelerate the reactions and/or to improve the charge values
b. a fine filter can be connected in front of the activated carbon adsorbent to retain the harmful solids
c. dampening the activated carbon, using fine granulates instead of powders, and feeding it in below the water level in the reactor/basin can help to overcome problems due to dust formation in stirring.

Achieved environmental benefits
By using membrane techniques waste waters with organic and inorganic pollutants can be treated without any considerable addition of chemicals.

Cross-media effects
Through process optimisation, the permeate of a membrane facility should usually be purified sufficiently to be recycled into the industrial process or to comply with minimum quality standards for discharge into water bodies. The concentrate is usually subjected to further treatment, such as:

- re-use
- disposal
- evaporation
- immobilisation.

Applicability
Membrane techniques as used for substance separation and accumulation have become a key technology in water and waste water treatment because no chemicals are necessary, - except for the cleaning of the membrane, - due to the purely technical nature of the separation. As a consequence, the separating components are neither chemically nor thermally polluted. Due to those factors, the economics of the treatment even make it efficient in smaller plants and decentralised treatment of waters at the place of origin is also possible.

The applicability of membrane techniques is influenced both by the construction and design of the modules/membrane systems and by a number of additional limiting factors.

Some of these are:

- damaging factors: free chloride, organic solvents, strong oxidants
- blocking factors
- fouling (metal hydroxides, colloids, biological substances, organic substances)
- scaling (precipitation of salts with low solubility)
- performance-impairing factors
- osmotic pressure, viscosity.

However, these factors are usually not exclusive just to membrane techniques. Nevertheless they generally require a detailed pre-assessment of the water that is to be treated with respect to:

- choice of membrane (polymer or keramics)
- selection of material (synthetic, steal)
- necessary pretreatment (filtration, inhibition, biocides etc.)
- purification programme (acid, alkaline).

Example plants

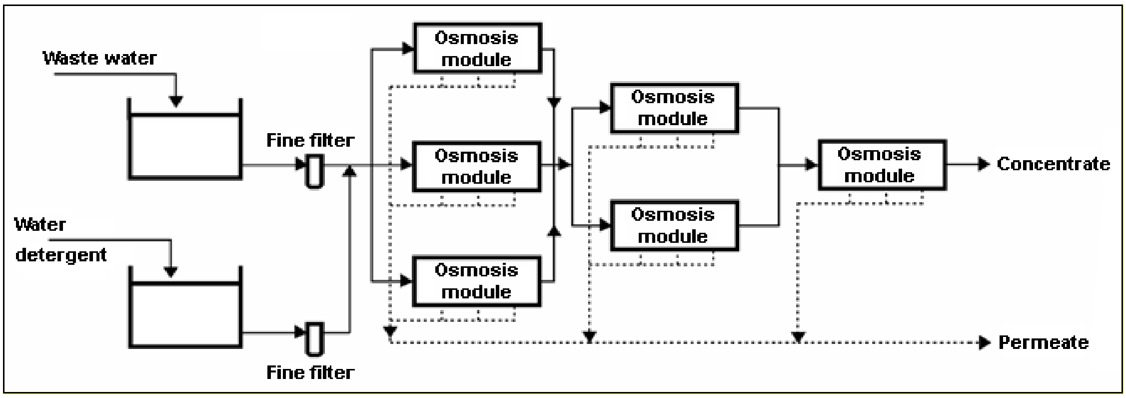


Figure 4.11: Example of a diagram showing a three-step reverse osmosis plant
[150, TWG, 2004]

Reference literature
[134, UBA, 2003], [150, TWG, 2004]

4.7.6.4 Ozone/UV treatment

Description
Highly polluted waste waters can be treated with ozone alone or with ozone and UV-light in combination with biological treatment processes.

The ozone reaction is a wet chemical reaction. At pH-values below 9 ozone reacts ioniccally by decomposition, leaving one active oxygen atom behind, or as a radical by adsorption of the whole molecule to organic carbon double bonds, breaking them up at pH-values above 9. Oxygen radicals or hydroxyl radicals can also be created from ozone by the exposure to UV-light. These radicals are even more reactive than ozone.

Additionally Nitrogen compounds can be degraded through a combination of the ozone treatment with biological procedures. There the waste water is transported from the influx pump to the denitrification container. Phosphoric acid is added to the influx. Before the fluid enters the denitrification container the runback from the nitrification is added.

In ozone reactors, the ozone can react with the oxidisable substances contained in the waste water. In downstream UV-reactors, the ozone that still remains in the water is destroyed or converted into radicals, which then also react with organic substances.

The remaining oxygen is utilised by aerobic bacteria for nitrification.

After the treatment with ozone and UV-light, part of the cycling water is discharged from the process into the outflow as purified waste water.

Achieved environmental benefits

The wet chemical oxidation with ozone alone or with ozone in combination with UV-light reduces the concentration of:

- dissolved organic hydrocarbons (DOC)
- halogenated hydrocarbons
- polycyclic aromatic carbohydrates (PAC)
- pesticides
- dioxins
- (pathogenic) micro-organisms.

The aim of wet chemical oxidation is the direct degradation of pollutants at a low pressure and temperature. Ozone reacts with all organic substances that contain carbon-carbon double bonds.

Some short-chained aliphatic compounds and carbon-halogen compounds do not easily react with ozone. The bonds of these molecules can be more easily broken if ozone and UV-light are applied in combination.

Depending on the boundary conditions (type of waste water contents, ozone entry, reaction time) the reaction can produce carbon dioxide at the complete oxidation point, and biologically degradable substances (increase of BOD_5) or substances that are not readily biodegradable.

Cross-media effects

If ozone/UV-treatment is combined with a biological step, sludges are produced by the biological treatment which then have to be subjected to further treatment.

Applicability

Some issues to note are:

- longer-chained aliphatic compounds without double bonds are not altered by ozone/UV treatment
- with coloured or turbid waste water, treatment is possible only if UV-treatment is not necessary for the degradation of the contents
- inorganic substances contained in the waste water are not modified and at high salt concentrations can lead to disruption of the process.

Example plants

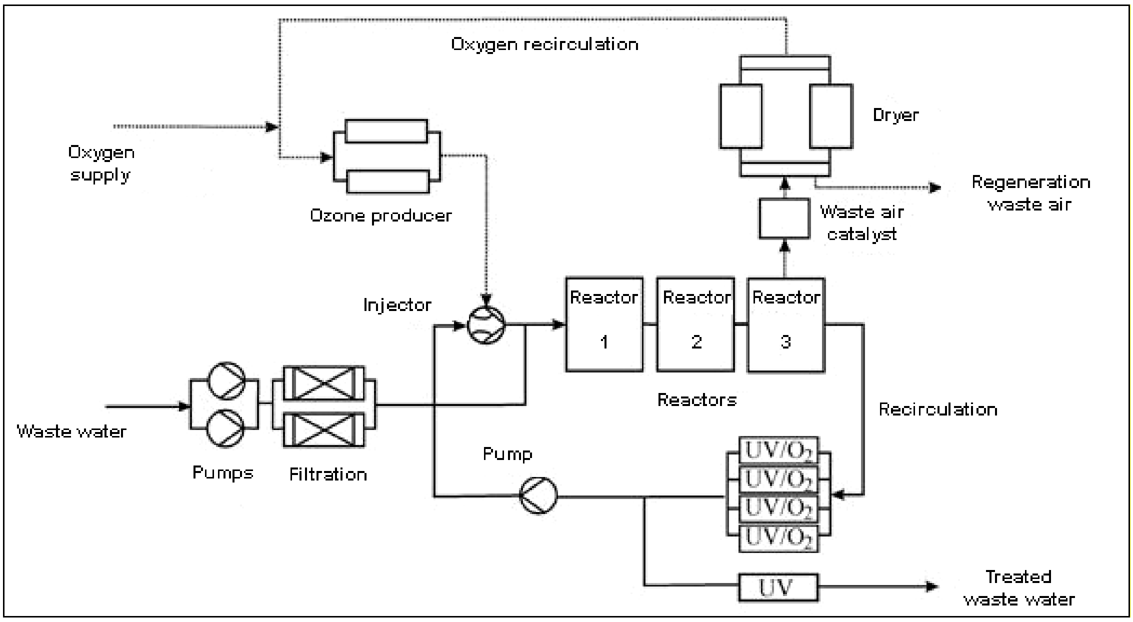


Figure 4.12: Example of a flow sheet showing ozone/UV treatment of waste water [150, TWG, 2004]

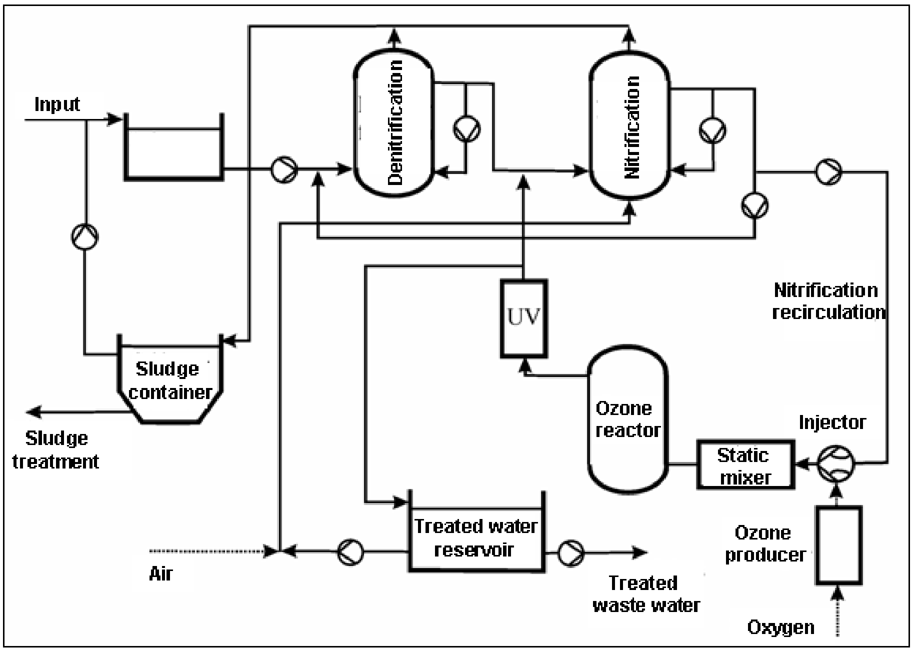


Figure 4.13: Example of a flow sheet showing a biological and UV treatment
[150, TWG, 2004]

Reference literature
[134, UBA, 2003], [150, TWG, 2004]

4.7.7 Reporting of the components in the effluent generated in waste treatment facilities

Description
This section is intended to give some guidelines on the type of water parameter (pollutans) to be analysed in the effluent coming out from a waste treatment installation. The following Table 4.78 gives information on the water parameters analysed, the achievable levels, the frequency of the measurement and an indication of whether such a parameter is monitored continuously and which type of waste treatment installations requires the particular parameter.

Water parameter	Achieved emission levels (mg/l)	Time average (continuous, daily, monthly, yearly)	Example of WT installations where the parameter has been reported
pH		Continuous	All
Dry Solids	17000 – 27000		Ph-c treatments
Suspended solids	0.1 – 79	Continuous	All
Conductivity (µS/cm)	900 – 21000	Continuous	Ph-c treatments
Total nitrogen	110 – 3500	Monthly	Biological and Ph-c treatments
Ammonia	10 – 2500		Biological and Ph-c treatments
Nitrite	0.01 – 10		All
Nitrate	0.9 – 10		Biological and Ph-c treatments
Total Phosphorus	<0.1 – 2.6	Monthly	Dealing with phosphorus waste e.g. in Ph-c treatments
Chloride total	1500 – 18240		Biological and Ph-c treatments
Chloride free	≤0.1 – 0.4		Ph-c treatments
Cyanide free	<0.01 – 0.1		Ph-c treatments
Fluoride	0.5 – 10		Ph-c treatments
Cyanide total	≤0.1		Ph-c treatments
Sulphate	65 – 1070		Ph-c treatments
Sulphite	≤1 - 50		Ph-c treatments
Sulphide	≤0.1		Ph-c treatments
Aquatic toxicity			
Microbial indicators (e.g. pathogens)			
Bacteria luminescence			
BOD	20 – 3000		
BTEX	<0.1 – 0.7		Ph-c treatments
COD	120 – 5000		All
Detergents	0.6 – 5.3		
Hydrocarbons	<0.1 – 3.8		All
PAH			
AOX	0.1 – 0.5		All
Phenols	0.1 – 1.9		Ph-c treatments
VOC	<0.01 – 0.1		Ph-c treatments
Solvents			
TOC			
TPH			
Metals		Monthly	Ph-c treatment
Ag	≤0.1		
Al	<0.1 – 2		Ph-c treatments
As	<0.01 – 0.1		Arsenic bearing wastes Ph-c treatments
Ba	≤5		Ph-c treatments
Cd	≤0.1		Ph-c treatments
Co	<0.1 – 1.0		Ph-c treatments
Cr(VI)	<0.01 – 0.1		Ph-c treatments
Cr	<0.1 – 0.5		Ph-c treatments
Cu	≤0.1 – 0.5		Ph-c treatments
Fe	0.1 – 5.2		Ph-c treatments
Hg	0.001 – 0.01		Ph-c treatments
Mn	<0.1 – 0.9		
Ni	<0.1 – 1.0		Ph-c treatments
Pb	<0.1 – 0.5		Ph-c treatments
Se	≤0.1		Ph-c treatments
Sn	<0.1 – 2.0		Ph-c treatments
Zn	<0.1 – 2.0		Ph-c treatments

Table 4.78: Water parameters monitored in waste treatment facilities
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [116, Irish EPA, 2003], [134, UBA, 2003], [59, Hogg, et al., 2002], [150, TWG, 2004]

Achieved environmental benefits
Identifies and assists the monitoring of pollutants that are typically released.

Example plants
In general, the discharge consent reflects the type of activity carried out at the site, ie those handling large volumes of solvent are required to test for solvent content; others may be required simply to test for pH and COD.

Reference literature
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [86, TWG, 2003], [116, Irish EPA, 2003], [134, UBA, 2003], [150, TWG, 2004]

4.7.8 Examples of some waste water treatment plants in the sector

[56, Babtie Group Ltd, 2002]

An example of a WWTP used in waste oil treatment plants may include the aqueous waste going through a physico-chemical unit where ferric chloride is added as a flocculant and sludge is taken off to the filter press. The aqueous phase may then be dosed with polyelectrolytes and lime to raise the pH and to produce another sludge layer that then goes to the sludge press. Liquors from the press plus the supernatant liquors will go onto a biological treatment, but now the liquors will be substantially free from oil residues and metals, and the overall COD level will have also been reduced.

4.8 Residue management

The word 'residue' is used in this section to mean the solid waste generated by the waste treatment activity and is not directly related with the type of waste treated in the installation. This is the same type of convention used in Chapter 3 and throughout this document (see also Glossary). Remember that Chapter 3 called the waste coming out from the installation as waste OUT. Waste OUT has a direct relation with the waste IN of the installation. In Chapter 3, such waste was called the process generated waste, as was shown by the schematic in Figure 3.1. This section covers the following type of techniques:

- techniques for the reduction of waste generated due to the treatment (analysed in each of the previous sections of this chapter)
- management of the waste generated due to the treatment, and
- those techniques focused on a reduction of the contamination of soil.

4.8.1 Residue management plan

Description
Waste minimisation is a systematic approach to the reduction of waste at source, by understanding and it necessary changing the processes and activities to prevent and reduce waste. A variety of techniques can be classified under the general term of waste minimisation and they range:

- from basic housekeeping techniques
- through statistical measurement techniques
- to application of clean technologies
- to the use of waste as fuel.

In particular, some techniques include:

a. undertaking an analysis of the sludge/filter cake to ensure the treatment process objectives are being met and that the process is working effectively. Filter cakes and treatment sludges are typically analysed less frequently but an analysis could still enable a calculation of the metals level to be made. Filter cakes and treatment sludges are normally not suitable for landfilling, as they do not fulfil the criteria of the Landfill directive
b. identifying, characterising and quantifying each of the waste streams generated and that need to be removed from the installation. 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 side
c. identifying the current or proposed handling arrangements
d. fully describing how each waste stream is proposed to be recovered or disposed of. If it is to be disposed of, the explanation needs to cover why recovery is technically and economically not possible and then describe/explain the measures planned to avoid or reduce impact on the environment
e. ensuring that the dry solids content are not less than 15 w/w-%, to facilitate handling of the mixture
f. ensuring that dust accumulations requiring removal are analysed, in order to ensure the correct disposal route is chosen, for example, for pH, COD, heavy metals and other known contaminants from the spillage.

Some techniques for minimisation include:

g. recycling the filter cake arising from treatment of acidic and alkali solutions and metal precipitation, as it may contain percentage levels of metals such as zinc and copper with options for metal recovery
h. recycling contaminated drums.Undamaged 205 litre drums and 800 and 1000 litre IBCs can be recovered with cleaning and reconditioning. Damaged containers for which there is no reconditioning market and which held non-hazardous materials may be released into the secondary metals market. Where possible, empty containers which are in sound condition and which are free from, or which contain only insignificant quantities of, residual waste need to be sent for reconditioning and re-use or recycling
i. using multiusable containers instead of drums for all purposes if available
j. utilising the waste with sufficient heat content and low contamination values (see Energy System Sections) as primary/secondary fuel
k. applying housekeeping operations, these can be as simple as sweeping prior to washing floors, these measures can substantially reduce waste volumes.

Achieved environmental benefits
The steps above help to ensure the prudent use of natural resources and can reduce waste generation in the WT installation. Reduces emissions from the management of the residues handled in the installations and minimises the amount of residue arising, as well as helping to identify a good disposal route.

Soluble contaminants may appear in the eluant with the water removed by the filter pressing operation.

Cross-media effects
The burning of residues can lead to higher air emissions than from the use of conventional fuels.

Operational data
Related with technique h (in the description section above), before re-using drums, the labels and inscriptions need to be removed.

Applicability
The use of residues as fuel is common in waste oil treatment facilities.

The re-use of packaging and palettes depends also whether the packaging is made for re-use or not. In several cases such a re-use may conflict with ADR regulations if the packaging is not retrofitted appropriately.

Related with technique h (in the description section above), the recycle of drums need to take into account the contamination of the drums with the content. Drums not being suitable for direct recycling are typically send to appropriate treatment e.g. incineration. For example, polyethylene drums are completely incinerated, steel drums are cleaned and typically are sorted out from the slags and recycled afterwards. Landfilling of contaminated drums is typically excluded.

Economics
In terms of capital expenditure and operating costs, sludge treatment is a significant component and the management and disposal of solid waste will remain as one of the most fundamental issues facing operators.

Driving force for implementation
The prevention and minimisation of generation of waste as well as reducing its hazardousness is a general principle of IPPC and waste hierarchy.

The types of waste produced on each site are in many countries part of the permitting process. The permit can also describe how to store such wastes and how often to analyse them.

Re-using drums is restricted to cases where the drums are still fit for purpose, in accordance with ADR rules and can readily be cleaned. All other drums have to be pretreated before the scrap can be re-used.

Example plants
In Germany, the use of drums has been reduced as much as possible.

Reference literature
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.8.2 Techniques to prevent the contamination of soil

Description
These techniques relate to water spills and other fugitive emissions as already dealt with in Section 4.1.3.6 and todecommissioning as already dealt with in Section 4.1.9. Some specific techniques include:

a. providing and then maintaining the surfaces of operational areas, including applying measures to prevent or quickly clear away leaks and spillages, and ensuring maintenance of drainage systems and other subsurface structures
b. utilising an impermeable base and internal site drainage
c. applying separate drainage systems and sumps enable the isolation of specific areas of the site where waste is handled and bulked, in order to to contain possible spills and to protect surface water drainage from contamination. These can help to reduce liquid emissions
d. minimising the installation site and minimising the use of underground vessels and pipework
e. carrying out regular monitoring of subsurface vessels for potential leakages (e.g vessel level checks during periods of inactivity)
f. designing the areas where water-endangering liquids are transferred as watertight bunds. Then, the bund must be watertight so that in the event of accident, the hazardous liquid can be contained until security measures are in place
g. ensuring that the areas where water-endangering substances are handled, as well as bunded areas, are specially sealed against seepage by e.g. painting, coatings, concrete quality, sealing systems applied on the inside. There, the sealing system needs to be capable of being inspected at any time
h. equipping the containers used for the storage/accumulation of water-endangering materials must be equipped with double-walls or standing them in bunded tanks. There their volume capacity needs to be measured in such a way that the total volume of the largest container can be collected or 10 % of the volume of all containers in each case, the larger volume is decisive
i. equipping the containers used for the storage/accumulation of water-endangering materials with overflow controls, linked by a signal relay to the control room, as well as optical and acoustic signals. There the pumps used to fill the containers, as well as associated shut off devices (e.g. slide gate valves) should be connected to the overflow control.

Achieved environmental benefits
Can prevent the short- and long-term contamination of the site. Minimisation of underground vessels and pipes makes easier the tasks of maintenance as well as inspections.

Cross-media effects
Problems such as cracks, blocked outlets on drains, drainage channels of gravel between concrete slabs have all been identified in some cases.

Applicability
Most sites have an impermeable base and operate an internal site drainage (e.g. full concrete base).

Driving force for implementation
IPPC requires that in carrying out industrial activities there needs to be no pollution risk from the site. Some EU directives and national legislation also apply to prevent the contamination of soil.

Example plants
Some examples have been reported, where although most of the sites had an impermeable base and internal site drainage, the condition of these was suspect. Almost all hazardous waste transfer stations have a secure base, which is laid with falls that drain rainwater and liquid/solid spills to one or more liquid tanks or interceptors.

Ph-c plants are typically equipped with seal systems to prevent spillages which can lead to groundwater or subsoil contamination. Of fundamental importance for all technical emission protection measures is the selection of construction materials, which need to offer high resistance, e.g. against acids, alkalis, organic solvents (depending on the application).

Reference literature
[50, Scori, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [121, Schmidt and Institute for environmental and waste management, 2002], [135, UBA, 2003], [150, TWG, 2004]

4.8.3 Techniques to reduce the accumulation of residues within the installation

Description
Some techniques include:

a. making a clear distinction between sales and technical staff and their roles and responsibilities. If non-technical sales staff are involved in waste disposal enquiries then a final technical assessment prior to approval needs to be made. It is this final technical checking that needs to be used to avoid a build up of the accumulation of wastes and to ensure that sufficient capacity exists on site. It is not the commercial streams which regulate the waste arrival on the site, but rather should be a specific stream of co-ordination, involving technical staff as well
b. avoiding an accumulation of waste, which may in turn lead to a deterioration or deformation of the container
c. keeping a monitoring inventory of the waste on-site by using records of the amount of wastes received on-site and records of the wastes processed
d. conducting a monthy inventory of all the waste on-site to monitor stock levels and to identify any ageing waste on-site
e. ensuring that any accumulations of liquids in bunds, sumps etc, are dealt with promptly.

Achieved environmental benefits
In some reported plants, failure to ensure an adequate throughput of wastes has lead to a large number of waste, drums and containers being stored. The wastes involved are typically unchecked and drums are often simply just left to deteriorate. Such situations are often associated with large scale site clearances and may be accompanied by competitive pressures and customer’s insistence to accept additional waste streams. Typically the wastes involved are difficult to handle and/or treat and may have been transferred between various operators, with a consequent loss of information about the original producer and composition.

Longstanding accumulations may also compromise standards relating to record keeping, which in turn may result in the loss of identity of the waste, further exacerbating the storage situation.

Driving force for implementation

Typically in operating permits, the amount of different kinds of waste to be allowed for storage is well defined. Generally, operators have limited capacities in their permit and a delay may be given to state the time between the waste reception and its treatment.

Reference literature

[55, UK EA, 2001], [86, TWG, 2003]

4.8.4 Promoting the external residue exchange

Description

Whilst re-using a residue inside a manufacturing facility is the most desirable form of recycling, it is not always possible to find another department or process that can effectively utilise the residue. An alternative therefore may be to locate another company that can make use of the residue. A waste exchange is a regional clearing-house for such transactions. Waste exchanges maintain computer databases and/or publish periodic lists of wastes available or materials sought by various industries. The waste exchange information base typically includes:

a. company ID code
b. category (e.g., acid, solvent, etc.)
c. description of the primary usable constituents
d. contaminants
e. physical state
f. quantity
g. geographic area
h. packaging.

Achieved environmental benefits

Allows a more appropriate use or disposal of a waste.

Reference literature

[53, LaGrega, et al., 1994]

5 BEST AVAILABLE TECHNIQUES

In understanding this chapter and its contents, the attention of the reader is drawn back to the preface of this document and in particular the fifth section of the preface: ‘How to understand and use this document’. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this chapter have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for the waste treatment sector. These are related with air emissions, emission to water, waste, soil contamination as well as energy. However, due to the variety of waste treatments and types of waste involved in this document not all types of emissions are relevant for all waste treatments
- examination of the techniques most relevant to address those 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 performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of these techniques
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(11) and Annex IV of the Directive.

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

On the basis of this assessment, techniques, and as far as possible consumption and emission levels associated with the use of BAT, are presented in this chapter that are considered to be appropriate to the sector as a whole and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels ‘associated with best available techniques’ are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, in this sector, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross-media considerations, they are not considered to be appropriate as BAT for the sector as a whole. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The consumption and emission levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of ‘levels associated with BAT’ described above is to be distinguished from the term ‘achievable level’ used elsewhere in this document. Where a level is described as ‘achievable’ using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous chapters. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.

It is intended that the general BAT in this chapter are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way they will assist in the determination of appropriate 'BAT-based' conditions for the installation or in the establishment of general binding rules under Article 9(8). It is foreseen that new installations can be designed to perform at or even better than the general BAT levels presented here. It is also considered that existing installations could move towards the general BAT levels or do better, subject to the technical and economic applicability of the techniques in each case.

While the BREFs do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable consumption and emission levels when using specified techniques. The appropriate limit values for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

Some key findings to help users/readers of this document
During the preparation of this document, several important issues were raised and considered by the TWG; a knowledge of these issues may help users/readers of this document.

- due to the complex nature of the sector, it is strongly recomended to read Chapter 5 in conjunction with Chapter 4. To help the user/reader in this subject, cross-references to Chapter 4 have been included in Chapter 5
- many factors influence decisions about whether or not a waste treatment facility should apply a certain process technique or pollution abatement technique. Factors such as the type of treatment and type of waste processed need to be taken into account when using this document at local level
- in addition to the BAT referenced in this chapter, BAT for a waste treatment facility will also contain elements from other IPPC documents and international regulations. In this context, special attention is drawn to the BAT Reference Document on Emissions from Storage, Industrial Cooling Systems, Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector, Waste Incineration and the Reference Document on the General Principles of Monitoring
- a waste treatment installation covered in this document is only a part of the whole waste management chain. Issues occurring upstream and downstream of a waste treatment installation have a huge impact on the installation, consequently influencing their environmental performance
- overall waste management involves many different kinds of treatment operations (chains of operations) which will ultimately lead to recovery or disposal, actions which may be outside of the scope of this BREF. For instance, according to waste hierarchy, operations aiming for recovery prevail over disposal. However, it has been reported that in certain situations this hierachy may not be the best environmental choice especially when the effect on a complete waste management chain (outside of the scope of this document) is taken into account. These considerations, together with non-environmental aspects, can influence the choice of waste treatment applied.

Some aids to understand the remainder of this chapter
In this chapter, the BAT conclusions for the waste treatment sector are set out on two levels. Section 5.1 deals with generic BAT conclusions, i.e. these are generally applicable to the whole sector. If there are exceptions when the BAT is not applicable in certain circumstances or cases, this issue is mentioned in the BAT conclusion. Section 5.2 contains more specific BAT conclusions, e.g. those for the various types of specific processes and activities defined in the scope. So, BAT for any specific type of waste treatment facility is the combination of the non-activity specific elements applied to waste treatment (generic or common issues) and the activity specific elements applicable to the particular case and the other BREFs mentioned above. Emission values associated to the use of BAT in this chapter correspond to daily averages.

Due to the huge variation in the different types of wastes that are covered in this document, it is practically impossible to consider all the differences that may be found in the EU. For this reason, wastes are categorised into two types in this chapter. One deals with non-hazardous waste which represents the general basis for BAT for the waste sector. The other type corresponds to more dangerous waste (e.g hazardous waste) where further measures may be included as BAT. *To help the user/reader, BAT related to hazardous waste have been presented in italics.*

Particularly for this document, BAT is described as qualitative and mainly based on current practice. This is due to the lack of information on quantification of environmental performance parameters (e.g. emissions, consumptions) due to the fact that the majority of information provided corresponds to emission limit values applied in certain countries or regions.

5.1 Generic BAT

Environmental management
These are techniques related to the continuous improvement of environmental performance. They provide the framework for ensuring the identification, adoption and adherence to BAT options that nevertheless remain important and can play a role in improving environmental performance of the installation. Indeed, these good house housekeeping/management techniques/tools often prevent emissions.

A number of environmental management techniques are determined as BAT. The scope (e.g. level of detail) and nature of the Environmental Management System (EMS) (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have. BAT is to:

1. implement and adhere to an EMS that incorporates, as appropriate to individual circumstances, the following features (see Section 4.1.2.8).
    a. definition of an environmental policy for the installation by top management (commitment of the top management is regarded as a precondition for a successful application of other features of the EMS)
    b. planning and establishing the necessary procedures
    c. implementation of the procedures, paying particular attention to
        - structure and responsibility
        - training, awareness and competence
        - communication
        - employee involvement
        - documentation
        - efficient process control
        - maintenance programme
        - emergency preparedness and response
        - safeguarding compliance with environmental legislation.
    d. checking performance and taking corrective action, paying particular attention to
        - monitoring and measurement (see also the Reference document on General Principles of Monitoring)
        - corrective and preventive action
        - maintenance of records
        - independent (where practicable) internal auditing in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained.
    e. review by top management.

Three further features, which can complement the above stepwise, are considered as supporting measures. However, their absence is generally not inconsistent with BAT. These three additional steps are:

   f. having the management system and audit procedure examined and validated by an accredited certification body or an external EMS verifier
   g. preparation and publication (and possibly external validation) of a regular environmental statement describing all the significant environmental aspects of the installation, allowing for year-by-year comparison against environmental objectives and targets as well as with sector benchmarks as appropriate
   h. implementation and adherence to an internationally accepted voluntary system such as EMAS or EN ISO 14001:1996. This voluntary step could give higher credibility to the EMS. In particular EMAS, which embodies all the above-mentioned features, gives higher credibility. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

Specifically for this industry sector, it is also important to consider the following potential features of the EMS:

   i. giving consideration to the environmental impact from the eventual decommissioning of the unit at the stage of designing a new plant
   j. giving consideration to the development of cleaner technologies
   k. where practicable, sectoral benchmarking on a regular basis, including energy efficiency and energy conservation activities, choice of input materials, emissions to air, discharges to water, consumption of water and generation of waste.

2. ensure the provision of full details of the activities carried out on-site. A good detail of that is contained in the following documentation (see Section 4.1.2.7 and related to BAT number 1.g)
   a. descriptions of the waste treatment methods and procedures in place in the installation
   b. diagrams of the main plant items where they have some environmental relevance, together with process flow diagrams (schematics)
   c. details of the chemical reactions and their reaction kinetics/energy balance
   d. details on the control system philosophy and how the control system incorporates the environmental monitoring information
   e. details on how protection is provided during abnormal operating conditions such as momentary stoppages, start-ups, and shutdowns
   f. an instruction manual
   g. an operational diary (related to BAT number 3)
   h. an annual survey of the activities carried out and the waste treated. The annual survey should also contain a quarterly balance sheet of the waste and residue streams, including the auxiliary materials used for each site (related to BAT number 1.g).

3. have a good housekeeping procedure in place, which will also cover the maintenance procedure, and an adequate training programme, covering the preventive actions that workers need to take on health and safety issues and environmental risks (see Sections 4.1.1.4, 4.1.1.5, 4.1.2.5, 4.1.2.10, 4.1.4.8 and 4.1.4.3)

4. try to have a close relationship with the waste producer/holder in order that the customers sites implement measures to produce the required quality of waste necessary for the waste treatment process to be carried out (see Section 4.1.2.9)

5. have sufficient staff available and on duty with the requisite qualifications at all times. All personnel should undergo specific job training and further education (see Section 4.1.2.10. This is also related to BAT number 3)

Waste IN

To improve the knowledge of the waste IN, BAT is to:

6. have a concrete knowledge of the waste IN. Such knowledge needs to take into account the waste OUT, the treatment to be carried out, the type of waste, the origin of the waste, the procedure under consideration (see BAT number 7 and 8) and the risk (related to waste OUT and the treatment) (see Section 4.1.1.1). Guidance on some of these issues is provided in Sections 4.2.3, 4.3.2.2 and 4.4.1.2

7. implement a pre-acceptance procedure containing at least the following items (see Section 4.1.1.2):
    a. tests for the incoming waste with respect to the planned treatment
    b. making sure that all necessary information is received on the nature of the process(es) producing the waste, including the variability of the process. The personnel having to deal with the pre-acceptance procedure need to be able due to his profession and/or experience to deal with all necessary questions relevant for the treatment of the wastes in the WT facility
    c. a system for providing and analysing a representative sample(s) of the waste from the production process producing such waste from the current holder
    d. a system for carefully verifying, if not dealing directly with the waste producer, the information received at the pre-acceptance stage, including the contact details for the waste producer and an appropriate description of the waste regarding its composition and hazardousness
    e. making sure that the waste code according to the European Waste List (EWL) is provided
    f. identifying the appropriate treatment for each waste to be received at the installation (see Section 4.1.2.1) by identifying a suitable treatment method for each new waste enquiry and having a clear methodology in place to assess the treatment of waste, that considers the physico-chemical properties of the individual waste and the specifications for the treated waste.

8. implement an acceptance procedure containing at least the following items (see Section 4.1.1.3):
    a. a clear and specified system allowing the operator to accept wastes at the receiving plant only if a defined treatment method and disposal/recovery route for the ouput of the treatment is determined (see pre-acceptance in BAT number 7). Regarding the planning for the acceptance, it needs to be guaranteed that the necessary storage (see Section 4.1.4.1), treatment capacity and dispatch conditions (e.g. acceptance criteria of the output by the other installation) are also respected
    b. measures in place to fully document and deal with acceptable wastes arriving at the site, such as a pre-booking system, to ensure e.g. that sufficient capacity is available
    c. clear and unambiguous criteria for the rejection of wastes and the reporting of all non conformances
    d. a system for identifying the maximum capacity limit of waste that can be stored at the facility (related to BAT number 10.b, 10.c, 27 and 24.f)
    e. visually inspect the waste IN to check compliance with the description received during the pre-acceptance procedure. *For some liquid and hazardous waste, this BAT is not applicable* (see Section 4.1.1.3).

9. implement different sampling procedures for all different incoming waste vessels delivered in bulk and/or containers. These sample procedures may contain the following items (see Section 4.1.1.4):
    a. sampling procedures based on a risk approach. Some elements to consider are the type of waste (e.g. *hazardous* or non-hazardous) and the knowledge of the customer (e.g. waste producer)
    b. check on the relevant physico-chemical parameters. The relevant parameters are related to the knowledge of the waste needed in each case (see BAT number 6)

- c. registration of all waste materials
- d. have different sampling procedures for bulk (liquid and solids), large and small containers and laboratory smalls. The number of samples taken should increase with the number of containers. In extreme situations, small containers must all be checked against the accompanying paperwork. The procedure should contain a system for recording the number of samples and degree of consolidation
- e. details of the sampling of wastes in drums within designated storage, e.g. the time-scale after receipt
- f. sample prior to acceptance
- g. maintenance of a record at the installation of the sampling regime for each load, together with a record of the justification for the selection of each option
- h. a system for determining and recording:
  - a suitable location for the sampling points
  - the capacity of the vessel sampled (for samples from drums, an additional parameter would be the total number of drums)
  - the number of samples and degree of consolidation
  - the operating conditions at the time of sampling.
- i. a system to ensure that the waste samples are analysed (see Section 4.1.1.5)
- j. in the case of cold ambient temperatures, a temporary storage may be needed in order to allow sampling after defrosting. This may affect the applicability of some of the above items in this BAT (see Section 4.1.1.5).

10. have a reception facility covering at least the following issues (see Section 4.1.1.5):
    - a. have a laboratory to analyse all the samples at the speed required by BAT. Typically this requires having a robust quality assurance system, quality control methods and maintaining suitable records for storing the analyses results. *Particularly for hazardous wastes, this often means that the laboratory needs to be on-site*
    - b. have a dedicated quarantine waste storage area as well as written procedures to manage non-accepted waste. If the inspection or analysis indicates that the wastes fail to meet the acceptance criteria (including, e.g. damaged, corroded or unlabelled drums) then the wastes can be temporarily stored there safely. Such storage and procedures should be designed and managed to promote the rapid management (typically a matter of days or less) to find a solution for that waste
    - c. have a clear procedure dealing with wastes where inspection and/or analysis prove that they do not fulfil the acceptance criteria of the plant or do not fit with the waste description received during the pre-acceptance procedure. The procedure should include all measures as required by the permit or national/international legislation to inform competent authorities, to safely store the delivery for any transition period or to reject the waste and send it back to the waste producer or to any other authorised destination
    - d. move waste to the storage area only after acceptance of the waste (related to BAT number 8)
    - e. mark the inspection, unloading and sampling areas on a site plan
    - f. have a sealed drainage system (related to BAT number 63)
    - g. a system to ensure that the installation personnel who are involved in the sampling, checking and analysis procedures are suitably qualified and adequately trained, and that the training is updated on a regular basis (related to BAT number 5)
    - h. the application of a waste tracking system unique identifier (label/code) to each container at this stage. The identifier will contain at least the date of arrival on-site and the waste code (related to BAT number 9 and 12).

Waste OUT

To improve the knowledge of the waste OUT, BAT is to:

11. analyse the waste OUT according to the relevant parameters important for the receiving facility (e.g. landfill, incinerator) (see Section 4.1.1.1)

Management systems

BAT is to:

12. have a system in place to guarantee the traceability of waste treatment. Different procedures may be needed to take into account the physico-chemical properties of the waste (e.g. liquid, solid), type of WT process (e.g. continuous, batch) as well as the changes that may occur to the physico-chemical properties of the wastes when the WT is carried out. A good traceability system contains the following items (see Section 4.1.2.3):
    a. documenting the treatments by flow charts and mass balances (see Section 4.1.2.4 and this is also related to BAT number 2.a)
    b. carrying out data traceability through several operational steps (e.g pre-acceptance/acceptance/storage/treatment/dispatch). Records can be made and kept up-to-date on an ongoing basis to reflect deliveries, on-site treatment and dispatches. Records are typically held for a minimum of six months after the waste has been dispatched
    c. recording and referencing the information on waste characteristics and the source of the waste stream, so that it is available at all times. A reference number needs to be given to the waste and needs to be obtainable at any time in the process to enable the operator to identify where a specific waste is in the installation, the length of time it has been there and the proposed or actual treatment route
    d. having a computer database/series of databases, which are regularly backed up. The tracking system operates as a waste inventory/stock control system and includes: date of arrival on-site, waste producer details, details on all previous holders, an unique identifier, pre-acceptance and acceptance analysis results, package type and size, intended treatment/disposal route, an accurate record of the nature and quantity of wastes held on-site including all hazards details on where the waste is physically located in relation to a site plan, at which point in the designated disposal route the waste is currently positioned
    e. only moving drums and other mobile containers between different locations (or loaded for removal off site) under instructions from the appropriate manager, ensuring that the waste tracking system is amended to record these changes (see Section 4.1.4.8).

13. have and apply mixing/blending rules oriented to restrict the types of wastes that can be mixed/blended together in order to avoid increasing pollution emission of down-stream waste treatments. These rules need to consider the type of waste (e.g. *hazardous,* non-hazardous), waste treatment to be applied as well as the following steps that will be carried out to the waste OUT (see Section 4.1.5)

14. have a segregation and compatibility procedure in place (see Section 4.1.5 and this is also related to BAT number 13 and 24.c), including:
    a. keeping records of the testing, including any reaction giving rise to safety parameters (increase in temperature, generation of gases or raising of pressure); a record of the operating parameters (viscosity change and separation or precipitation of solids) and any other relevant parameters, such as generation of odours (see Sections 4.1.4.13 and 4.1.4.14)
    b. packing containers of chemicals into separate drums based on their hazard classification. Chemicals which are incompatible (e.g. oxidisers and flammable liquids) should not be stored in the same drum (see Section 4.1.4.6).

15. have an approach for improving waste treatment efficiency. This typically includes the finding of suitable indicators to report WT efficiency and a monitoring programme (see Section 4.1.2.4 and this is also related to BAT number 1)

16. produce a structured accident management plan (see Section 4.1.7)

17. have and properly use an incident diary (see Section 4.1.7 and related to BAT number 1 and to quality management system)

18. have a noise and vibration management plant in place as part of the EMS (see Section 4.1.8 and this is also related to BAT number 1). For some WT installations, noise and vibration may not be an environmental problem

19. consider any future decommissioning at the design stage. For existing installations and where decommissioning problems are identified, put a programme to minimise these problems in place (see Section 4.1.9 and this is also related to BAT number 1.i).

Utilities and raw material management

BAT is to:

20. provide a breakdown of the energy consumption and generation (including exporting) by the type of source (i.e. electricity, gas, liquid conventional fuels, solid conventional fuels and waste) (see Section 4.1.3.1 and related to BAT number 1.k). This involves:
    a. reporting the energy consumption information in terms of delivered energy
    b. reporting the energy exported from the installation
    c. providing energy flow information (for example, diagrams or energy balances) showing how the energy is used throughout the process.

21. continuously increase the energy efficiency of the installation, by (see Section 4.1.3.4):
    a. developing an energy efficiency plan
    b. 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
    c. defining and calculating the specific energy consumption of the activity (or activities), setting key performance indicators on an annual basis (e.g. MWh/tonne of waste processed) (related to BAT number 1.k and 20).

22. carry out an internal benchmarking (e.g. on an annual basis) of raw materials consumption (related to BAT number 1.k). Some applicability limitations have been identified and these are mentioned in Section 4.1.3.5

23. explore the options for the use of waste as a raw material for the treatment of other wastes (see Section 4.1.3.5). If waste is used to treat other wastes, then to have a system in place to guarantee that the waste supply is available. If this cannot be guaranteed, a secondary treatment or other raw materials should be in place in order to avoid any unnecessary waiting treatment time (see Section 4.1.2.2)

Storage and handling

BAT is to:

24. apply the following techniques related to storage (see Section 4.1.4.1):
    a. locating storage areas:
        - away from watercourses and sensitive perimeters, and
        - in such a way so as to eliminate or minimise the double handling of wastes within the installation
    b. ensuring that the storage area drainage infrastructure can contain all possible contaminated run-off and that drainage from incompatible wastes cannot come into contact with each other
    c. using a dedicated area/store which is equipped with all necessary measures related to the specific risk of the wastes for sorting and repackaging laboratory smalls or similar waste. These wastes are sorted according to their hazard classification, with due consideration for any potential incompatibility problems and then repackaged. After that, they are removed to the appropriate storage area
    d. handling odorous materials in fully enclosed or suitably abated vessels and storing them in enclosed buildings connected to abatement
    e. ensuring that all connections between the vessels are capable of being closed via valves. Overflow pipes need to be directed to a contained drainage system (i.e. the relevant bunded area or another vessel)

   f. having measures available to prevent the building up of sludges higher than a certain level and the emergence of foams that may affect such measures in liquid tanks, e.g. by regularly controlling the tanks, sucking out the sludges for appropriate further treatment and using anti-foaming agents
   g. equipping tanks and vessels with suitable abatement systems when volatile emissions may be generated, together with level meters and alarms. These systems need to be sufficiently robust (able to work if sludge and foam is present) and regularly maintained
   h. storing organic waste liquid with a low flashpoint under a nitrogen atmosphere to keep it inertised. Each storage tank is put in a waterproof retention area. Gas effluents are collected and treated.

25. separately bund the liquid decanting and storage areas using bunds which are impermeable and resistant to the stored materials (see Section 4.1.4.4)

26. apply the following techniques concerning tank and process pipework labelling (see Section 4.1.4.12):
    a. clearly labelling all vessels with regard to their contents and capacity, and applying an unique identifier. Tanks need to have an appropriately labelled system depending on their use and contents
    b. ensuring that the label differentiates between waste water and process water, combustible liquid and combustible vapour and the direction of flow (i.e. in or outflow)
    c. keeping records for all tanks, detailing the unique identifier; capacity; its construction, including materials; maintenance schedules and inspection results; fittings; and the waste types which may be stored/treated in the vessel, including flashpoint limits.

27. take measures to avoid problems that may be generated from the storage/accumulation of waste. This may conflict with BAT number 23 when waste is used as a reactant (see Section 4.1.4.10)

28. apply the following techniques when handling waste (see Section 4.1.4.6):
    a. having systems and procedures in place to ensure that wastes are transferred to the appropriate storage safely
    b. having in place a management system for the loading and unloading of waste in the installation, which also takes into consideration any risks that these activities may incur. Some options for this include ticketing systems, supervision by site staff, keys or colour-coded points/hoses or fittings of a specific size
    c. ensuring that a qualified person attends the waste holder site to check the laboratory smalls, the old original waste, waste from an unclear origin or undefined waste (especially if drummed), to classify the substances accordingly and to package into specific containers. In some cases, the individual packages may need to be protected from mechanical damage in the drum with fillers adapted to the packaged waste properties
    d. ensuring that damaged hoses, valves and connections are not used
    e. collecting the exhaust gas from vessels and tanks when handling liquid waste
    f. unloading solids and sludge in closed areas which are fitted with extractive vent systems linked to abatement equipment when the handled waste can potentially generate emission to air (e.g. odours, dust, VOCs) (see Section 4.1.4.7)
    g. using a system to ensure the bulking of different batches only takes place with compatibility testing (see Section 4.1.4.7 and 4.1.5 and this is also related to BAT number 13, 14 and 30).

29. ensure that the bulking/mixing to or from packaged waste only takes place under instruction and supervision and is carried out by trained personnel. For certain types of wastes, such a bulking/mixing needs to be carried out under local exhaust ventilation (see Section 4.1.4.8)

30. ensure that chemical incompatibilities guide the segregation required during storage (see Section 4.1.4.13 and 4.1.4.14 and this is also related to BAT number 14)

31. apply the following techniques when containerised wastes are handled (see Section 4.1.4.2):
    a. storing of containerised wastes under cover. This can also be applied to any container that is held in storage pending sampling and emptying. Some exceptions on the applicability of this technique related to containers or waste not affected by ambient conditions (e.g. sunlight, temperature, water) have been identified (see Section 4.1.4.2). Covered areas need to have adequate provision for ventilation
    b. maintaining the availability and access to storage areas for containers holding substances that are known to be sensitive to heat, light and water, under cover and protected from heat and direct sunlight.

Other common techniques not mentioned above

BAT is to:

32. perform crushing, shredding and sieving operations in areas fitted with extractive vent systems linked to abatement equipment (see Section 4.1.6.1) when handling materials that can generate emission to air (e.g. odours, dust, VOCs)

33. perform crushing/shredding operations (see Sections 4.1.6.1 and 4.6) under full encapsulation and under an inert atmosphere for drums/containers containing flammable or highly volatile substances. This will avoid ignition. The inert atmosphere is to be abated

34. perform washing processes considering (see Section 4.1.6.2):
    a. identifying the washed components that may be present in the items to be washed (e.g. solvents)
    b. transfering washings to appropriate storage and then treating them in the same way as the waste from which they were derived
    c. using treated waste water from the WT plant for washing instead of fresh water. The resultant waste water can then be treated in the WWTP or re-used in the installation.

Air emission treatments

To prevent or control the emissions mainly of dust, odours and VOC and some inorganic compounds, BAT is to:

35. restrict the use of open topped tanks, vessels and pits by:
    a. not allowing direct venting or discharges to air by linking all the vents to suitable abatement systems when storing materials that can generate emissions to the air (e.g. odours, dust, VOCs) (see Section 4.1.4.5)
    b. keeping the waste or raw materials under cover or in waterproof packaging (see Section 4.1.4.5 and this is also related to BAT number 31.a)
    c. connecting the head space above the settlement tanks (e.g. where oil treatment is a pretreatment process within a chemical treatment plant) to the overall site exhaust and scrubber units (see Section 4.1.4.1).

36. use an enclosed system with extraction, or under depression, to a suitable abatement plant. This technique is especially relevant to processes which involve the transfer of volatile liquids, including during tanker charging/discharging (see Section 4.6.1)

37. apply a suitably sized extraction system which can cover the holding tanks, pretreatment areas, storage tanks, mixing/reaction tanks and the filter press areas, or to have in place a separate system to treat the vent gases from specific tanks (for example, activated carbon filters from tanks holding waste contaminated with solvents) (see Section 4.6.1)

38. correctly operate and maintain the abatement equipment, including the handling and treatment/disposal of spent scrubber media (see Section 4.6.11)

39. have a scrubber system in place for the major inorganic gaseous releases from those unit operations which have a point discharge for process emissions. Install a secondary scrubber unit to certain pretreatment systems if the discharge is incompatible, or too concentrated for the main scrubbers (see Section 4.6.11)

40. have leak detection and repair procedures in place in installations a) handling a large number of piping components and storage and b) compounds that may leak easily and create an environmental problem (e.g. fugitive emissions, soil contamination) (see Section 4.6.2). This may be seen as an element of the EMS (see BAT number 1)

41. reduce air emission to the following levels

Air parameter	**Emission levels associated to the use of BAT (mg/Nm^3)**
VOC	7 – 20[1]
PM	5 – 20

[1] For low VOC loads, the higher end of the range can be extended to 50

by using a suitable combination of preventive and/or abatement techniques (see Section 4.6). The techniques mentioned above in the BAT 'Air emission treatments' section (BAT numbers 35 – 41) also contribute to achieve these values

Waste water management

BAT is to:

42. reduce the water use and the contamination of water by (see Sections 4.1.3.6 and 4.7.1):
    a. applying site waterproofing and storage retention methods
    b. carrying out regular checks of the tanks and pits especially when they are underground
    c. applying separated water drainage according to the pollution load (roof water, road water, process water)
    d. applying a security collection basin
    e. performing regular water audits, with the aim of reducing water consumption and preventing water contamination
    f. segregating process water from rainwater (see Section 4.7.2 and this is also related to BAT number 46).

43. have procedures in place to ensure that the effluent specification is suitable for the on-site effluent treatment system or discharge (see Section 4.7.1)

44. avoid the effluent by-passing the treatment plant systems (see Section 4.7.1)

45. have in place and operate an enclosure system whereby rainwater falling on the processing areas is collected along with tanker washings, occasional spillages, drum washings, etc. and returned to the processing plant or collected in a combined interceptor (see Section 4.7.1)

46. segregrate the water collecting systems for potentially more contaminated waters from less contaminated water (see Section 4.7.2)

47. have a full concrete base in the whole treatment area, that falls to internal site drainage systems which lead to storage tanks or to interceptors that can collect rainwater and any spillage. Interceptors with an overflow to sewer usually need automatic monitoring systems, such as pH checks, which can shut down the overflow (see Section 4.1.3.6 and this is also related to BAT number 63),

48. collect the rainwater in a special basin for checking, treatment if contaminated and further use (see Section 4.7.1)

49. maximise the re-use of treated waste waters and use of rainwater in the installation (see Section 4.7.1)

50. conduct daily checks on the effluent management system and to maintain a log of all checks carried out, by having a system for monitoring the effluent discharge and sludge quality in place (see Section 4.7.1)

51. firstly identify waste waters that may contain hazardous compounds (e.g. adsorbable organically bound halogens (AOX); cyanides; sulphides; aromatic compounds; benzene or hydrocarbons (dissolved, emulsified or undissolved); and metals, such as mercury, cadmium, lead, copper, nickel, chromium, arsenic and zinc) (see Section 4.7.2). Secondly, segregate the previously identified waste water streams on-site and thirdly, specifically treat waste water on-site or off-site.

52. ultimately after the application of BAT number 42, select and carry out the appropriate treatment technique for each type of waste water (see Section 4.7.1)

53. implement measures to increase the reliability with which the required control and abatement performance can be carried out (for example, optimising the precipitation of metals) (see Section 4.7.1)

54. identify the main chemical constituents of the treated effluent (including the make-up of the COD) and to then make an informed assessment of the fate of these chemicals in the environment (see Section 4.7.1 and their applicability restrictions identified)

55. only discharge the waste water from its storage after the conclusion of all the treatment measures and a subsequent final inspection (see Section 4.7.1)

56. achieve the following water emission values before discharge

Water parameter	Emission values associated with the use of BAT (ppm)
COD	20 – 120
BOD	2 – 20
Heavy metals (Cr, Cu, Ni, Pb, Zn)	0.1 – 1
Highly toxic heavy metals:	
As	<0.1
Hg	0.01 – 0.05
Cd	<0.1 – 0.2
Cr(VI)	<0.1 – 0.4

by applying a suitable combination of techniques mentioned in Sections 4.4.2.3 and 4.7. The techniques mentioned above in this section on ‘waste water management’ (BAT number 42 – 55) also contribute to reach these values.

Management of the process generated residues

BAT is to:

57. have a residue management plan (see Section 4.8.1) as part of the EMS including:
    a. basic housekeeping techniques (related to BAT number 3)
    b. internal benchmarking techniques (see Section 4.1.2.8 and this is also related to BAT numbers 1.k and 22).

58. maximise the use of re-usable packaging (drums, containers, IBCs, palettes, etc.) (see Section 4.8.1)

59. re-use drums when they are in a good working state. In other cases, they are to be sent for appropriate treatment (see Section 4.8.1)

60. keep a monitoring inventory of the waste on-site by using records of the amount of wastes received on-site and records of the wastes processed (see Section 4.8.3 and this is also related to BAT number 27)

61. re-use the waste from one activity/treatment possibly as a feedstock for another (see Section 4.1.2.6 and this is also related to BAT number 23)

Soil contamination

To prevent soil contamination, BAT is to:

62. provide and then maintain the surfaces of operational areas, including applying measures to prevent or quickly clear away leaks and spillages, and ensuring that maintenance of drainage systems and other subsurface structures is carried out (see Section 4.8.2)

63. utilise an impermeable base and internal site drainage (see Section 4.1.4.6, 4.7.1 and 4.8.2)

64. reduce the installation site and minimise the use of underground vessels and pipework (see Section 4.8.2 and this is also related to BAT number 10.f, 25, and 40)

5.2 BAT for specific types of waste treatments

This section presents the BAT elements for each process/activity covered in this document. It has been structured in a similar way as previous chapters.

Biological treatments
BAT is to:

65. use the following techniques for storage and handling in biological systems (see Section 4.2.2):
    a. for less odour-intensive wastes, use automated and rapid action doors (opening times of the doors being kept to a minimum) in combination with an appropriate exhaust air collection device resulting in an under pressure in the hall
    b. for highly odour-intensive wastes, use closed feed bunkers constructed with a vehicle sluice
    c. house and equip the bunker area with an exhaust air collection device.

66. adjust the admissible waste types and separation processes according to the type of process carried out and the abatement technique applicable (e.g. depending on the content of non-biodegradable components) (see Section 4.2.3)

67. use the following techniques when applying anaerobic digestion (see Sections 4.2.4 and 4.2.5):
    a. application of a close integration between the process with the water management
    b. a recycling of the maximum amount of waste water to the reactor. See some operational issues that may appear when applying this technique in Section 4.2.4
    c. operate the system under thermophilic digestion conditions. For certain types of wastes, thermophilic conditions cannot to be reached (see Section 4.2.4)
    d. measure TOC, COD, N, P and Cl levels in the inlet and outlet flows. When a better control of the process is required, or a better quality of the waste OUT, more parameters are necessary for measuring and controlling
    e. maximise the production of biogas. This technique needs to consider the effect on the digestate and biogas quality.

68. reduce the air emissions of the exhaust gas when using biogas as a fuel by restricting the emissions of dust, NO_x, SO_x, CO, H_2S and VOC by using an appropriate combination of the following techniques (see Section 4.2.6):
    a. scrubbing the biogas with iron salts
    b. using de-NO_x techniques such as SCR
    c. using a thermal oxidation unit
    d. using activated carbon filtration.

69. improve the mechanical biological treatments (MBT) by (see Sections 4.2.2, 4.2.3, 4.2.8, 4.2.10, 4.6.23):
    a. using fully enclosed bioreactors
    b. avoiding anaerobic conditions during aerobic treatment by controlling the digestion and the air supply (by using a stabilised air circuit) and by adapting the aeration to the actual biodegradation activity
    c. using water efficiently
    d. thermally insulating the ceiling of the biological degradation hall in aerobic processes
    e. minimising the exhaust gas production to levels of 2500 to 8000 Nm^3 per tonne. Levels below 2500 Nm^3 per tonne do not have been reported
    f. guaranteeing a uniform feed
    g. recycling process waters or muddy residues within the aerobic treatment process to completely avoid water emissions. If waste water is generated, then this should be treated to reach the values mentioned in BAT number 56

   h. continuously learning of the connection between the controlled variables of biological degradation and the measured (gaseous) emissions
   i. reducing emissions of nitrogen compounds by optimising the C:N ratio.

70. reduce the emissions from mechanical biological treatments to the following levels (see Section 4.2.12)

Parameter	Treated exhaust gas
Odour (ouE/m^3)	<500 – 6000
NH_3 (mg/Nm^3)	<1 – 20
For VOC and PM, see the generic BAT 41 The TWG recognised that N_2O (see Section 4.6.10) and Hg also needed to be added to this table, however not enough data were provided to validate values on these issues.	

   by using an appropriate combination of the following techniques (see Section 4.6):
   a. maintaining good housekeeping (related to BAT number 3)
   b. regenerative thermal oxidiser
   c. dust removal.

71. reduce the emissions to water to the levels mentioned in BAT number 56. In addition, restrict the emissions to water of total nitrogen, ammonia, nitrate and nitrite as well (see Section 4.7.7 and the concluding remarks Chapter 7)

Physico-chemical treatments

For the physico-chemical treatment of waste waters, BAT is to:

72. apply the following techniques in physico-chemical reactors (see Section 4.3.1.2):
   a. clearly defining the objectives and the expected reaction chemistry for each treatment process
   b. assessing each new set of reactions and proposed mixes of wastes and reagents in a laboratory-scale test prior to waste treatment
   c. specifically designing and operating the reactor vessel so that it is fit for its intended purpose
   d. enclosing all treatment/reaction vessels and ensuring that they are vented to the air via an appropriate scrubbing and abatement system
   e. monitoring the reaction to ensure that it is under control and proceeding towards the anticipated result
   f. preventing the mixing of wastes or other streams that contain metals and complexing agents at the same time (see Section 4.3.1.3).

73. in addition to the generic parameters identified for waste water in BAT number 56, additional parameters need to be idenfied for the physico-chemical treatment of waste waters. Some reference is given on this issue in the concluding remark Chapter 7.

74. apply the following techniques for the neutralisation process (see Section 4.3.1.3)
   a. ensuring that the customary measurement methods are used
   b. separately storing the neutralised waste water
   c. performing a final inspection of the neutralised waste water after a sufficient storage time has elapsed.

75. apply the following techniques to aid precipitation of the metals in treatment processes (see Section 4.3.1.4):
    a. adjusting the pH to the point of minimum solubility where the metals will precipitate
    b. avoiding the input of complexing agents, chromates and cyanides
    c. avoiding organic materials that may interfere with precipitation from entering the process
    d. allowing the resulting treated waste to clarify by decantation when possible, and/or by the addition of other dewatering equipment
    e. using sulphidic precipitation if complex agents are present. This technique may increase the sulphide concentration in the treated waste water.

76. apply the following techniques to break-up emulsions (see Section 4.3.1.5):
    a. testing for the presence of cyanides in the emulsions to be treated. If cyanides are present, the emulsions need a special pretreatment first
    b. setting up simulated laboratory tests.

77. apply the following techniques to oxidation/reduction (see Section 4.3.1.6):
    a. abating the air emissions generated during the oxidation/reduction
    b. having safety measures and gas detectors in place (e.g. suitable for detecting HCN, H_2S, NO_x).

78. apply the following techniques to waste waters containing cyanides (see Section 4.3.1.7):
    a. destroying the cyanides by oxidation
    b. adding caustic soda in excess to prevent a decrease in pH
    c. avoiding the mixing of cyanide wastes with acidic compounds
    d. monitoring the progress of the reaction using electropotentials.

79. apply the following techniques to waste waters containing chromium (VI) compounds (see Section 4.3.1.8):
    a. avoiding the mixing of Cr(VI) wastes with other wastes
    b. reducing Cr(VI) to Cr(III)
    c. precipitating the trivalent metal.

80. apply the following techniques to waste waters containing nitrites (see Section 4.3.1.9):
    a. avoiding mixing nitrite wastes with other wastes
    b. checking and avoiding nitrous fumes during the oxidation/acidification treatment of nitrites.

81. apply the following techniques to waste waters containing ammonia (see Section 4.3.1.11):
    a. using a dual column air stripping system with an acidic scrubber for waste with ammonia solutions up to 20 w/w-%
    b. recovering the ammonia in the scrubbers and returning it to the process prior to the settlement stage
    c. removing the ammonia removed in the gas phase by scrubbing the waste with sulphuric acid to produce ammonium sulphate
    d. extending any air sampling for ammonia in exhaust stacks or filter press areas to cover the VOCs in filtration and dewatering (see Section 4.3.1.12).

82. link the air space above filtration and dewatering processes to the main abatement system of the plant (see Section 4.3.1.12)

83. add flocculation agents to the sludge and waste water to be treated, to accelerate the sedimentation process and to facilitate the further separation of solids (see Section 4.3.1.16 for some applicability restrictions identified). To avoid use of flocculation agents, evaporation is better in those cases where it is economically viable (see Section 4.7.6.1)

84. apply rapid cleaning and steam- or high pressure water jet cleaning of the filter apertures of the sieving processes (see Section 4.3.1.17).

For the physico-chemical treatment of solid wastes, BAT is to:

85. promote the insolubilisation of amphoteric metals, and to reduce the leaching of toxic soluble salts by a suitable combination of water washing, evaporation, recrystallisation and acid extraction (see Section 4.3.2.1, 4.3.2.8, 4.3.2.9) when inmobilisation is used to treat solid waste containing hazardous compounds for landfilling

86. test the leachability of inorganic compounds, by using the standardised CEN leaching procedures and by applying the appropriate testing level: basic characterisation, compliance testing or on-site verification (see Section 4.3.2.2)

87. restrict the acceptance of wastes to be treated by solidification/immobilisation treatment to those not containing high levels of VOCs, odorous components, solid cyanides, oxidising agents, chelating agents, high TOC wastes and gas cylinders (see Section 4.3.2.3)

88. apply control and enclosure techniques for loading/unloading and enclosed conveyor systems (see Section 4.3.2.3)

89. have an abatement system(s) in place to handle the flow of air, as well as the peak loadings associated with charging and unloading (see Section 4.3.2.3)

90. use at least a solidification, vitrification, melting or fusion process before landfilling solid waste according to techniques in Sections from 4.3.2.4 to 4.3.2.7.

For the physico-chemical treatment of contaminated soil, BAT is to:

91. control the rate of excavation, the amount of contaminated soil area that is exposed, and the duration that soil piles are left uncovered during the excavation and removal of contaminated soil (see Section 4.3.2.10)

92. use a bench-scale test to determine the suitability of the process to be applied and the best operational conditions for its use (see Section 4.3.2.11)

93. have collection and control equipment in place such as afterburners, thermal oxidisers, fabric filters, activated carbon, or condensers for the treatment of the gases from thermal treatments (see Section 4.3.2.11)

94. report the efficiency achieved during the processes for the different components reduced and also for those that have not been affected by the process (see Section 4.3.2.3)

Recovery of materials from waste

For the re-refining of waste oils, BAT is to:

95. operate a careful control of the incoming materials supported by analytical equipment (viscometry, infrared, chromatography and mass spectrometry as appropriate), laboratories and resources (see Section 4.1.1.1)

96. check at least for chlorinated solvents and PCBs (see Sections 4.1.1.1 and 4.4.1.2)

97. use condensation as a treatment for the gas phase of the flash distillation unit (see Section 4.6.8)

98. have vapour return lines for loading and unloading vehicles, routing all vents to a thermal oxidiser/incinerator or an activated carbon adsorption installation (see Sections 4.1.4.6, 4.6.7 and 4.6.14)

99. direct vent streams to a thermal oxidiser with waste gas treatment if chlorinated species are present in the vent stream. If high levels of chlorinated species are present then condensation followed by caustic scrubbing and an activated carbon guard bed is the preferred treatment path (see Section 4.6)

100. utilise a thermal oxidation at 850 °C with a two seconds residence time for the vacuum distillation vent of vacuum generators or for the air from process heaters (see Section 4.6)

101. use a highly efficient vacuum system (see Section 4.4.1.1)

102. use the residues from vacuum distillation or thin film evaporators as asphalt products (see Section 4.4.1.15)

103. use a re-refining process of waste oil which can achieve a yield higher than 65 % on a dry basis (see Sections from 4.4.1.1 to 4.4.1.12)

104. achieve the following values in the discharged waste water from the re-refining unit (see Section 4.4.1.14):

Waste water parameter	**Concentration (ppm)**
Hydrocarbons	<0.01 – 5
Phenols	0.15 – 0.45
For other water parameters, refer to BAT number 56 in the Generic BAT section	

by using a suitable combination of process-integrated techniques and/or primary, secondary, biological and finishing treatments (see Sections 4.4.1.14 and 4.7).

For the treatment of waste solvent, BAT is to:

105. operate a careful control of the incoming materials as supported by analytical equipment, laboratories and resources (see Section 4.1.1.1)

106. evaporate the residue from the distillation columns and to recuperate the solvents (see Section 4.4.2.4)

For the regeneration of waste catalyst, BAT is to:

107. use bag filters to abate particulates from the fumes generated during the regeneration process (see Sections 4.4.3 and 4.6.5)

108. use a SO_x abatement system (see Section 4.4.3.3).

For the regeneration of waste activated carbon, BAT is to:

109. have an effective quality control procedure in place to ensure that the operator can differentiate between the carbon used for potable water or food grade carbon and the rest of spent carbons (the so-called ‘industrial carbons’) (see Section 4.4.4.2)

110. require a written undertaking from customers indicating what the activated carbon has been used for (see Section 4.1.2.3 and this is also related to BAT number 12.c)

111. utilise an indirect fired kiln for industrial carbons –it may be argued that this could equally be applied to potable water carbons. However, limits on capacity and corrosion may deem that only multiple hearth or direct fired rotary kilns may be used (see Section 4.4.4.1)

112. utilise an afterburner with a minimum of 1100 °C, two seconds residence time and 6 % excess oxygen for the regeneration of industrial carbons where refractory halogenated or other thermally resistant substances are likely to be present. In other cases, less stringent thermal conditions are sufficient (see Section 4.4.4.2)

113. utilise an afterburner with a minimum heating temperature of 850 °C, two seconds residence time and 6 % excess oxygen for potable water and food grade active carbons (see Section 4.4.4.2)

114. apply a flue-gas treatment train consisting of quench and/or venturi and aqueous scrubbing sections, followed by an induced draft fan (see Section 4.4.4.2)

115. utilise a caustic or soda ash scrubbing solutions to neutralise acid gases for industrial carbon plants (see Section 4.4.4.2)

116. have a WWTP containing an appropriate combination of flocculation, settlement, filtration and pH adjustment for the treatment of potable water carbons. For effluents of industrial carbons, applying additional treatments (e.g. metal hydroxide precipitation, sulphide precipitation) are also considered BAT (see Section 4.4.4.3)

Preparation of waste to be used as fuel

For the preparation of waste to be used as fuel, BAT is to:

117. try to have a close relationship with the waste fuel user in order that a proper transfer of the knowledge of the waste fuel composition is carried out (see Section 4.5.1)

118. have a quality assurance system to guarantee the characteristics of the waste fuel produced (see Section 4.5.1)

119. manufacture different type of waste fuels according to the type of user (e.g. cement kilns, different power plants), to the type of furnace (e.g. grate firing, blow feeding) and to the type of waste used to manufacture the waste (e.g. hazardous waste, municipal solid waste) (see Section 4.5.2)

120. when producing waste fuel from hazardous waste, use activated carbon treatment for low contaminated water and thermal treatment for highly polluted water (see Sections 4.5.6 and 4.7). In this context, thermal treatment relates to any thermal treatment in Section 4.7.6 or incineration which is not covered in this document

121. when producing waste fuel from hazardous waste, ensure correct follow-up of the rules concerning electrostatic and flammability hazards for safey reasons (see Sections 4.1.2.7 and 4.1.7)

For the preparation of solid waste fuels from non-hazardous waste, BAT is to:

122. visually inspect the incoming waste to sort out the bulky metallic or non-metallic parts. The purpose is to protect the plant against mechanical destruction (see Section 4.1.1.3 and this is also related to BAT 8.e)

123. use magnetic ferrous and non-ferrous metal separators. The purpose is to protect the pelletisers as well as fulfill the requirements of the final users (see Sections 4.5.3.3 and 4.5.3.4)

124. make use of the NIR technique for the sorting out of plastics. The purpose is the reduction of organic chlorine and some metals which are part of the plastics (see Section 4.5.3.10)

125. use a combination of shredder systems and pelletisers suitable for the preparation of the specified size waste fuel (see Sections 4.5.3.1 and 4.5.3.12)

For some installations preparing solid waste fuels from source-separated waste streams, the use of some or all of the above-mentioned techniques may not be necessary to comply with BAT (see Section 4.5.3.1)

For the <u>preparation of solid waste fuel from hazardous waste</u>, BAT is to:

126. *consider emissions and flammability hazards in case a drying or heating operation is required (see Sections 4.1.2.7 and 4.5.4.1)*

127. *consider carrying out the mixing and blending operations in closed areas with appropriate atmosphere control systems (see Sections 4.1.4.5, 4.5.4.1 and 4.6)*

128. *use bags filters for the abatement of particulates (see Section 4.6.26)*

For the <u>preparation of liquid waste fuels from hazardous waste</u>, BAT is to:

129. *use heat-exchange units external to the vessel if heating of the liquid fuel is required (Section 4.5.4.1)*

130. *adapt the suspended solid content to ensure the homogeneity of the liquid fuel (see Section 4.5.4.1)*

6 EMERGING TECHNIQUES

Emerging technique is understood in this document as a novel technique that has not yet been applied in any industrial sector on a commercial basis. This chapter contains those techniques that may appear in the near future and that may be applicable to the waste treatment sector.

[5, Concawe, 1996], [36, Viscolube, 2002], [30, Eklund, et al., 1997], [41, UK, 1991], [81, VDI and Dechema, 2002], [90, Rogut, 2003], [101, Greenpeace, 1998], [122, Eucopro, 2003], [132, UBA, 2003], [141, Magistrelli, et al., 2002], [150, TWG, 2004], [152, TWG, 2004], [154, UNEP, 2004]

On-line analysis

Description
The technique of the online-analysis is one of the latest developments on the field of analysis and quality assurance. It can be used for all applications in the field of preparation of solid recovered fuels.

On-line analysis is used for crushed and/or for non-crushed materials with automatically elimination of materials which do not comply with the quality criteria for e.g solid recovered fuels - especially when the chlorine- and/or bromine values are exceeded.

The mode of function is based on a new X-ray fluorescence-analysis with high speed analysis, so that a large quantity of crushed or not crushed materials (it depends on technical performance and determination) per hour can be analysed and/or detected and it can be automatically eliminate by overdraw nominal stock.

The configuration of the measuring unit and/or analyser takes place directly above a conveyor. A material stream as uniform as possible is directed under the measuring-unit and/or analyser and is analysed and/or measured.

If a limit-value is exceeded an electronically signal (digital or analogue) follows. There upon controlled through a software and/or electronics-unit the objectionable material is automatically (mechanically, hydraulically, pneumatically, electrostatically or magnetically magnetically) discharged. The measuring-unit and/or analyser can be equipped with one or more X-ray tubes or with one or more detectors.

As a additional control and quality assurance for the material input, also a handheld-unit can be used. The handheld-unit is also based on the X-ray fluorescence-method and it can ecspecially used for the analyse and/or detection from chlorine, bromine and heavymetals.

Achieved environmental benefits
Following elements can be analysed and detected with this tool (depending on equipment and software): Cl, Br, Cd, Hg, Pb, As, Se, Ni, Sb, Cu, Ba, Cr, Sn, Mo, Zn, Sr, Fe, Co, Ti, V, Rb, Ir, Pt, Au, Ag, Pd, Nb, W, Bi, Mn, Ta, Zr, Hf, Re.

Cross-media effects

Operational data
The tool is developed for the highest analyse quality under hardest attendance (dirt, rain, dust – are no problems!) The most fasted electronic deliver analyse quality as in the laboratory, nevertheless on the spot, measurement for measurement, equal what material, no standards or re-calibrations.

Applicability
This tool seems to be now the fastest and exact handheld analysis tool for practically all recycling metal – plastic – oldwood – glass – ground – waste – mud – non-ferrous metal.

Reference literature
[150, TWG, 2004]

Biological degradation times in MBT processes

The minimal biological degradation times required to comply with the landfill criteria with sufficient operational reliability will have to be determined by future experience with the new optimised MBT plants.

Immobilisation of heavy metal chlorides

A method for the stabilisation of heavy metals wastes generated in the fly ashes vitrification process is based on the batch conversion of heavy metal chlorides with ammonium dihydrogenphosphate ($NH_4H_2PO_4$). Conversion of heavy metal chlorides into phosphate and its immobilisation in phosphate glass matrix.

Ferrous sulphate stabilisation of FGT waste

Description
This stabilization involves a five-step procedure, where the solid material are first mixed with a $FeSO_4$ solution and then aerated with atmospheric air at L/S 3 l/kg in order to oxidise Fe(II) to Fe(III) and precipitate iron oxides. This step also includes extraction of soluble salts. The pH of the suspension is then maintained at pH 10 - 11 for about 0.5 to 1 hour to allow dissolved heavy metals to bind to the precipitated iron oxides. The fourth step of the process is dewatering and finally a washing step to exchange remaining water and remove remaining salts. The final stabilised product has a water content of about 50 %.

Achieved environmental benefits
The main advantage of this stabilization process is the improved leaching properties of the final product. The leaching characteristics of waste OUT are shown to be very good, and it is expected that low release of heavy metals can be maintained for extended periods of time, as iron oxides are known to endure in geological time frames. The pollution potential of the waste OUT is documented rather detailed and the waste OUT are expected to be less prone to physical disintegration than cement stabilised products because of the fact that most salts are removed. This process stabilises FGT waste and typically have far better leaching properties than cement solidified wastes. This process reduces the amount of waste OUT by about 10 % per dry weight.

Cross-media effects
No reutilization strategies have yet been demonstrated, however it has been suggested that the waste OUT can be utilised in road construction after thermal treatment in the combustion chamber of the incinerator. Research activities are currently addressing this issue.

The process produces waste water with high content of salts and relatively low concentrations of metals because Fe(II) is present in the extraction step. The waste water can in most cases be discharged to a marine recipient after a simple treatment or can be deionised by crystallization.

Operational data
The process has been demonstrated in pilot scale at a batch plant of about 200 kg dry weight. Parameters like water consumption, mixing of water and materials, Fe(II) oxidation rate, reaction time, pH and pH controlling additive have been optimised. It has been demonstrated that the process is robust with respect to the properties of the waste IN, although some variations in process parameters arise. Typical process data are for one tonne of waste IN: 10 - 50 kg Fe, 20 - 50 minutes aeration, 30 - 60 minutes reaction time, H_2SO_4 or $FeSO_4$ as pH controlling additive, optimum pH of 10 - 11, and a water consumption of 3 - 4 m^3. In the current setup, dewatering of the treated material was done with a plate and frame filter press.

Applicability

The stabilization unit can be implemented as an integrated part of the incinerator but may also exist as a centralised treatment plant handling residues from several incinerators. The technique has been demonstrated on semidry FGT waste as well as fly ash alone and fly ash combined with sludge from the wet scrubbers (Bamberg product); all with good results.

Economics

Treatment cost is estimated to about EUR 65/tonne with a plant capacity of 20000 tonne/year including investment costs.

Driving force for implementation

The main reason for implementing this technology is the very good leaching properties of the waste OUT and the fact that this is expected to last in a long-term perspective.

Example plants

The process has only been demonstrated in pilot scale, however it has also been designed in full-scale. No full-scale plants have yet been implemented.

Reference literature

[124, Iswa, 2003]

Carbon dioxide and phosphate stabilisation of FGT waste

Technical description

Chemical agents used here are CO_2 and/or H_3PO_4. This process involves a two-step procedure where the waste IN are first washed at L/S 3 l/kg in order to extract soluble salts. After this the material are dewatered and washed again in a plate and frame filter press at L/S 3 l/kg. The residues are then re-suspended, and CO_2 and/or H_3PO_4 is added. The stabilization reactions are allowed to occur for 1 - 1.5 hours while pH decreases, and another hour where pH is maintained around pH 7. Finally, the residues are dewatered again and washed at the filter press with another 3 l/kg. The final product has a water content of about 50 %. The use of CO_2 and H_3PO_4 as stabilizing agent ensures that heavy metals are bound as carbonates or phosphates.

Achieved environmental benefits

It shows very good leaching properties similar to the Ferrox stabilization. Metal carbonates and phosphates are known to generally have low solubilities, and the leaching characteristics of the waste OUT are expected to remain good for extended periods of time. The pollution potential of the waste OUT is documented rather detailed and physical disintegration of the waste OUT in a long-term perspective is expected to be less important than in the case of cement stabilization, because of the fact that most salts are removed. Waste OUTs typically have far better leaching properties than the ones treated with cement. The process reduces the amount of material by about 15 % per dry weight.

Cross-media effects

No reutilization strategies have yet been demonstrated. The process produces waste water from first dewatering step. All other process water is recycled in the process. The waste water needs to be treated for dissolved heavy metals in a standard unit, for example using pH adjustment and TMT addition.

Operational information

The process has been demonstrated in pilot scale at a batch plant of about 200 kg dry weight. Parameters like water consumption, mixing of water and solid material, CO_2 and H_3PO_4 addition, reaction time, pH and pH controlling approach have been optimised. It has been demonstrated that the process is robust with respect to the properties of the waste IN, although some variations in process parameters arise. Depending on waste IN composition, either CO_2 or

H_3PO_4 or both have been used. It has also been demonstrated that flue-gas can be used as CO_2 source.
Typical process data for 1 tonne of waste IN are: 5 - 20 kg of CO_2, 0 - 40 kg H_3PO_4 and 3 m^3 H_2O.

Applicability of technique
The stabilization unit can be implemented as an integrated part of the incinerator but may also exist as a centralised treatment plant handling residues from several incinerators. The technique has been demonstrated on semidry FGT waste as well as fly ash alone and fly ash combined with sludge from the wet scrubbers (Bamberg product); all with good results.

Economics
Treatment cost for stabilization is estimated to about EUR 80/tonne with a plant capacity of 20000 tonne/year; including investment costs.

Driving force of implementation
The main reason for implementing this technology is the very good leaching properties of the waste OUT and the fact that this is expected to last in a long-term perspective.

Examples
The process has only been demonstrated in pilot scale, however it has also been designed in full-scale. No full-scale plants have yet been implemented.

References
[124, Iswa, 2003], [152, TWG, 2004]

Emerging techniques for soil vapour extraction for soil remediation
Approaches such as microwave, radio frequency, and electrical heating have been tested at the pilot scale, but full-scale results are not yet available.

Phytoextraction of metals from the soil
In the field of environmental reclamation through biological process, the methodology known as phytoremediation has recently received mounting attention from operators in the field. Phytoremediation encompasses various techniques used for cleaning up both soil and water. For metal contaminated soil, phytoextraction represents one of the best solutions from the eco-environmental point of view. Through this technique, metals are absorbed and transported from the soil to the harvestable tissues of plants.

Treatments of waste contaminated with POPs
Such type of waste is actually mostly treated by incineration. However other types of technique are emerging as shown in next Table 6.1.

Technique	Comment
Base catalyzed dechlorination	Organochlorines are reacted with an alkaline polyethylene glycol, forming a glycol ether and/or a hydroxylated compound, which requires further treatment, and a salt. Dioxins have been identified in process residues. Destruction efficiencies are not high
Catalytic hydrogenation	Organochlorines are reacted with hydrogen in the presence of noble metal catalysts, yielding hydrogen chloride and light hydrocarbons.
Electrochemical oxidation	At low temperature and atmospheric pressure, electrochemically-generated oxidants react with organochlorines to form carbon dioxide, water and inorganic ions with high destruction efficiencies. All emissions and residues can be captured for assay and re-processing, if needed. An electrochemical cell is used to generate oxidising species at the anode in an acid solution, typically nitric acid. These oxidisers and the acid then attack any organic compounds, converting most of them to carbon dioxide, water and inorganic ions at low temperature (<80 °C) and atmospheric pressure. Compounds that have been destroyed by this process include aliphatic and aromatic hydrocarbons, phenols, organophosphorous and organosulphur compounds, and chlorinated aliphatic and aromatic compounds. Data describing concentrations in gaseous, liquid and solid residues of dioxins and other POPs potentially formed by this process were not available for review. No industrial application is currently known
Electron beam oxidation	
Mediated electro-chemical oxidation by cerium	This technique uses electrochemical cells for the generation of the active Cerium(IV) oxidant at the anode, a liquid phase reactor for primary organic destruction, a gas phase reactor to destroy any fugitive emissions from the liquid reactor and an acid gas scrubber for removal of acid gases prior to venting to the air. The process operates at low temperature (90 – 95 °C) and at atmosphere pressure
Mediated electro-chemical oxidation by silver	This process uses silver (II) to oxidise organic waste streams. Reactions take place in an electro-chemcial cell similar to the type utilised in the chlor-alkali industry. Thre process operates at low temperature (~90 °C) and at atmospheric pressure
Molten metal	Organochlorines and other materials are oxidised in a vat of molten metal, yielding hydrogen, carbon monoxide, ceramic slag and metal by-products. There is currently designing facilities for four commercial customers in US
Molten salt	Organochlorines and other materials are oxidised in a vat of molten salt, yielding carbon dioxide, water, molecular nitrogen, molecular oxygen, and neutral salts. Destruction efficiencies may be high. It is suitable for the destruction of pesticides but not for treatment of contaminated soils
Photocatalysis	Use light to activate a catalyst that oxidise/reduce the compounds. A wide range of compounds can be destroyed. Useful for liquid and gaseous wastes
Ultraviolet oxidation	

Table 6.1: Emerging destruction techniques of POPs
[101, Greenpeace, 1998], [150, TWG, 2004], [154, UNEP, 2004]

Emerging techniques for treatment of waste oil

Presently, around the world, there are many activities to improve the existing used oil recycling technologies and to develop new ones. Next table sumarises those techniques under development:

Technique	Comment
FILEA Process by C.E.A.	Supercritical CO_2 filtration
MRD solvent extraction	Solvent extraction of used oil vaccum distillates produced by TFE with a high efficient and selective solvent (e.g. NMP). Complete waste free technology with high efficiency and flexibility and production of high quality base oils. Their major advanges are: • quantitative reduction of PNAs to a level not achievable by any other re-refining technology (ppb level) • complete retention of the high valued synthetic base oil components more and more present in used oils resulting in very high qualities of the produced base oils. It is expected that a unit will be in operation in Germany by March 2005
New Meinken technology	It has been developed a new process applying a novel absorbent to vacuum distillates. The catalyst absorbent seems to be an activated clay. No industrial application is currently known
Probex Process)	
ROBYS^{TM} Process	Catalytic cracking and stabilisation for diesel production
Supercritical treatments	This technology applies to the deasphalting and also the fractionation. Pre-flash and hydrotreating do not change with respect to the standard assembly of a PDA unit. • *Supercritical Deasphalting:* the asphaltic fraction is separated by extraction with light hydrocarbons (C_2/C_3) under supercritical conditions. The clarified oil is separated from the extraction medium and fractionated in a standard column under vacuum conditions. • *Supercritical Fractionation:* the clarified oil from the supercritical deasphalting unit. still mixed with the extraction medium. is directly separated into two or more cuts by varying the physical conditions of the mixture. Both technologies reduce the investment and operating costs when compared with the standard PDA technologies (1 and 2 stages). Two independent pilot plant projects have been developed

Table 6.2: Waste oil treatment technologies under development
[5, Concawe, 1996], [36, Viscolube, 2002], [150, TWG, 2004]

Regeneration of activated carbon

	Stage of development
Activated carbon regeneration technologies	
Biological regeneration of spent activated carbon	Currently at the research and development stage
Oxidative regeneration	Currently at the research and development stage
Novel pollution control techniques for the abatement of emissions	
Circulating fluidised bed absorber	
Electrocatalytic oxidation of sulphur dioxide (the ELCOX process)	
Electrochemical processes	
Flue-gas irradiation	
Methanol injection	

Table 6.3: Emerging techniques that may be applied to activated carbon regeneration
[41, UK, 1991], [150, TWG, 2004]

Preparation of solid fuel from organic/water mixtures

The process consists in preparation of a fuel for the use in cement kilns. The process is the mixing of the organic-water mixtures with a lime hydrate porous structure in order to capture the organics and use such product as raw material in the cement industry. This technique is able to deal with clinical waste, municipal waste, hazardous/chemical waste and non-hazardous industrial and commercial waste.

Emerging techniques for hazardous waste preparation for energy recovery

New adsorbents for the preparation of solid waste fuel from hazardous waste. There is a permanent research for other absorbents in order to replace the fresh sawdust.

Cracking of polymer materials

Liquid or gaseous fuels like gasoils or heavy fuel oils can be also substituted with a prior step to crack the waste polymer into a liquid or a gas. Efforts in this field have mostly not progressed further than pilot scale tests.

7 CONCLUDING REMARKS

From the first meeting onwards, it has been difficult to have a common understanding within the TWG of which waste treatment activities need to be covered by this document. These different views on what should or should not be covered by this document have made the process more difficult and has probably restricted the development of the BAT chapter further (see ‘Recommendations for future work’ below).

There are some views that the scope of this document should cover all waste treatment installations now available in the waste sector. Their view was based on three rationales: first, the technical characteristics of such additional treatments are very similar if not equal to some of the treatments covered in this document; secondly they maintain that such issues may benefit the competitiveness of some waste treatments not covered by IPPC because such installations may be allowed to operate at less stringent environmental standards than required by BAT; and third it may be interpreted that because these treatments are not covered, no BAT can be determined and that they cannot run under BAT conditions. Scope of this document should not be interpreted as any attempt to interpret IPPC Directive or any waste legislation.

Annex I of the IPPC Directive lists the installations that are covered by the IPPC Directive. The installations are derived from the Recovery/Disposal (R/D) codes mentioned in the the Waste Framework Directive (75/442/EEC). However, it is difficult to distinguish between the R and the D codes ad they are so closely related. For example, there are waste treatments that are not covered when an ‘R’ treatment is carried out to a certain waste (e.g. aerobic digestion to produce compost) but covered when a ‘D’ treatment is carried out (e.g. aerobic digestion to landfill). This issue will create difficulties on the implementation of the Directive to certain waste treatment installations and may create market conflicts because some installations will be required to have an IPPC permit and others will not.

Some readers have tried to interpret the structure of the document as the tool to try to distinguish between some R and D codes. One example showing this can be the interpretation of R1, R9 and D10 codes for treatment of waste oils. There are two main options (see Section 2.4.1) for the treatment of waste oils. One is the re-refining of waste oil (covered in Section 2.4.1 under the section on recovery of materials) and the other one is the treatment of the waste oil to produce a material that will be mainly used as fuel. This latter option, in some cases, generates materials that can be used as naphthalene absorbant in coke oven gas cleaning, mould release oil or flotation oil. These treatments are covered in Section 2.5.2.4 when used as fuel. It must be stressed that this document does not in any way interpret any legislation.

Annex I of the IPPC Directive also makes the distintion for treatment of hazardous and non-hazardous waste. This issue creates an extra difficulty on a clear scope for this document as well as for the structure of this document. The point is that the same type of installations treating hazardous waste are included but not those treating non-hazardous waste.

Some information considered not to be within of the scope of this document has been included whereas other information provided has not been included at all (e.g. composting). In order to avoid confusion, it has been considered appropriate to maintain the information on these issues that were in the second draft but restricting such information from being included in Chapter 1 to Chapter 3. An example is the bottom ash (slag) treatment to be used as a construction material in Section 2.3.3.15. Some information provided was also agreed to be reviewed by some TWG members after the second TWG meeting. However, the TWG was not able to reach the deadline agreed at the meeting so the information is not available in this document. The information was related to pickling acid for waste water treatments, thermal purification sludge containing oil, thermal treatment of contaminated soil, treatment of blasting grit and treatment of asphalt containing tar.

Some information was given together with the comments to the second draft of this document (see timing of the work section below). As a consequence, there has not been enough time for a full peer review. This means that some techniques in Chapter 4 (e.g. Sections 4.1.4.11, 4.3.1.1, 4.3.1.19, 4.3.1.20, 4.3.1.21, 4.3.2.16, 4.3.3.3, 4.4.1.12, 4.4.2.1, 4.4.2.5, 4.5.2, 4.5.4.3) have not been properly peer reviewed and assessed to decide if they are elements of BAT for the sector. However, some of this new information is now included in the document. Some of this information was probably not provided earlier in the process because of the lack of clarity in the scope of the work. The information that is included in this category is some of the information that was provided by the Netherlands, Germany and Cefic.

This IPPC industrial sector is highly regulated and the terminology used is not the same throughout the EU. Moreover, there are different interpretations of the same wording in the different countries, especially that related to the qualification of Recovery and Disposal. To solve this difficulty, the glossary of this document plays an important role. It informs the user/reader in which sense each conflicting word identified by the TWG has been used in this document. This glossary should not be understood as an interpretation of any legislation and it may conflict with some national legislation definitions. To prevent some difficulties that have been encountered, this document has tried to use ‘neutral’ words with the intention to avoid waste related debates such as waste vs. non-waste, recovery vs. disposal, and hazardous vs. non-hazardous.

Techniques analysed in this document are the most relevant ones for the sector, however as is the case with all BREFs, they are restricted to the information provided.

Timing of the work

The work on this document started with the first plenary meeting of the TWG in February 2002. A first draft was issued in February 2003 followed by a second draft in January 2004. A final plenary meeting of the TWG was held in two sessions in Septerber and October 2004 after which the document was completed. All parts of this final document have thus been subjected to peer review by the TWG.

Sources of information

More than 150 items of information were used for the preparation of this document. Several reports from industry and MS authorities were used as main sources of information and assisted in the drafting, some of them were specifically prepared for this document. Only three Member States actively delivered documents. The others only provided some information when sending comments for the two drafts. The reports submitted mainly focused on specific waste treatments and some covered only some type of wastes, thus partially covering the WT sector. Complementary to that information, 35 site visits to eight EU countries (Austria, Belgium, Finland, France, Germany, Italy, the Netherlands and Spain), 10 meetings with permit writers and technology providers and attendance at six conferences were carried out. The formal consultations on drafts also prompted the submission of new and additional information, as well as providing opportunities for the TWG to verify information already submitted.

On the analysis of information provided, it needs to be emphasised that especially in the case of specific treatments, the core information came from one source. This issue meant that some of the sections of this document may be seen as representative for one country or as partial view of some TWG members. This has created criticism from a few TWG members that some conclusions are based on very little information or are not even representative of the entire EU sector. However, the BAT conclusions could only be achieved on information provided and rely on the expert judgement of the TWG.

110 experts form the TWG, 52 from EU Member States, 47 from Industry, two from Environmental NGO, two from non-Member States and seven from different services of the Commission. However, the attendance at the second TWG meeting was low considering the number of TWG members. Some MSs chose not to participate in the final meeting.

Degree of consensus reached

The conclusions of the work were agreed at the final plenary meeting in September – October 2004 and a high level of consensus was reached. There was full agreement on all the BAT conclusions as presented in this document. However, it needs to be emphasised that there is disagreement from Industry (except one Industry association) and one Member State on the scope of this document (see also first paragraphs of the Concluding remarks chapter). They claim that the coverage of this document should be enlarged to cover the entire WT sector ignoring whether the treatment is formally covered by IPPC or not. Their view was based on the developments on the waste sector since the Waste Framework and IPPC Directives were issued as well as market distorsions that may be generated because only a part of the sector is covered. Composting installations were mentioned as a good illustrative example on the previous points.

Recommendations for future work

The information exchange and the result of this exchange, i.e. this document, present an important step forward in achieving the integrated prevention and control of pollution from the waste treatment industry. On a few topics, however, the information is incomplete and did not allow BAT conclusions to be reached. As a consequence, this is considered as an important issue to focus on during the revision of this document. Future work could usefully focus on collecting the following information:

1. clarification and enlargement of the scope to include the majority, if not all, of the waste treatment activities. It would be advisable to clarify the installations to be covered by IPPC and to restrict the use of R/D codes as well as reference to hazardous and non-hazardous waste. Some waste treatments highlighted that may be good candidates for enlarging the scope of this document have been composting, end-of-life materials (including vehicles, fridges, electronic waste, cathode ray tubes, glass preparation, fluorescents containing mercury, batteries, switches) and treatment of slag from combustion processes (e.g. from incineration) to be used for example as construction material. As a consequence of such a decision, this actual document does not contain specific BAT for such processes. However, it needs to be noted that some of these processes are relatively similar to some of the processes already covered

2. on-site remediation is not included in this document because it was seen to be outside the scope of IPPC. Clarification as to whether on-site remediation needs to be covered by this document has been proposed.

3. the document does not give guidance of what ‘dilution’ is considered to be. A better analysis of what is understood by ‘dilution’ is required as this can have a big impact on other waste policies. However, at the same time it should be determined whether this guidance is possible to be given under the framework of the IPPC Directive because, as is mentioned in the Scope chapter, IPPC focuses on installations and not the full chain of waste management. It may be possible that when analysing ‘dilution’, other considerations outside the scope of IPPC may be taken into account

4. there is a shortage of current consumption and emission levels and on the performance of techniques to be considered in the determination of BAT. This was generally true throughtout the whole document. Thus, it is proposed to collect data on this issue to generate a better base document and enlarge the BAT chapter

5. this document does not include emission levels associated with the use of BAT for physico-chemical treatment of waste waters. These waste streams have some of the largest volumes in Europe, however there is a lack of identification of values for these treatments. The number of generic waste water parameters identified (i.e. COD, BOD and heavy metals) for this sector are considered to be insufficient for this particular treatment

6. some lack of information have been identified on some issues covered by this document and some have limited the BAT conclusions. These are:

   - off-site remediation treatments
   - mixing and blending treatments. This issue is identified as very important in the sector but it has not been well developed. The BAT chapter lacks further conclusions on this issue
   - emission levels when biogas is used as the fuel (some information is actually available in the LCP BREF for installations larger than 50 MWth)
   - waste water emission levels from biological treatments
   - dioxins, nitrous oxide and mercury emission levels to the air from mechanical biological treatments. One member state considered important to include the dioxins parameter in table of BAT 70 of Chapter 5
   - destruction of POPs. Basel convention provides technical guidelines for environmental sound management of waste consisting of, containing or contaminated with PCBs, PCTs and PBBs
   - treatments of waste containing mercury
   - treatment of asbestos
   - recovery of components from abatement techniques.

Suggested topics for future R&D projects
The information exchange has also exposed some areas where additional useful knowledge could be gained from research and development projects. These relate to the following subjects:

- studies to build on the knowledge of the definition of dilution
- clarify the distinction between Recovery and Disposal of waste and to define, if possible, the stage where recovery is completed and when the waste turns into a tradeable product.

The EC is launching and supporting, through its RTD programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially these projects could provide a useful contribution to future BREF reviews. Readers are therefore invited to inform the EIPPCB of any research results which are relevant to the scope of this document (see also the preface of this document).

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GLOSSARY

The glossary of this document includes the symbols and accronyms used and that have been identified by the TWG to have different interpretations by different readers. Thus, it is highly recommended to refer to this glossary when a certain word is used in this document. The reason for including these terms here is to give an appropriate guidance of the terms used in this document. Due to the singularity of this industrial sector (mainly related to legislation interpretation), the TWG concluded that it would be advantageous to include these terms. However, the definitions below shall not be read as interpretation of any legislation, and consequently they only have the validity to guide the reader of this document.

This IPPC industrial sector is highly regulated and the terminology used is not the same throughout the EU. Moreover, there are different interpretations of the same wording in the different countries, especially those related with the qualification of recovery and disposal. The TWG has tried to use three rules in order to select what type of word needs to be used in this document. These rules are:

1. <u>external convention.</u> Certain words used in this document are used with the same meaning as, for example, EU legislation. In this case, wording can be imported to be in line with existing legislation. This option is not always applicable due to different interpretations and imprecise meanings of certain words.
2. <u>BREF convention</u>. The BREF convention rule typically tries to avoid the use of difficult words with different meanings for different users. These words are described in the Glossary and used in this document. This category includes ‘waste IN’, ‘waste OUT’, ‘output’, etc.
3. <u>respect wording used by the information provided</u>. Due to the interpretation difficulties of the information provided by the TWG, it is sometimes impossible to properly ‘translate’ some words to the ones used in legislation. In some cases, different countries interpret the same words differently so therefore, it is difficult for the EIPPCB to change such wording. Some examples in this area are ‘product’, ‘materials’, ‘chemical’, ‘recovery’, ‘disposal’, and so on. In this case, the EIPPCB respects the wording used in the information provided.

Symbols

~	More or less. Approximately
€	Euro, EUR (European currency)

A

AD	Anaerobic digestion
ADR	European agreement concerning the international carriage of dangerous goods by road
APME TEC	Association of Plastic Manufacturers in Europe, Technical Centre
AOX	Adsorbable organically bound halogens
API	American Petroleum Institute
AT_4	Respiratory activity after four days (measured in mg O_2/gram of total solid)

B

Biological degradation	Used for the biological processes that naturally occur on biomass in the atmosphere, mostly aerobic. In some countries the term ‘rotting’ is used to define this term
Blending	Used in this document as mixing liquid or semi-liquid wastes
BOD	Biochemical oxygen demand
Bottom ash	Solid residues from the combustion processes. Used in this document as a synonym for ‘combustion slags’.
Brightstock	Fraction of lubricant
BREF	BAT reference document
BTEX	Benzene, toluene, ethylbenzene (phenylethane) and xylenes

Bund	A tank farm bund (or dike) is designed to contain large spills, such as that caused by a shell rupture or a large overfill. The bund consists of a wall around the outside of the tank (or tanks) to contain any product in the unlikely event of a spill. The bund is typically constructed of well compacted earth or reinforced concrete. The volume is normally sized to accommodate the contents of the largest tank within the bund. For more information see Storage BREF

C

CEN	European committee for normalisation
CFC	Chloro fluoro carbons
CHP	Co-generation of heat and power
COD	Chemical oxygen demand
Conradson	Concarbon: measurement of the carbon residue (expressed in w/w-%). Measurement of the tendency of an organic compound to form coke
Cuts	Term used in distillation, fractionation to name the different distillation fractions that are optained
C_x	Hydrocarbon with x number of carbons

D

D	Disposal (codes given by EC legislation to disposal treatments)
DAF	Dissolved air flotation
DCH	Direct contact hydrogenation process of waste oils
DCM	Dichloro methane
Diffuse emissions	Emissions arising from direct contact of volatile or light dusty substances with the environment under normal operating circumstances (see Monitoring BREF)
Digestate	Solid residue after anaerobic digestion
DIN	Deutsches Institut für Normung (DIN, the German Institute for Standardization) is a German national organization for standardization
Dispatch	Delivery of the waste OUT to the following activity or customer
Disposal	Defined by EC Waste Framework Directive
DM	Dry matter. The matter after drying of its moisture content
DRE	Destruction and removal efficiency. It takes into account only stack emissions with no consideration of other releases and residues
DS	dry solids (content). The mass of a material remaining after drying by the standard method of test

E

EC	European Commission
EDTA	Ethylene diamine tetraacetic acid
EMS	Environmental management systems
EOP	End-of-pipe technique. Typically used as a synonym for ‘abatement technique’
eq.	Equivalent (i.e. eq. crude oil)
EU	European Union
EU+	European Union + EFTA (European Free Trade Association) countries + Candidate countries
EUR	Euro, EUR, (European currency)
EWL	European Waste List from the European Waste Framework Directive

F

FGT	Flue-gas treatments. Abatement techniques (e.g. particulate abatement, SO_x abatement, NO_x abatement) typically used for the cleaning of the flue-gases generated after combustion processes

FGT waste	Refers to the waste generated in the flue-gas treatment of combustion processes and it is considered as a 'waste IN' in this document. Please note that this term is used with a different meaning to 'FGT residue' referred to below. For more information see Section 8.3.7
FGT residue	Refers to the residues generated when flue-gas treatment is applied to WT installations. Please note that this term is used to differenciate from 'FGT waste'as noted above
FID	Flame ionization detector
Fugitive emissions	Emission caused by non-tight equipment/leak: emission into the environment resulting from a gradual loss of tightness from a piece of equipment designed to contain an enclosed fluid (gaseous or liquid), basically caused by a difference of pressure and a resulting leak. Examples of fugitive emissions: leak from a flange, a pump, a sealed or tightened equipment… (see Monitoring BREF)

G

GB21	Anaerobic gas production
GAC	Granular activated carbon
GE	German odour unit
GNP	Great Northern Processing Inc.

H

H&S	Health and Safety programme
HC	Hydrocarbons
HCFC	Hydrogen chloro fluoro carbons
HF	Hydrofinishing
HMIP	Her Majesty's Inspectorate of Pollution (UK)
HRT	Hydraulic retention time

I

IBC	Intermediate bulk container
IEF	Information Exchange Forum (see Preface)
IFP	Institute Français du Petrole
IRR	Internal rate of return (Economic concept)

L

L/S	Liquid/solid ratio
Lab smalls	Term typically used to define the waste that comes from laboratories. Typically in small quantities and very variable in composition
LDAR	Leak detection and repair system. Programe applied to reduce fugitive emissions. More information in Section 4.6.2
LHV	Low heat value
Light ends	Term used in distillations, fractionation to name the light volatile components that end up at the top of the columns
Liquid waste fuel	Liquid or semi-liquid fuel prepared from waste. Typically prepared from hazardous waste
LPG	liquefied petroleum gas
LSHV (h^{-1})	Liquid hourly space velocity

M

M	Million (10^6)
MBT	Mechanical biological treatment
MEK	Methyl ethylketone
MIBK	Methyl isobutyl ketone
Mixing	Used in this document as put together solid waste
NMVOC	Non-methane VOC emissions
MS	Member State (One of the 25 Member States of the EU)

MSW	Municipal solid waste
N	
n.a.	Not available
n/a	Not applicable
ndM	Analytical method
NF	Nanofiltration
NIR	Near-infrared spectroscopy technique
NPV	Net payback value
NTA	Nitrilotriacetic acid
O	
ouE	European Odour Unit. The amount of odorant(s) that, when evaporated into one cubic metre of neutral gas at standard conditions, elicits a physiological response from a panel (detection threshold) equivalent to that elicited by one European Reference Odour Mass (EROM), evaporated in one cubic metre of neutral gas at standard conditions (CEN TC264)
Output	Includes the waste OUT (main output) and the other types of solid residues, emissions, waste water, etc produced during a waste treatment
P	
PAG	Polyalkylene glycol
PAH	Polycyclic aromatic hydrocarbons
PBB	Polybrominated biphenyl
PCB	Polychlorinated biphenyl
PCB/PCT	Polychlorinated biphenyls and terphenyls
PCDD/PCDF	Polychlorinated dibenzodioxins and polychlorinated dibenzofurans
PDA	Propane de-asphalting (for waste oils)
PF	Preflash (typically used for waste oils)
Ph-c	Physico-chemical treatment. Typically used in this document for treatment of waste waters or solid waste
PM	Particulate matter
PM_x	Particulate matter of less than x microns
POP	Persistant organic pollutant
ppm	Parts per million (mg/kg. Closely equivalent to mg/l in cases of concentration in water)
ppmv	parts per million refered to volume (litre per litre)
Process generated waste	The non-usable waste (e.g. waste lime, bottoms of storage tanks, sludges) is generated by the process/operations and is different from the target waste OUT. The reason for differentiating between the wastes is that the waste OUT may be used for different purposes, but process generated waste is typically not re-used. See the introduction to chapter 3 and Figure 3.1 for more information.
R	
R	Recovery (codes given by EC legislation to recovery treatments)
R/D	Recovery and Disposal
R&D	Research and Development
RDF	Refuse derive fuel. The RDF (a type of solid waste fuel) do have certain standards.
Recycle	Used in this document with two meanings: One means the recycling of some part of the waste to another industrial sector and the other means recycling within the WT installation. The latter one is most commonly used in this document
Recovery	Defined by EC waste framework Directive. Also used in this document as the treatment for the recovery of or part of material from the waste

Redox	The most fundamental reactions in chemistry are the redox processes. The term redox process accounts for all processes in which atoms have their oxidation number (oxidation state) changed.
REF	Recovered fuels
Refinery	Mineral oil refinery (see Refinery BREF)
Regeneration	Used in this document for the treatment of liquid and solid waste for recovery of the majority of the waste material. However, one exception exists because the term ‘re-refining’ is used in the case of regeneration of waste oil to be reconverted to base oils
Remediation	Generic term used in this document to refer to treatment of contaminated soil
Re-refining	Used in this document for the treatments carried out to waste oil to be transformed to base oil
RO	Reverse osmosis
RTD	Research, Technology and Development. EC research programmes
S	
SCR	Selective catalytic reduction. Catalytic control technology applied to reduction of NO_x emissions
Selectopropane	PDA unit
Slag	Solid residues from combustion processes. The term ‘bottom ash’ is the most frequently used term in this document
SNCR	Selective non-catalytic reduction. Non-catalytic control technology applied to reduction of NO_x emissions
Solidification	Treatment that uses additives to change the physical properties of the waste (see Section 2.3.3.5)
Secondary fuel	Term used in this document as any type of fuel whether (prepared from waste or not) that it is used to supplement the primary fuel used in a combustion facility
Solid waste fuel	Solid fuel prepared from waste. It can be prepared from hazardous or non-hazardous waste
Specification	Physico-chemical values given in legislation to certain compounds (e.g. lubricant oils)
SRF	Solid recovered fuel. The SRF (a type of solid waste fuel) meets certain standards
T	
t/yr	Tonnes per year
TCE	Trichloroethylene
TCT	Thermal cracking treatment
TDA	Thermal de-asphalting (technique used for the treatment of waste oils)
TEQ	Toxicity equivalent. Unit used for PCDD and PCDFs
TFE	Thin film evaporation (technique used for the treatment of waste oils)
Transfer station	Used throughout this document to include bulking and storage activities
TOC	Total organic carbon
TPH	Total petroleum hydrocarbons
TRI	Toxic release inventory from US (http://www.epa.gov/tri/)
TS	Total solid content
TWG	Technical Working Group for Waste Treatments (composed of experts from Member States, Waste Treatment industries, Environmental NGO and co-ordinated by EIPPCB)
U	
UK	United Kingdom
Used oil	Includes only those oils which arise from the use of lubricating oils
USAEPA	Environmental Protection Agency of the US
US DOE	US department of Energy

V

Virgin oil	Lubricant oil which has not yet been used
VOC	Volatile organic compounds. Typically measured as mass of carbon
vol-%	volume by volume ratio (e.g. Y vol-% means Y litres of compound X per 100 litres of gas)
vs.	versus

W

w/w-%	percentage by weight ratio (e.g. w/w-% means kg of X per 100 kg of material)
Waste contaminated with PCBs and dioxins	WT BREF is mentioned in COM (2001) 593 to include also the treatment of such type of waste. This term is used with the same meaning as in this legislation
Waste fuel	This term is used in this document to generally refer to any type of waste or prepared material from waste that is used as fuel in any combustion process. It embraces terms such as 'SRF' and 'secondary fuel' used elsewhere
Waste oil	Includes used oils and other recovered oils from drainage systems, fuel storage, refineries, etc.
Waste IN	Waste that can be treated in a waste treatment installation. For a further explanation, consult the introduction to Chapter 3
Waste OUT	Relates to the waste output (being a waste or a product) of a waste treatment facility. However, in this document it is differentiated from process related waste. For a further explanation, consult the introduction to Chapter 3
White goods	Large household appliances that are typically finished in white enamel such as refrigerators, washing machines, etc.
Waste holder	Installation from where the waste is received. Sometimes this installation is the waste producer if no intermediate is between the waste treatment facility and the waste producer. Sometimes this installation is the waste transfer facility
Waste operator	Company that runs the waste treatment installation
Waste producer	Installation where waste is produced. The waste is then delivered to a waste manager or a waste treatment provider
Waste transfer	Installations mainly dedicated to collect different types of waste in order to increase its quantity and send it for treatment
Waste treatment	Any of the installations that perform a waste treatments covered by the scope of this document
WI	Waste incineration (typically referred to in the WI BREF)
WO	Waste oil
WT	Waste treatment(s)
WWT	Waste water treatment
WWTP	Waste water treatment plant

	Country Name	**Abbreviation**	**Currency ISO Code**
EU-25 EU countries	Belgium	BE	EUR
	Czech Republic	CZ	CZK
	Denmark	DK	DKK
	Germany	DE	EUR
	Estonia	EE	EEK
	Greece	EL	EUR
	Spain	ES	EUR
	France	FR	EUR
	Ireland	IE	EUR
	Italy	IT	EUR
	Cyprus	CY	CYP
	Latvia	LV	LVL
	Lithuania	LT	LTL
	Luxembourg	LU	EUR
	Hungary	HU	HUF
	Malta	MT	MTL
	Netherlands	NL	EUR
	Austria	AT	EUR
	Poland	PL	PLN
	Portugal	PT	EUR
	Slovenia	SI	SIT
	Slovakia	SK	SKK
	Finland	FI	EUR
	Sweden	SE	SEK
	United Kingdom	UK	GBP
Accession countries	Bulgaria	BG	BGN
	Romania	RO	ROL
	Turkey	TR	TRL
Other countries	Australia	AU	AUD
	Canada	CA	CAD
	Iceland	IS	ISK
	Japan	JP	JPY
	New Zealand	NZ	NZD
	Norway	NO	NOK
	Switzerland	CH	CHF
	United States	US	USD

Table 0.1: Country codes and currencies
Notes: Information from http://eur-op.eu.int/code/en/en-5000500.htm

8 ANNEXES

Five annexes have been prepared to complement the information provided in this document, each relating to a specific topic, i.e.:

Annex I. Environmental legislation and emission limit values applied to the waste treatment sector

Annex II. Questionnaire used to gather environmental information of European waste treatment plants

Annex III: Types of waste and waste production in the EU

Annex IV. Quality assurance systems for secondary recovered fuel

8.1 Annex I. Environmental legislation and emission limit values applied to the waste treatment sector

[5, Concawe, 1996], [6, Silver Springs Oil Recovery Inc., 2000], [7, Monier and Labouze, 2001], [36, Viscolube, 2002], [37, Woodward-Clyde, 2000], [55, UK EA, 2001], [86, TWG, 2003], [95, RAC/CP, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004]

8.1.1 Waste Directive

Table 8.1 shows the classification of waste treatment operations. Such a classification of waste treatment operations according to these entries is used for several purposes (e.g. statistics, export of waste). The table also contains examples of the type of installations that may be included in each type of operation. However, these examples do not represent any definition of those terms. It is recognised that some of these definitions may be technically ambiguous but they correspond to existing legal definitions, which are outside the scope of this document.

Disposal (D) operations		**Examples of installations**
D1	Deposit into or onto land (e.g. landfill, etc.)	
D2	Land treatment (e.g. biodegradation of liquid or sludgy discards in soils, etc.)	
D3	Deep injection (e.g. injection of pumpable discards into wells, salt domes or naturally occurring repositories, etc.)	
D4	Surface impoundment (e.g. placement of liquid or sludgy discards into pits, ponds or lagoons, etc.)	
D5	Specially engineered landfill (e.g. placement into lined discrete cells which are capped and isolated from one another and the environment, etc.)	Hazardous landfill: typically used to landfill hazardous waste from third parties. Mono landfill: where only one type of waste is landfilled. Typically if more than one type of waste is landfilled, segregation is used.
D6	Release into a water body except seas/oceans	
D7	Release into seas/oceans including sea-bed insertion	
D8	Biological treatment not specified elsewhere in this list which results in final compounds or mixtures which are discarded by means of any of the operations numbered D1 to D12	Operations that include the use of biological processes or use micro-organisms for the treatment of waste.
D9	Physico-chemical treatment not specified elsewhere in this list which results in final compounds or mixtures which are discarded by means of any of the operations numbered D1 to D12 (e.g. evaporation, drying, calcination, etc.)	Operations carried out for the treatment of waste prior disposal by means of physico or chemical processes or a combination of both. Some operations are stabilisation, dehydratation, solidification, sterilisation, autoclave, disinfection of hospital waste, etc.
D10	Incineration on land	Operations for the destruction of waste by incineration, with the main objective being to destroy the waste, with or without energy recovery.
D11	Incineration at sea	
D12	Permanent storage (e.g. emplacement of containers in a mine, etc.)	
D13	Blending or mixing prior to submission to any of the operations numbered D1 to D12	
D14	Repackaging prior to submission to any of the operations numbered D1 to D13	
D15	Storage pending any of the operations numbered D1 to D14 (excluding temporary storage, pending collection, on the site where it is produced)	
Recovery (R) operations		
R1	Use principally as a fuel or by other means to generate energy	Large combustion plants, cement and lime kilns, ceramic installations or similar (e.g. cogeneration).
R2	Solvent reclamation/regeneration	Operations aimed at regeneration of solvent independent of the type of process used
R3	Recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes)	Operations aimed at regeneration of, for example, plastic containers, refrigerant gases, combustibles. It also includes cleaning activities. Operations for the recovery of PCB contaminated waste.

R4	Recycling/reclamation of metals and metal compounds	Operations aimed at recycling metal wastes or reclamation of metals and metal compounds. Waste as slags, metal powders, metalic containers, lead batteries, copper wires, mercury from batteries, fluorescents, scrap metals, metal salts from metalurgic processes. Vehicles, end-of-life fridges, and toners may also be included here. Cleaning activities before the recycling of metal containers are also included.
R5	Recycling/reclamation of other inorganic materials	Operations aimed at the recycling of inorganic materials which are not metal or the reclamation of inorganic material from waste (e.g mineral materials from construction and demolition waste, flocculants from acids (ferric chloride)).
R6	Regeneration of acids or bases	Operations aimed at the regeneration of acid or bases independent of the process used.
R7	Recovery of components used for pollution abatement	
R8	Recovery of components from catalysts	Operations aimed at the recovery of components as metals or ceramics from catalysts
R9	Oil re-refining or other re-uses of oil	Operations aimed at the regeneration of waste oils
R10	Land treatment resulting in a benefit to agriculture or ecological improvement	
R11	Use of wastes obtained from any of the operations numbered R1 to R10	
R12	Exchange of wastes for submission to any of the operations numbered R1 to R11	
R13	Storage of wastes pending any of the operations numbered R1 to R12 (excluding temporary storage, pending collection, on the site where it is produced)	

Table 8.1: Type of waste treatments installations and examples of installations included in each different category of waste operation
Annex II A and B of Council Directive 91/156/EC

8.1.2 EU legislation applicable to waste oils

Directive	**Name**
75/439/EEC	About waste oils
75/442/EEC	About wastes and the definition of wastes
87/101/EEC	Amendment to Directive 75/439 giving priority to re-refining
89/369/EEC	About preventive measures of air pollution of incinerating plants and emissions
89/429/EEC	Control of special wastes
91/156/EEC	To encourage clean technologies and the recovering of wastes without a risk to the environment and human health
91/689/EEC	About hazardous wastes
91/689/EEC	List of dangerous wastes Article 1, paragraph 4, Directive 91/689 EEC
91/692/EEC	Standardisation and realisation of some environmental directives
92/12/EEC	About the excise duties on mineral oils
92/81/EEC	Harmonisation of excise duties on mineral oils
92/82/EEC	Rates of excise duties on mineral oils
92/108/EEC	Amendment of Directives 92/12 and 92/81
94/62/EC	About packing and wastes from packing
94/67/EC	About the incineration and co-incineration of wastes and emission limits
96/61/EC	About preventive measures and integral reduction of the pollution
2000/76/EC	Directive on waste incineration

Table 8.2: EC Directives in force affecting waste oils
[36, Viscolube, 2002], [150, TWG, 2004]

8.1.3 Other EU waste legislation

There are different types of legislation important for holders of waste products, which need to be known for the treatment of waste. Some of the most important ones are summarised in the Table 8.3:

Reference	Name
	Waste sector regulations
94/62/EEC	Packaging issued - PWD
2000/53/EC	Automotive issued - ELV, End of Life Vehicle Directive
13/6/2000	Electrical & Electronics - WEEE, Proposal for a Directive on Waste Electrical and Electronic Equipment
	Horizontal issue regulations
2000/2037EC	Ozone depleting substances - ODP, Ozone Depleting Substances
1999/31/EC	Landfill disposal - LWD, Landfill of Waste Directive
2000/76/EC	Waste incineration - WID, Waste Incineration Directive
2000/53L/EC	Waste List - EWL, Commission decision of May 2000
67/548/EEC	Dangerous Substances Directive - DSD, Dangerous Substance Directive
1999/45/EC	Dangerous Preparation Directive - DP, Dangerous Preparation Directive
	Solvents Emissions Directive (SED)
	Landfill Directive
	Seveso Directive
	Water Framework Directive
	Industrial Safety, VawS (s.a.), others...

Table 8.3: EU legislation related with waste treatment installations

8.1.4 Legislation in some EU countries

8.1.4.1 France

France has adopted the main European regulations on hazardous waste management. Decree (2002 - 540) has been recently adopted to adapt the classification of hazardous wastes to new European regulations (Decision 2000/532/CE) [95, RAC/CP, 2003].

8.1.4.2 Germany

The legislation applied in Germany according to waste treatment may be summarised by the following legislation:

- Technical Instruction on Waste management (Technische Anleitung zur Lagerung, chemisch/physikalischen, biologischen Behanlung, Verbrennung und Ablagerung von besonders überwachungsbedürftigen Abfällen – TA Abfall)
- Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste treatment facilities of 20 February 2001
- Ordinance on Requirements for the discharge of waste water into water/waste water ordinance (Abwasserverordnung – AbwV) of 15October 2002
- TA Luft
- 30. BImSchV.

Requirements for waste water treatment are set in: Annex 23 ‘Facilities for Biological Treatment of Waste’ and, Annex 27 ‘Treatment of Waste by Chemical and Physical Processes (Ph-c facilities) and processing of used oil’ of the ‘Ordinance on Requirements for the Discharge of Waste Water into Waters (Waste Water Ordinance - AbwV) of 15 October 2002’.

Waste water discharges or blending

The Ph-c plants in Germany are subject both to control relating to waste and water legislation. The waste water may be discharged into water bodies only insofar as process water from process and waste-air treatment in mechanical-aerobic-biological treatment facilities cannot be used completely in internal processes.

According to the ordinance, the generated waste water is often used for a waste gas cleaning process, e.g. for humidification of the bio filter or for the operation of the bio scrubber. In some cases it is applied for cooling processes with an open evaporation. Because of the small volumes of waste water, filter techniques are the main applied operations.

Emission limit values (ELV) for MBTs

	Emission limit values	Units
Daily mean values (continuous measurement):		
total dust	10	mg/m^3
organic substances, given as total carbon	20	mg/m^3
Half hour mean values (continuous measurement):		
total dust	30	mg/m^3
organic substances, given as total carbon	40	mg/m^3
Monthly mean values, determined as mass ratio[1]:		
nitrous oxide	100	g/t
organic substances, given as total carbon	55	g/t
Single measurements		
odours	500	GE/m^3
dioxins/furans (total value)	0.1	ng/m^3

[1] Gram TOC or N_2O per tonne of treated waste

Comment to 5 % of oxygen. The reference to oxygen has proven not to be practical because oxygen content in the MBT exhaust gas is similar to atmospheric oxygen content. Insufficient accuracy of the oxygen measurement causes large uncertainties in the reference calculation. An appropriate combination of load limits and concentration limits is the better alternative for the prevention of dilution effects.

Table 8.4: German emission limit values applied to MBTs
[150, TWG, 2004]

8.1.4.3 Greece

Despite the fact that a hazardous waste 'National Plan' is still being developed in Greece, mechanisms to manage industrial and hazardous wastes are already in place. The main regulations with regard to the management of industrial waste are:

- Law 1650/86 on Environmental Protection
- Law 3010/02 on Environmental Protection
- CMD 69728/96 on Solid Waste Management
- CMD 114218/97 on Technical Specifications on Solid Waste Management
- CMD 113944/97 National Plan on Solid and Hazardous Waste Management.

Specific regulations on hazardous industrial waste management are the following

- CMD 72751/85 and CMD 19396/97 on Hazardous Waste management
- CMD 98012/97 on Used Oils Management
- CMD 73537/95 on Lead Batteries and CMD 19817/00 on Batteries
- CMD 8243/91 on Asbestos Waste and CMD 7589/00 on PCBs/PCTs
- CMD 2487/99 on Pollution Prevention from Incineration of Hazardous waste.

8.1.4.4 Italy

The legal framework concerning the management of industrial and hazardous waste is well developed in Italy.

The national framework law on waste issued in 1997 (Legislative decree 22/97) transposed the European Waste Framework Directive 75/442/EEC, the Directive on Hazardous waste 91/689/EC and the Directive on packaging and packaging waste 94/62/EC (73) to national legislation.

Law 22/97 introduces an integrated waste management policy, as set up by the European hierarchy: waste minimisation and prevention at source followed by recovery in its triple dimension of re-use, recycling and energy recovery and, finally safe disposal. This law represents a reform in the field of waste management in Italy. It promotes clean technologies, Ecolabel, the EMAS certification system, integrated networks of recovery and disposal facilities, and voluntary agreements between public administrators and economic operators in order to create real opportunities for waste recycling.

Wastes are classified according to the European Waste List (decision 2000/532/EC). The waste information system is based on the National Register of Waste, which was first established by law in 1994 and reorganised in 1998.

Recently Directive 99/31/EC has been transposed into Italian legislation by the Legislative Decree 13 January 2003 for the provision of technical and operational tools for a better landfilling management and measures/procedures to minimise the environmental impact and effect on human health. Furthermore, Directive 2000/53/EC concerning the end of life vehicles, is in the process to be transposed into Italian legislation.

Table 8.5 shows the emission limit values applied to a waste oil refinery.

Air parameter	Emission limit values	Units
Fume temperature	150	°C
PM	30	mg/Nm^3
Heavy metals	5	mg/Nm^3
TOC	10	mg/Nm^3
HCl	10	mg/Nm^3
HF HBr	3	mg/Nm^3
HCN	0.5	mg/Nm^3
P	5	mg/Nm^3
PAH	0.05	mg/Nm^3
PCDD + PCDF	0.01	µg/Nm^3
TCDD + TCDF	0.05	µg/Nm^3
PCB + PCN + PCT	0.1	mg/Nm^3
Notes: Values referred to a percentage of O_2 of 10 %		

Table 8.5: Air emission limit values for a waste oils refinery
[36, Viscolube, 2002]

Water parameter	Emission limit values	Units
Temperature	25	ºC
Acidity	5.5/9.5	pH
COD	160	mg/l
Phenols	0.5	mg/l
NH_4^+	15	mg/l
P (total)	10	mg/l
Anionic tensioactives		mg/l
Non-anionic tensioactives		mg/l
Total tensioactives	2	mg/l
Al	1	mg/l
Fe	2	mg/l
Colour	Not detectable	
Suspended solids	80	mg/l

Table 8.6: Water discharge emission limit values from a waste oils refinery
[36, Viscolube, 2002]

8.1.4.5 Spain

A legal framework with regard to the management of industrial and hazardous wastes has been developed in Spain. The main regulations on hazardous waste are the following:

- Law 10/98 of 21 April, on Waste
- Decree 833/1988 of 20 July that develops Law 20/1986, on Hazardous Wastes. (Modified by Royal Decree 952/1997)
- Ordinance MAM/304/2002 on Hazardous Waste Classification
- Hazardous Waste National Plan (1995 - 2000)
- Hazardous Waste National Plan (2002 - 2008) (being developed).

Specific regulations exist on the management of used oils, PCB, PCT, and batteries.

8.1.4.6 United Kingdom

England and Wales	Scotland	Northern Ireland
PPC Regulations (England and Wales) 2000	PPC (Scotland) Regulations 2000; SI 200/323	
Waste Management Licensing Regulations SI 1994 1056	Waste Management Licensing Regulations SI:1994 1056	No NI equivalent
The Water Resources Act 1991	COPA 1974 (S30A-30E equiv to Part III WRA91) Natural Heritage (Scotland) Act 1991(Part II equiv to Part I WRA91)	The Water (NI) Order 1999
SI 1989 No 317: Clean Air, The Air Quality Standards Regulations 1989	SI 1989/317: Clean Air, The Air Quality Standards Regulations 1989	The Air Quality Standards Regulations (Northern Ireland) 1990. Statutory Rules of Northern Ireland 1990 No 145
SI 1997 No 3043: Environmental Protection, The Air Quality Regulations 1997	SSI 2000/97 The Air Quality (Scotland) Regs	No NI equivalent
SI 1989 No 2286 and 1998 No 389 the Surface Water (Dangerous Substances Classification) Regulations. (Values for List II substances are contained in SI 1997/2560 and SI 1998/389)	SI 1990/126 Surface Water (Dangerous Substances) (Classification) (Scotland) Regs	Surface Waters (Dangerous Substances) (Classification) Regulations 1998. Statutory Rules of Northern Ireland 1998 No 397 SI 1991/1597:
SI 1991/1597: Bathing Waters (Classification) Regs.	SI 1991/1609 Bathing Waters (Classification) (Scotland) Regs	The Quality of Bathing Water Regulations (NI) 1993
SI 1992/1331 and Direction 1997 Surface Waters (Fishlife) (Classification) Regs.	SI 1997/2471 Surface Waters (Fishlife) (Classification) Regs	The Surface Water (Fishlife) (Classification) Regulations (NI) 1997
SI1997/1332 Surface Waters (Shellfish) (Classification) Regs.	SI 1997/2470 Surface Waters (Shellfish) (Classification) Regs	The Surface Water (Shellfish) (Classification) Regulations (NI) 1997
SI1994/2716 Conservation (Natural Habitats etc) Regulations 1994	SI 1994/2716 Conservation (Natural Habitats etc) Regs	Conservation (Natural Habitats etc) Regulations (Northern Ireland) 1995
Control of Major Accident Hazards Regulations 1999 (COMAH)	SI 1999/743 Control of Major Accident Hazards Regs	Control of Major Accident Hazard Regulations (Northern Ireland) 2000
Special Waste Regulations 1996		The Special Waste Regulations (Northern Ireland) 1998

Table 8.7: UK related waste legislation and correspondence
[55, UK EA, 2001]

8.1.4.7 Belgium

The burning of used oils in asphalt mixing plants has been illegal since January 1999 in the Flemish region of Belgium [11, Jacobs and Dijkmans, 2001].

8.1.4.8 The Netherlands

The risk of use of materials in agriculture and diffusion of toxic substances, especially heavy metals, in the environment and in crops have been legislated in the Netherlands. Standards are set for the application of anaerobic digestate into farmlands, set in the Quality and Use of Other Organic Fertilisers Decree: Cd <1.25 mg/kg, Cr <75 mg/kg, Cu <75 mg/kg, Hg <0.75 mg/kg, Ni <30 mg/kg, Pb <100 mg/kg, Zn <300 mg/kg, As <15 mg/kg (concentrations in mg/kg dry matter).

8.1.4.9 Austria

Emission limit values for MBTs

Parameters	Emission Limit Value	Units
1. organic substances, as total organic carbon		
half hourly average values	40	mg/m^3
daily average values	20	mg/m^3
mass ratio[1]	100	g/t$_{waste}$
2. nitrogen dioxide (as NO_2)[2]		
half hourly average values	150	mg/m^3
daily average values	100	mg/m^3
3. ammonia	20	mg/m^3
4. dioxins/furans[3] (2-, 3-, 7-, 8-TCDD-equivalent (I-TEF))	0.1	ng/m^3
5. total dust	10	mg/m^3
6. odour	500	GE/m^3
7. other parameters[4]		

[1] see Chapter 7.2.2.2, paragraph. 2 of 'MBA-Richtlinie'.

[2] if the applied technique of waste gas treatment precludes the formation of nitrogen dioxides

[3] if the applied technique of waste gas treatment precludes the formation of polychlorinated dibenzo-pdioxins (PCDD) and/or dibenzofurans (PCDF)

[4] depending on the treatment technology and the type of waste which will be treated, the possibility of greenhouse gases emissions (e.g. N_2O) has to be taken into consideration, which has to be limited as the case may be. Therefore, special provisions for IPPC installations according to the Austrian Waste Management Act.

In this table, the levels for emissions from MBT relate to an oxygen concentration of 5 %

Table 8.8: Austrian emission limit values for air emissions in MBTs
[150, TWG, 2004]
Note: Emission limit values according to the Austrian 'MBA-Richtlinie' (Guideline for the mechanical-biological treatment of wastes, 2002, Republic of Austria, Federal Ministry of Agriculture, Forestry, Environment and Water Management, Band 2/2002, March 2002)

8.1.5 Waste legislation in some other countries

Canada
In Canada, used oils containing more than 2 ppm PCBs have to be taken to an incinerator.

US
The USEPA has regulations for Standards for the Management of Used Oil. Within these regulations the burning of used oil is subject to a comprehensive set of process controls unless it can be shown that the used oil falls within set specifications related to contaminant levels. USEPA, United States Code of Federal Regulations, CFR64 Part 279, United States used oil Specification give a specification for a waste not be considered as a hazardous waste. Table 8.9 shows the specifications of waste to not be named as a hazardous waste.

Compound	Maximum value in mg/kg
Arsenic	5
Cadmium	2
Chromium	10
Lead	100
Total halogens	4000

Table 8.9: Specification of waste oil not to be named as a hazardous waste
US EPA

8.2 Annex II. Questionnaire used to gather environmental information of European waste treatment plants

PURPOSE OF THE QUESTIONNAIRE
Requested by the Technical Working Group on Waste Treatments (WT) and with the aim of standardising the type of information that is needed for the WT BREF

WHAT IS GOING TO BE DONE WITH THIS INFORMATION?
The information that will be gathered will be used only for the purpose of the WT BREF

IF ANY PART OF THE QUESTIONNAIRE IS CONFIDENTIAL, PLEASE SPECIFY
Confidential data will be treated by EIPPCB as such and will not be openly discussed in the BREF

BUT, I DO NOT HAVE ALL THE INFORMATION REQUESTED
Partial information is also important because it is equally important to know why certain information does not exist

WHICH CELLS DO I HAVE TO FILL IN?
Those that allow you to put information in, and which are coloured in blue

THIS FIGURE SUMMARISES HOW YOUR INSTALLATION NEEDS TO BE SEEN
TO PROPERLY FILL IN THE QUESTIONNAIRE

Person completing the questionnaire
Name
e-mail
This information will be used only if any further clarification is needed.

CREATED BY: Miquel A. Aguado-Monsonet (EIPPCB)
Ludwig Ramacher (FEAD)

FOR QUESTIONS: Miquel A. Aguado-Monsonet (EIPPCB)
at miguel.aguado@cec.eu.int

ONCE COMPLETED PLEASE SEND TO:
Miquel A. Aguado-Monsonet (EIPPCB)
at miguel.aguado@cec.eu.int

GENERAL INFORMATION ABOUT THE WT INSTALLATION		
1	Country	
2	Operator	
3	Name and site of the plant	
4	Plant operating since	
5	The data provided in this questionnaire corresponds to year. . . (year of reference)	
6	Additional remarks	

THIS WORKSHEET CONTAINS DATA ON THE INPUTS TO THE INSTALLATION

WASTE TREATED

Amount of waste treated in the year of reference	▨ **tonnes/yr**

Types of waste treated	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**Number of hazardous codes that you treat**	**Annual percentage for each type of waste treated** %
01	▨	▨	▨	▨	▨									0	▨
02	▨	▨	▨	▨	▨	▨	▨							▨	▨
03	▨	▨	▨											▨	▨
04	▨	▨												▨	▨
05	▨	▨	▨	▨	▨	▨	▨	▨						▨	▨
06	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
07	▨	▨	▨	▨	▨	▨	▨							▨	▨
08	▨	▨	▨	▨	▨									▨	▨
09	▨													▨	▨
10	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
11	▨	▨	▨	▨										▨	▨
12	▨	▨	▨											▨	▨
13	▨	▨	▨	▨	▨	▨								▨	▨
14	▨	▨	▨	▨	▨									▨	▨
15	▨	▨												▨	▨
16	▨	▨	▨	▨	▨	▨	▨	▨						▨	▨
17	▨	▨	▨	▨	▨	▨	▨							▨	▨
18	▨	▨												▨	▨
19	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨				▨	▨
20	▨	▨	▨											▨	▨

UTILITIES INPUT

Type of fuel used	▨	(fossil fuel (gas, liquid, solid) and waste (e.g. RDF))
Fuel consumption	▨	MJ/yr
Electricity consumption	▨	MWh/yr
Heat consumption	▨	MWh/yr
Water	▨	m^3/yr
Cooling	▨	MJ/yr

OTHER INPUTS (e.g. Chemicals)

▨	▨	tonnes/yr

THIS WORKSHEET CONTAINS A BRIEF EXPLAINATION OF THE PLANT AND THE ACTIVITIES/PROCESSES INVOLVED

TYPE OF PLANT

	production of fuel from non-hazardous waste
	production of fuel from hazardous waste
	mechanical/biological treatment of non-hazardous waste
	anaerobic digestion
	treatment of spent catalysts
	treatment of flue-gas cleaning residues and ashes
	treatment of waste oils
	treatment of waste solvents
	physico-chemical treatment for oil water mixtures and emulsions
	treatment of contaminated soil

BRIEF SUMMARY OF THE INSTALLATION

(Please mention the list of processes/activities carried out in your installation (note: storage is already included). Please add a flow sheet of the plant (in the next worksheet) to assist in the understanding of your process)

		Number	**Remarks**
1	Gas storage		
2	Liquid storage		
3	Solid (including waste) storage		
4			
5			
6			

AIR ABATEMENT PROCESSES

Please mention in the following table which types of flue-gas cleaning system are used

	Type of system in use	**abatement efficiency**	**basis of the efficiency**	**Remarks**
A1	dry electrostatic precipitator		PM	
A2	wet electrostatic precipitator		PM	
A3	cyclone		PM	
A4	quench			
A5	bag filter		PM	
A6	bag house filter with active carbon injection		PM	
A7	acidic wet scrubber			
A8	alkalic wet scrubber			
A9	additional scrubber system			
A10	dry scrubber with lime injection			
A11	non selective catalytic reduction		NO_x	
A12	selective catalytic reduction for NO_x		NO_x	
A13	selective catalytic reduction for NO_x and dioxins			
A14	active carbon filter (steady)			
A15	VOC incinerator		VOC	
A16	biofilter			
A17				

Are you planning to implement any other air abatement technique in the short term (2 years?)

	If yes, please specify which.

WASTE WATER TREATMENT PLANT (WWTP)

Does your installation generate waste water?

If yes, please respond below

Is the waste water generated by your installation treated in a WWTP?

If yes, please respond below

The WWTP only treats waste water generated by your installation

Overall efficiency % In TOC terms

%

	Type of treatments contained in the WWTP	**remarks**
W1	sedimentation	
W2	neutralisation	
W3	chemical treatment with	
W4	separation of emulsions	
W5	filtration	
W6	dewatering	
W7	filterpress	
W8	ion exchange	
W9	flocculation	
W10		

Are you planning to implement any other water treatment in the short term (2 years?)

If yes, please specify which.

PASTE HERE AN IMAGE OF THE FLOW SHEET OF THE INSTALLATION

THIS WORKSHEET CONTAINS QUESTIONS ABOUT THE CURRENT EMISSIONS OF THE INSTALLATION

PRODUCTS					
Name of products with positive market price					
Annual amount of products made (tonnes/yr)					
Electricity (MWh/yr)					
Heat (MWh/yr)					

Notes: C:Continuous, D:Discontinuous, IM: Indirect measurement, E:estimated

If an emission parameter is not applicable for the process include N/A in the table. If you know that may be some emission but you don't have it please leave the cell blank.

AIR EMISSIONS	Types of measurement				
Parameter	**(C, D, IM, E)**	**Concentration**	**Units**	**Load**	**Units**
Fumes generated					Nm³/yr
Oxygen percentage used for the data below			%		
Averaging time period					
CO_2					kg/yr
Dust			mg/Nm³		kg/yr
SO_2			mg/Nm³		kg/yr
NO_x			mg/Nm³		kg/yr
N_2O			mg/Nm³		kg/yr
TOC			mg/Nm³		kg/yr
CO			mg/Nm³		kg/yr
HCl			mg/Nm³		kg/yr
HF			mg/Nm³		kg/yr
Total metals			mg/Nm³		kg/yr
Hg			mg/Nm³		kg/yr
Cd + Tl			mg/Nm³		kg/yr
PAH			mg/Nm³		kg/yr
PCB			mg/Nm³		kg/yr
Chlorobenzenes			mg/Nm³		kg/yr
PCDD/PCDF			(ngTEQ/Nm³)		g/yr
CFC			mg/Nm³		kg/yr
Odour					
Noise					

Note: N means normal conditions (0 °C and 1 atm). Please give the data in dry conditions.

WATER EMISSIONS	**Types of measurement (C, D, IM, E)**				
Parameter		**Concentration**	**Units**	**Load**	**Units**
Averaging time period					
Waste water generated					m^3/yr
SS (Suspended Solids (dried 105 °C))			mg/l		kg/yr
TOC (Total Organic Carbon)			mg/l		kg/yr
BOD_5 (Biological Oxygen Demand 5 days)			mg/l		kg/yr
COD (Chemical Oxygen Demand 2 hours)			mg/l		kg/yr
Hydrocarbons			mg/l		kg/yr
Phenols			mg/l		kg/yr
AOX			mg/l		kg/yr
BTX			mg/l		kg/yr
Total Nitrogen (as N)			mg/l		kg/yr
Nitrit N (NO_2 - N)			mg/l		kg/yr
CN (free)			mg/l		kg/yr
Sulphide (free)			mg/l		kg/yr
F, total			mg/l		kg/yr
P, total			mg/l		kg/yr
Total metals			mg/l		kg/yr
Al (mg/l)			mg/l		kg/yr
Fe (mg/l)			mg/l		kg/yr
As			mg/l		kg/yr
Cr, total			mg/l		kg/yr
Cr (VI)			mg/l		kg/yr
Cu			mg/l		kg/yr
Hg			mg/l		kg/yr
Ni			mg/l		kg/yr
Pb			mg/l		kg/yr
Zn			mg/l		kg/yr

RESIDUES GENERATED BY THE PROCESS

Residues produced by the process					
Annual amount of residues (tonnes/yr)					
Composition					
Subsequent fate					

Please include in this worksheet those techniques implemented or that will be implemented shortly in your installation and that you think are Good Environmental Practices (GEP). For each techniques please give the following information

	Information
Description	
Achieved environmental benefits	
Cross-media effects	
Operational data	
Applicability	
Economics	
Driving force for implementation	
Example plants	
Reference literature	

8.3 Annex III: Types of waste and waste production in the EU

[7, Monier and Labouze, 2001], [39, Militon, et al., 2000], [40, Militon and Becaud, 1998], [41, UK, 1991], [42, UK, 1995], [53, LaGrega, et al., 1994], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [100, UNEP, 2000], [121, Schmidt and Institute for environmental and waste management, 2002], [122, Eucopro, 2003] [124, Iswa, 2003], [125, Ruiz, 2002], [126, Pretz, et al., 2003], [150, TWG, 2004].

This Annex summarises the types of waste produced in the EU and its classification in the EU, as well as summarising the production of waste in individual EU countries and some other European countries. As stated in Chapter 1, waste treatment installations are designed to manage waste. This waste is the input (called raw material in other industrial sectors) to these installations. Viewing the waste treatment sector, as a whole, it can be seen that the physico-chemical properties of such inputs can vary widely. Waste can be liquid to solids (e.g from a physical properties perspective), to organic or to inorganic in character (e.g. from a chemical properties perspective).

The European Waste Framework Directive classifies waste according to the activities that generate the waste, categorising the waste into twenty different groups as listed below.

EWL Code	Groups of waste as mentioned in EWL
01	Wastes resulting from exploration, mining, dressing and further treatment of minerals and quarry
02	Wastes from agricultural, horticultural, hunting, fishing and aquacultural primary production, food preparation and processing
03	Wastes from wood processing and the production of paper, cardboard, pulp, panels and furniture
04	Wastes from the leather, fur and textile industries
05	Wastes from petroleum refining, natural gas purification and pyrolytic treatment of coal
06	Wastes from inorganic chemical processes
07	Wastes from organic chemical processes
08	Wastes from the manufacture, formulation, supply and use of coatings (paints, varnishes and vitreous enamels), adhesives, sealants and printing inks
09	Wastes from the photographic industry
10	Inorganic wastes from thermal processes
11	Inorganic metal-containing wastes from metal treatment and the coating of metals; non-ferrous hydro-metallurgy
12	Wastes from shaping and surface treatment of metals and plastics
13	Oil wastes (except edible oils, 05 and 12)
14	Wastes from organic substances used as solvents (except 07 and 08)
15	Waste packaging; absorbents, wiping cloths, filter materials and protective clothing not otherwise specified
16	Wastes not otherwise specified in the list
17	Construction and demolition wastes (including road construction)
18	Wastes from human or animal health care and/or related research (except kitchen and restaurant wastes not arising from immediate health care)
19	Wastes from waste treatment facilities, off-site waste water treatment plants and the water industry
20	Municipal wastes and similar commercial, industrial and institutional wastes including separately collected fractions
Note: EWL stands for European Waste List	

Table 8.10: European classification of waste
Council Decision 2000/532/EC

In order to give a snapshot of the waste situation in Europe, the following tables (Table 8.11 to Table 8.13) show the amount of waste generated in each Member State (MS) and some other European countries, for each category of waste mentioned above. It should be noted that a waste with the same physico-chemical characteristics may appear with different codes.

	AT		BE		DE		DK		ES		EL		FR		FI		IT		IE		LU		NL		PT		SE		UK		IS		NO		CH	
EWL Code	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N
01	7		0				0		28						0	432			21						0	16971										
02	22		92				0		60						3,1	831	0						0		0	1483										
03			1				0		0						0,2	8525	0		0				0		0	2594										
04	0		0				1		7						< 0.1	13	1		0				0		0	3114										
05	38		3				9		61		15				32	3	29		6				10		8	4										
06	11		13				5		110						137	656	261		3				266		11	6										
07	1		29				11		215		1				46	47	842		146				2		32	35										
08	15		8				15		21						7	4	37		2				3		5	63					0					
09	5		2				10		4						1,4	0	164		0				1		1	1					0					
10	64		90				34		290		109				534	2095	367		1				51		10	1212										
11	5		57				7		132						272	71	298		0				82		5	3										
12	41		12				2		74		1				6	273	233		0				1		2	457										
13	33		33				35		42						42	1	392		28				50		122	0					5					
14	0		8				4		99						2,8	< 0.1	137		4				2		28	0					0					
15	32		7				1		48						9	146			0				0		0	327										
16	67		57				11		22		4				55	968	318		6				117		15	123					1					
17	66		18				5		1						2	897	21		0				2		0	1283										
18	3		4				10		0						2	< 0.1	133		3				0		0	0					0					
19	140		40				91		136		36				24	2301	164		4				11		14	605										
20	26		0				12		12						2	826	5		0				2		0	630										
SUB TOTAL	576	47059	474	48371	9093	39068	263	13229	1362	11096	450	3197	7000	623600	1177	18088	3401	28364	248	6179	180	2548	1520	54090	254	28908	500	3200	1844	248415	7		645	6847		2600
TOTAL	47635		48845		48161		13492		12458		3647		630600		19265		31765		6427		2728		55610		29162		3700		250259				7492			

Table 8.11: Amount of each type of waste generated by European country
Note: Data in kilotonnes per year. H: hazardous, N: non-hazardous

	AT		BE		DE		DK		ES		EL		FR		FI		IT		IE		LU		NL		PT		SE		UK		IS		NO	
EWL Code	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N	H	N
01	1.2		0.0				0.0		2.1		0.0				0.0	2.2	0.0		9.4				0.0		0.0	58.7					0.0			
02	3.8		19.4				0.0		4.4		0.0				0.3	4.3	0.0		0.0				0.0		0.0	5.1					0.0			
03	0.0		0.2				0.0		0.0		0.0				0.0	44.3	0.0		0.0				0.0		0.0	9.0					0.0			
04	0.0		0.0				0.4		0.5		0.0				0.0	0.1	0.0		0.0				0.0		0.1	10.8					0.0			
05	6.6		0.6				3.4		4.5		9.0				2.7	0.0	0.9		2.7				1.7		3.0	0.0					0.0			
06	1.9		2.7				1.9		8.1		0.0				11.6	3.4	7.7		1.3				44.3		4.3	0.0					0.0			
07	0.2		6.1				4.2		15.8		0.6				3.9	0.2	24.8		65.2				0.3		12.8	0.1					0.0			
08	2.6		1.7				5.7		1.5		0.0				0.6	0.0	1.1		0.9				0.5		2.1	0.2					0.0			
09	0.9		0.4				3.8		0.3		0.0				0.1	0.0	4.8		0.0				0.2		0.2	0.0					0.0			
10	11.1		19.0				12.9		21.3		65.7				45.4	10.9	10.8		0.4				8.5		4.0	4.2					0.0			
11	0.9		12.0				2.7		9.7		0.0				23.1	0.4	8.8		0.0				13.7		2.1	0.0					0.0			
12	7.1		2.5				0.8		5.4		0.6				0.5	1.4	6.8		0.0				0.2		0.9	1.6					0.0			
13	5.7		7.0				13.3		3.1		0.0				3.6	0.0	11.5		12.5				8.3		48.0	0.0					83.3			
14	0.0		1.7				1.5		7.3		0.0				0.2	0.0	4.0		1.8				0.3		11.0	0.0					0.0			
15	5.6		1.5				0.4		3.5		0.0				0.8	0.8	0.0		0.0				0.0		0.0	1.1					0.0			
16	11.6		12.0				4.2		1.6		2.4				4.6	5.0	9.3		2.7				19.5		6.0	0.4					16.7			
17	11.5		3.8				1.9		0.1		0.0				0.2	4.7	0.6		0.0				0.3		0.0	4.4					0.0			
18	0.5		0.8				3.8		0.0		0.0				0.1	0.0	3.9		1.3				0.0		0.1	0.0					0.0			
19	24.3		8.4				34.6		10.0		21.7				2.0	11.9	4.8		1.8				1.8		5.3	2.1					0.0			
20	4.5		0.0				4.6		0.9		0.0				0.2	4.3	0.1		0.0				0.3		0.1	2.2					0.0			
SUB TOTAL	1.3	98.7	1.6	98.4	18.9	81.1	2.1	97.9	23.4	76.6	12.3	87.7	1.1	98.9	6.1	93.9	10.7	89.3	3.9	96.1	6.6	93.4	2.7	97.3	0.9	99.1	13.5	86.5	0.7	99.3			8.6	91.4
TOTAL	100		100		100		100		100		100		100		100		100		100		100		100		100		100		100				100	

Table 8.12: Percentage of each type of waste generated by European country
Note: Data in percentages per year. The raw subtotal corresponds to the percentage of hazardous and non-hazardous waste generation for each country
[10, ANPA and ONR, 2001], [19, Brodersen, et al., 2002], [21, Langenkamp and Nieman, 2001], [86, TWG, 2003], [127, Oteiza, 2002], [150, TWG, 2004]

	Municipal	Industrial	Agricultural	Mining	Demolition	Sewage sludge	Hazardous
Belgium	3.5	27.0	53.0	7.1	0.7	0.7	0.9
Denmark	2.4	2.4	-	-	1.5	1.3	0.1
France	1.7	50.0	400.0	10.0	-	0.6	3.0
Germany	19.5	61.0	-	9.5	12.0	1.7	6.0
Greece	3.1	4.3	0.09	3.9	-	-	0.4
Ireland	1.1	1.6	22	1.9	0.2	0.6	0.02
Italy	17.3	40.0	30.0	57.0	34.0	3.5	3.8
Luxembourg	0.17	1.3	-	-	4.0	0.02	0.004
Netherlands	6.9	6.7	86.0	0.1	7.7	0.3	1.5
Portugal	2.4	0.7	0.2	3.9	-	-	0.16
Spain	12.5	5.1	45.0	18.0	-	10	1.7
UK	35.0	70.0	250.0	25.0	32.0	1.0	4.5
US	209.0	760.0	150.0	14.0	32.0	10	275.0 [a]
Japan	48.0	312.0	63.0	26.0	58.0	2	6.6
Units in million tonnes [a] Includes waste water							

Table 8.13: Estimated waste arisings in selected countries
OECD (1991) and Department of the Environment (1992) in [80, Petts and Eduljee, 1994]

The following sections cover more specific information, classified by type of waste. Not all types of waste are covered as in some cases the sector is minor or no information has been provided.

8.3.1 Municipal solid waste (MSW)

Table 8.14 shows a gross summary of the different components of MSW in the Member States as well as the total production of MSW in some European countries.

Country	Paper	Textiles	Plastics	Glass	Metals	Biodegradable waste		Others	Total
Austria	670	63	340	284	166	750	*29 %*	236	2509
Belgium									5014
Czech republic									3200
Cyprus									370
Denmark	505		122	94	42	923	*36 %*	894	2580
Estonia									560
Finland	536			116	53	662	*32 %*	735	2102
France	6250	750	2750	3250	1000	7250	*29 %*	3750	25000
Germany									40017
Greece	640	144	272	144	160	1568	*49 %*	272	3200
Hungary									4300
Ireland									1503
Italy	3300		1050	900	450	6450	*43 %*	2850	15000
Luxembourg	36	4	15	13	5	83	*44 %*	33	189
Netherlands	1785	230	395	445	230	2630	*38 %*	1220	6935
Poland									11800
Portugal	1074	154	503	254	109	1627	*36 %*	811	4532
Slovenia									1020
Spain	3025	689	1511	984	589	6303	*44 %*	1195	14296
Sweden	1408	64	224	256	64	960	*25 %*	224	3200
UK	7400	400	2000	1800	1400	3800	*19 %*	3200	20000
Norway									2722
Data in ktonnes and correspond to years between 1993 and 1997									

Table 8.14: Municipal solid waste composition in the EU and production in different European countries
[59, Hogg, et al., 2002], [92, EEA, 2002], [150, TWG, 2004]

Table 8.15 shows the metals that might be present in municipal solid wastes.

Metal	Present due to
Cd	Plastic pigments, batteries
Cr	Colours, pigments in plastics, textile dyes and leather tanning

Table 8.15: Metals in municipal solid waste
[113, COWI A/S, 2002]

8.3.2 Contaminated waters

Table 8.16 shows the amount of contaminated water generated in France.

Type of waste water	Amount (kt/yr)
Mix of water, hydrocarbons and sediments	10

Table 8.16: Amount of polluted water generated in France
[40, Militon and Becaud, 1998]

Table 8.17 describes efforts to reduce the quantities of waste, illustrated with the aid of statistics from the German federal state of North Rhine Westphalia.

Governmental districts of NRW (Germany)	Quantities of waste (m^3/yr)		
	In 1990	Projected quantity for 2005	
		Projection of 1994 [1]	Projection of 1996 [2]
Arnsberg	278300	204000	102600
Detmold	78300	66000	35300
Duesseldorf	337800	251200	140700
Cologne	264400	206000	98700
Münster	83400	69500	59600
Total	**1042200**	**796700**	**436900**
Valuation	**100 %**	**76 %**	**42 %**

NRW: North Rhine Westphalia
[1] Strategic Concept for Special Waste Disposal in NRW, 4th Edition, 1994, WAZ Press, Duisburg
[2] Strategic Concept for Special Waste Disposal in NRW, 5th Edition, 1996, WAZ Press, Duisburg

Table 8.17: Waste treated by Ph-c plants in North Rhine Westphalia/Germany in 1990 and projected quantity for 2005
[121, Schmidt and Institute for environmental and waste management, 2002], [150, TWG, 2004]

The changes in projected quantities of waste to be treated by Ph-c plants indicate which measures are most successful in achieving effective reductions in quantities of waste. These measures consist of production-integrated measures as well as improvements in production processes and, especially, auxiliary substances and additives.

Despite these measures to avoid and reduce the quantities of waste, waste which arises in the course of production still has to be contended with. However, reductions in the quantities of waste can frequently lead to a build up associated with a more expensive treatment procedure. Physico-chemical plants constantly adapt to these changes technically, operationally and organisationally.

8.3.3 Sewage sludge

Table 8.18 and Table 8.19 show the amount of sewage sludge produced in some European countries and the European average composition of sewage sludge.

Country	Quantity (kt dry matter)
Austria	211.9
Belgium	113
Denmark	200
Finland	158
France	878
Germany	2661
Greece	86
Ireland	43
Italy	
Luxembourg	13
Netherlands	349
Portugal	239
Spain	787
Sweden	236*
UK	1193
Norway	93
Data corresponding to year 1998, except * that correspond to year 1995	

Table 8.18: Amount of sewage sludge produced in some European countries [92, EEA, 2002], [150, TWG, 2004]

Compound	Concentration (mg/kg dry matter)
N	3500 – 46000
P	10400 – 45000
Cd	0.7 – 3.8
Cr	16 – 840
Cu	220 – 641
Hg	0.6 – 4
Ni	8 – 85
Pb	20 – 325
Zn	290 – 2580

Table 8.19: Ranges of contamination and content of sewage sludge [92, EEA, 2002]

8.3.4 Waste acids and bases

The European Waste List (EWL) specifies several waste acids and bases (e.g. sulphuric, hydrochloric, hydrofluoric, phosphoric, nitric acids, calcium hydroxide, soda and ammonia). HF is not regenerated; it is only neutralised. Bases are not typically regenerated; they are typically neutralised. An exception may be represented by the regeneration of black liquors in the pulp industry (covered in Pulp and Paper BREF)

8.3.5 Waste adsorbents

The adsorption of pollutants onto activated carbon, charcoal and ion exchange resins has been a common treatment technique for removing contaminants (e.g. COD, POPs, inorganics) from waste water and gaseous emissions for many years. Activated carbon is also used for the removal of VOCs from gaseous emissions (e.g. pesticide manufacture/formulation). Regeneration procedures for the spent carbon have been primarily limited to thermal reactivation technologies. Resins have found selective uses where recovery and re-use of the organic contaminant is an important objective, or where the contaminants are in reasonably high concentrations. They can also be used for inorganic removal and recovery (e.g. colour removal in the sugar industry, dyestuff and paper mill industries, for phenol removal, for processing new antibiotics, and for polishing high purity waters). Charcoal is primarily used as a fuel. As it is destroyed by combustion processes, charcoal is typically not reactivated.

8.3.6 Waste catalysts

Catalytic methods are used extensively in the production of inorganic and organic chemicals, in petroleum technology, in the processing of synthetic gaseous and liquid fuels, in pollution control, and in energy conversion. Some examples of the use of catalysts are shown in Table 8.20.

Industrial sector	Examples
Production of inorganic chemicals	Hydrogen, ammonia, sulphuric acid, etc.
Production of organic chemicals	Organic synthesis, hydrogenation, dehydrogenation, acid catalysed dehydration reactions, oxychlorination
Petroleum refining	Reforming, desulphurisation, hydrocracking, cracking, isomerisation, lube oil hydrofinishing
Pollution control techniques	NO_x abatement SCR, off-gas combustion purification

Table 8.20: Industrial sector where catalysts are used
[125, Ruiz, 2002]

The type of compounds used as catalysts depends on the process but metals, metal oxides and acids are the ones most commonly used, as shown in Table 8.21.

	Importance	Examples
Metals	They are among the most important and widely used industrial catalyst components	Ag, Au, and the platinum group metals Transition metals: Fe, Co, Ni, Mo, Ru, Rh, Pd, W, Re, Os, Ir and Pt. Nontransition metals: Cu, Zn, As, Se, Ag, Cd, Sn, Sb, Te, Au, Hg, Pb and Bi.
Metal oxides	They are common catalyst supports and catalysts.	Al_2O_3, SiO_2- Al_2O_3, V_2O_5, ZnO, NiO, MoO_3, CoO, WO_3.
Metal sulphides		MoS_2, WS_2
Acids	Insulators that show the transition from basic to amphoteric and acidic character	Na_2O, MgO, Al_2O_3 , SiO_2 , and P_2O_5
Bases	Limited industrial applications	$Ba(OH)_2$, $Ca(OH)_2$, Na
Multifunctional catalysts		$Bi_2O_3.MoO_3$
Ion exchangers		
Organometallic complexes		
Others		Co(acetate)$_2$, amines, benzoil peroxide, etc

Table 8.21: Overview of the types of catalysts used for industrial purposes
[125, Ruiz, 2002]

Theoretically, a catalyst remains unchanged after its use. However, when a catalyst may lose its activity because of deactivation (by, e.g. poisoning (by, e.g. P, S, As, Se, Te, Bi, C), fouling or sintering) and re-dispersion of the active centres of the catalysts. As a consequence, waste catalysts are mainly composed of the same materials as the native catalyst but contaminated with some additional components.

8.3.7 Wastes from combustion processes

Combustion wastes are generated during the combustion of coal, (heavy) liquid fuels or waste in large combustion plants, industrial heaters and boilers, and incinerators. Two types of wastes are produced in combustion processes. One type is the bottom ashes (slags) generated in the combustion chamber and the second corresponds to the flue-gas treatment (FGT) waste (sometimes so-called 'air pollution control' (APC) residues), regulated according to the European Legislation as hazardous waste. FGT waste can come from any combustion process (e.g. incinerators, large combustion plants, industrial boilers) and they are typically treated before re-use or being landfilled.

The term 'APC residue' is used with slightly differing meanings in the literature: strictly speaking the term only covers the solid residues (i.e. sludge and gypsum from wet systems, and excess reagent and reaction products from dry/semi-dry systems) generated to minimise emissions of acidic components in the flue-gas. Considering this definition, fly ashes should not be included. However, from a management point of view, all these solid residues (the fly ash, which is the major component, (most important by amount and even boiler ash in some MSs) are usually handled in combination (notably in the dry and semi-dry systems).

FGT waste is used as including all types of solid residues produced in or after the heat recovery systems (boiler/economiser). This includes fly ash, boiler ash, excess lime and reaction products (dry/semi-dry), sludge from scrubber solution treatment and gypsum (wet). No special emphasis is placed on managing sludge and gypsum separately, as the amounts are relatively small compared to fly ash. Table 8.22 and Table 8.23 indicate the waste generated by coal fired power plants and the total in some European countries.

Country	Fly ash	Slag and bottom ash	Gypsum	Other products from gas cleaning	Sludge	Total[1]
Austria	334.5	24.9	74.5	2.0	0.3	436.2
Belgium						1135
Denmark	1158	152	374	100	n.a.	1784
Finland						1274
France	1840 - 1940					2100
Germany						25310
Greece	10					10080
Ireland						450
Italy	872	182	4	3	2	1063
Luxembourg						
Netherlands						1525
Portugal	272	30				302
Spain	531					531
Sweden						600
UK	5100	1400				6500
Norway						

Data in kt/yr correspond to years from 1993 to 1999 depending on the country. Data contains ashes (bottom and fly) as well as residues from flue-gas cleaning (gypsum).

[1] Corresponds to waste from energy production plants

Table 8.22: Waste from coal-fired power plants
[40, Militon and Becaud, 1998], [92, EEA, 2002], [95, RAC/CP, 2003]

Data in ktonnes		Type of FGT system			
Country		**Dry/semi-dry**	**Wet**	**Not specified**	**Total**
Austria	Residues	0	8.1	0	8.1
	Waste	0	450.0	0	450.0
Belgium	Residues	2.7	0	4.4	7.1
	Waste	90.1	0	101.2	191.3
Denmark	Residues	26.6	30.9	5.1	62.6
	Waste	745.6	1348.8	234.6	2329.0
Germany	Residues	284.4	377.4	13.2	675.0
	Waste	3807.0	10027.0	247.0	14081.0
France	Residues	83.2	122.4	5.9	211.5
	Waste	551.7	1971.4	121.6	2644.7
Hungary	Residues	11.1	0	0	11.1
	Waste	352.2	0	0	352.2
Italy	Residues	0	0	50.2	50.2
	Waste	0	0	1109.4	1109.4
Netherlands	Residues	0	54.0	30.4	84.4
	Waste	0	1492.0	887.0	2379.0
Norway	Residues	0.4	3.4	0	3.8
	Waste	17.5	126.7	0	144.2
Portugal	Residues	27.4	0	0	27.4
	Waste	321.8	0	0	321.8
Spain	Residues	58.8	0	0	58.8
	Waste	817.9	0	0	817.9
Sweden	Residues	43.0	29.0	14.8	86.8
	Waste	699.8	901.8	327.4	1929.0
United Kinddom	Residues	30.9	0	0	30.9
	Waste	1074.1	0	0	1074.1
Switzerland	Residues	0	65.7	0	65.7
	Waste	0	2462.6	0	2462.6
Total	Residue	396.3	530.3	148.0	1074.6
	Waste	6266.2	12819.5	3787.9	22873.6

Table 8.23: Amounts of FGT waste in some European countries
[124, Iswa, 2003], [152, TWG, 2004]

An overview of the main components of solid FGT waste is given in Table 8.24.

Solid component	Dry/semi-dry systems	Wet systems
Fly ash/boiler ash	Always	Always
Excess reagent + reaction products	Always: can be mixed with fly ash; contain Cl salts and/or gypsum	-
Dioxin sorbent	Optional: usually included	Optional: usually handled separately or re-used as a neutralisation agent in Waste Water Treatment Plant
Sludge	-	Always: sometimes mixed with fly ash/boiler ash (Bamberg model)
Gypsum	Included in reaction products	Obtained if no liquid effluent: handled separately if recovery is intended
Cl salts	Included in reaction products; recovery possible in some cases	Obtained if no liquid effluent: recovery possible in some cases

Table 8.24: Main components of the FGT waste
[124, Iswa, 2003], [150, TWG, 2004]

8.3.8 Waste oil

Waste oil (WO) is a term defined by European law as any mineral-based lubrication or industrial oils which have become unfit for the use for which they were originally intended, and in particular used combustion engine oils and gearbox oils, and also mineral lubricating oils, oils for turbines and hydraulic oils (Council Directive 85/101/EEC). WOs are classified as hazardous waste by European law and should be collected so that they can be safely treated. Waste oil contaminated with more than 50 ppm of PCBs is not included in this category because they are treated differently by EU legislation.

WOs cover a wide range of materials, with further differences arising from their previous use under differing conditions. In this document, the term ‘used oil’ is understood to include only those WOs which arise from the use of lubricating oils. Slop oils recovered from drainage systems, refineries, fuel storage sites, etc. are another type of waste oil. They may end up in used oil collection systems, where they can decrease the value of the used oil. Oil filters and carburetor filters contain around 30 % hydrocarbons.

Used oils can be categorised according to market considerations as follow:

- (black) engine oils: these represent more than 70 % of used oil. The largest potential source of used oils is from vehicle use, particularly engine oils
- black industrial oils: these represent about 5 % of used oil
- light industrial oils: these represent about 25 % of used oil. They are relatively clean and their market value is high. Their market is very specific and independent from the classical supply routes of regeneration.

Used oil composition is becoming more and more complex due to different factors:

- the increasing use of dispersants, as well as esters and polyalphaolefins, e.g. to increase the life of the oil. However, as a result, the resulting WO has become more complex and dirty over time
- the progressive displacement of conventional mineral based auto lubricants by ‘synthetic’ products which have enhanced performance characteristics. Whereas some of these synthetic products can be regenerated along with mineral oils, others (those based upon esters for instance) are less suitable to regeneration because they tend to be less stable in the presence of caustic (often used by regeneration processes) and less stable to the hydro-finishing step.

A low proportion of base oil (less than 2 % of the total consumption) originates from agricultural sources, being produced from either sunflower or rape-seed. These bio-lubricants are used in applications where their characteristics represent a real advantage, in particular:

- their good biodegradability. This is important when lubrication losses into the environmental media, e.g. soil and water, can occur during use (woodcutting with motor saws, boats, cutting oils, etc.)
- their high viscosity index and low volatility for instance.

The fate of 1.1 million tonnes of used oils generated in Europe in 1993 was unrecorded. This represents approx. 20 % of the total virgin lubricating oils market. The following Figure 8.1 shows that the amount of waste oil recovered in EU has increased to ~50 %. In 1995, the Australian Industry Commission [13, Marshall, et al., 1999] estimated that, of the world’s total available waste oil, only 44 % was collected.

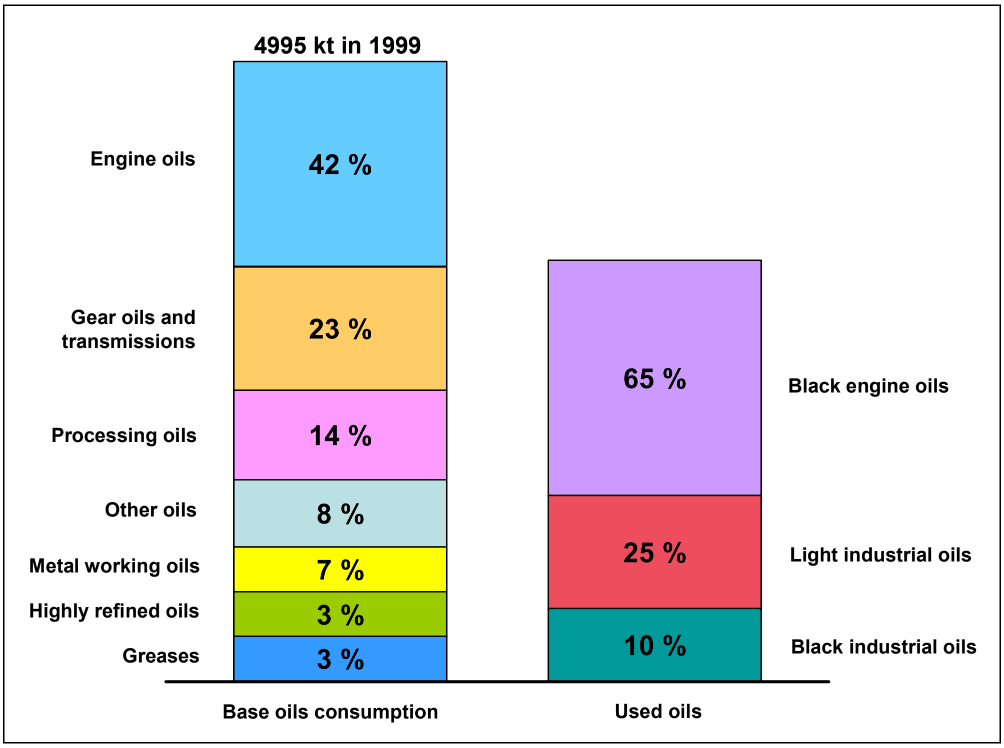

Figure 8.1: Base oils consumed and used oils generated in the EU
[7, Monier and Labouze, 2001]

More information on the amount collected in each MS and on issues related to the waste oil market can be found in [7, Monier and Labouze, 2001]. More information about the typology of lubricants and the different types of WO is given below.

Lubricants and waste oils
Table 8.25 details:

- the typology of lubricants and a split of the lubricant consumption according to this typology
- the average ratio to be considered for each category of lubricant to assess the WO generated during their use
- the type of WO, black oils (from engine origin or industrial origin) or light oils, generated in each case.

Lubricants Consumption					*WO*		
Category	**Application**	**Use**	**European Consumption 1999 (kt)**	**% of consumption**	**Ratio (oil consumed/ WO generated)**	**WO 1999 (kt)**	**Type of WO**
Engine oils	Engine oils for passenger cars	To diminish friction between moving parts of engine	2098	42 %	59 %	1238	Black oils
	First fill oils for passenger cars						
	Engine oils for commercial vehicles						
	First fill oils for industrial vehicles						
	Multipurpose diesel oils						
	Two-stroke engine oils						
	Other engine oils						
Gear oils & transmissions	Automatic transmission fluids	To inhibit wearing out of gears and bearings and also to inhibit oxidation and corrosion	1149	23 %	24 %	276	Black oils
	Automotive gear oils						
	Industrial gear oils						
	Hydraulic transmission oils						
	Shock absorber oils						
Greases	Automotive greases	To diminish friction between moving parts of engine	150	3 %	27 %	40	Black oils
	Industrial greases						
Metal working oils	Quenching oils	In metal working for lubricating and cooling of both tools and the metals to be worked	350	7 %	0 %	0	Lost
	Neat oils for metalworking						
	Soluble oils for metalworking						
	Rust prevention products						
Highly refined oils	Turbine oils		150	3 %	48 %	72	Light oils
	Electrical oils						
Other oils	Compressor oils	To inhibit wearing out of gears and bearings and also to inhibit oxidation and corrosion	400	8 %	61 %	244	Black oils
	General machine lubricants						
	Other oils for non-lubricating uses						
Processing oils	Process oils		699	14 %	77 %	538	Light oils
	Technical white oils						
	Medical white oils						
TOTAL			**4996**	**100 %**	**50 % on average**	**2408**	

Table 8.25: EU lubricant collectable waste oil
[7, Monier and Labouze, 2001]

End Use	Sales 1999 (tonnes)	% recoverable[1]	Potentially collectable (tonnes)
Gasoline and diesel engines	249488	65	162167
Agricultural engines	15000	65	9750
Other engines	7288	0	0
Marine engines	37728	25	9432
Aviation and turbine oils	2214	50	1107
Total engine oils	311718		182456
Hydraulic and transmission	96352	80	77082
Other gear oil	53815	80	43052
Total gear/transmission oils	150167		120134
Total greases	11815		1177
Total metal working oils	35548		7110
Turbine and electrical oils	27070	95	25717
General machine lubricants	15219	50	7610
Non-lubricating industrial oils	11792	10	1179
Other industrial oils	10939	20	2188
Total other oils	65020		36693
Total processing oils	129908		0
Deliveries to blenders	86151	50	43075
Total all lubricants	**790327**	**(49.4)**	**390646**
[1]Estimates based on CONCAWE WQ/STF-26 study			

Table 8.26: UK lubricant collectable waste oil estimates (tonnes)
[7, Monier and Labouze, 2001]

8.3.9 Waste solvents

In this document, the term 'waste solvent' is to be understood as including all those wastes from organic substances used as solvents, also including those used in organic chemical processes and from manufacture, formulation, supply, and those used in coatings (paints, varnishes and vitreous enamels), adhesives, sealants and printing inks.

Country	Annual production (kt/yr)	Treated (kt/yr)
ES		127
FR	800	90.7
IT		58.3

Table 8.27: Production of solvents and treatment of waste solvents
[40, Militon and Becaud, 1998], [95, RAC/CP, 2003]

8.3.10 Waste plastics

Plastics are mainly organic polymers with different compositions. Typical polymers are polystyrene (PS), polyethylene terephthalate (PET), polypropylene (PP), polyurethane (PU), polyacrylonitrile-butadiene-styrene (ABS), polycarbonate (PC), polyamides (PA), polybutylene terephthalate (PBT), polyethylene (PE), polyvinyl chloride (PVC), etc. Waste plastics can be differentiated according to its type of use as shown below:

Sectors	Polymers contained in the plastic waste
Packaging	PE, PP, PS, PET, etc.
Automotive	PP, PU, ABS, etc.
Electrical	PS, ABS, PP, etc.
Electronics	PC, PA, PBT, etc..
Building + Construction	Foams: PU, Expanded PS, Mix of PS, etc. Pipes: PE, PVC, etc.
Agricultural (films)	PE

Table 8.28: Waste plastics
[58, CEFIC, 2002], [150, TWG, 2004]

The requirements for each type of use greatly differs and the choice of plastic is made by the user, typically a downstream producer, on a cost performance ratio. Table 8.29 shows some examples of metals that are present in plastics.

Metal	Use	Comment
Pb	PVC stabiliser	About 0.7 – 2 % Pb as stabiliser in many types of rigid PVC for outdoor use
	Pigment in plastic	Lead chromate for yellow and red colours contains 64 % lead
Cd	Stabilisers (e.g. PVC)	About 0.2 %, up to a maximum of 0.5 % cadmium used as stabiliser in rigid PVC for outdoor applications (window profiles, sidings).
	Pigment	
Cr (Cr (III) and Cr (VI))	Colours and pigments	

Table 8.29: Presence of metals in plastics
[113, COWI A/S, 2002], [150, TWG, 2004]

8.3.11 Waste wood

Contaminated wood can arise from electrical and telephone fence posts, supports in railways and from all wood treated for use outdoors. This type of wood is typically treated and some of the product for treatment may contain metals. The treatments that they receive are based on creosote and pentachlorophenol, metallic salts, copper sulphate, CFK treatment (Cu, F, Cr treatment), CCB treatment (Cu, Cr, B treatment) or CCA treatment (Cu, Cr, As treatment). Table 8.30 shows some data on the amount of this type of waste generated in one MS (France).

Type of contaminated wood	Amount of waste generated per year	
	(m^3/yr)	(t/yr)
Wood treated with creosote	150000	75000
Wood treated with CCA	80000	40000

Table 8.30: Amount of contaminated wood generated
[40, Militon and Becaud, 1998]

8.3.12 Cyanide wastes

Cyanide wastes typically arise in solutions that have been used for a variety of operations in the metals/electroplating industries, such as cleaning, de-tarnishing, printing and electroplating solutions. Typically, the waste consists of solid or liquid cyanide salts. Cyanide wastes also arise as fused solids within a container or in block form when molten salts have been used for heat treatment purposes.

The volume of cyanide wastes arising has significantly decreased in recent years, mostly due to the replacement of cyanide based cleaners by surface active agents and the use of copper pyrophosphate plating solutions in place of copper cyanide.

8.3.13 Other inorganic waste

Waste containing silver mainly arises from film processing, but to a lesser degree also some from the custome sector and the dental sector, which also produces waste contaminated with mercury.

8.3.14 Refractory ceramics waste

The level of contamination of refractory ceramics depends on its utilisations. For example, it is known that ceramics used in the combustion of heavy fuel contain cadmium, vanadium, nickel and sulphur and that sulphur is common in refractory ceramics used in petrochemistry. The amount of waste generated per year in France is 200 kt [40, Militon and Becaud, 1998].

8.3.15 Hazardous waste from the construction and demolition sector

Table 8.31 shows the amount of hazardous waste produced from the construction and demolition sector in some European countries.

Country	Quantity (kt)
AU	8.4
DE	490.0
DK	8.4
EL	0.9*
ES (Region of Catalonia)	185.5
IE	159.0
Data from 1996 except for DE that corresponds to 1993 * Data refer only to asbestos	

Table 8.31: Amount of hazardous waste generated from the construction and demolition sectors in some European countries
[92, EEA, 2002], [95, RAC/CP, 2003]

8.3.16 Waste contaminated with PCBs

Some types of waste contaminated with PCBs are electrical transformers, capacitors, transformer oils and waste oils (waste oil contaminated with more than 50 ppm of PCB is considered by European Legislation to be a special waste which cannot be treated in the same way as waste oils). Some commonly found materials may also become polluted with PCBs (soils, building materials, waste clothing, other debris, etc.). These can typically be decontaminated by treatment with a solvent, and the resulting solvent and PCBs mixture may then be processed.

The uses of PCBs can be classified into three categories:

Closed applications
As the name implies, closed uses are those in which the PCBs are enclosed and cannot escape during normal use. The main examples are transformers and capacitors, which are sealed pieces of electrical equipment. Apart from accidents (fire, mechanical damage, etc.) the PCB will remain in a safe environment, at least until the end of the working life of the equipment in which it is enclosed.

Partially closed applications
In these, oil containing PCB is employed as a fluid which is called upon to move during use, for example as a heat transfer fluid or as a hydraulic fluid, in pumps or in switches. This movement implies the presence of joints and seals in the equipment, offering the possibility that these items of equipment can release small amounts of fluid during normal operation.

Open applications

In open applications, the PCBs are generally incorporated into a formulation, usually in small or very small quantities. Such products can be lubricants, adhesives, paints, inks, etc. The PCBs can become very dispersed depending on each application, and it is virtually impossible to destroy them. The solution to this problem is instead found further upstream, i.e. to ban the incorporation of PCBs in such products; this of course is already done in most countries, although many products manufactured earlier may still be in use.

This classification is useful since it indicates the likelihood with which the PCB can be released, intentionally or unintentionally, thereby leading to a PCB contamination problem.

8.4 Annex IV. Quality assurance systems for secondary recovered fuel (SRF)

[126, Pretz, et al., 2003]

There are several initiatives to characterise and set in place quality assurance systems for solid waste fuels (e.g. SRF). These can be divided into initiatives based either on a European wide level or on a national level. Some have been described in Section 3.5.4.4 of this document.

Quality assurance systems

Part of the description of the best available technique concerns the logistics of the SRF processing. By choosing and using specific waste materials, SRF producers set a kind of quality assurance themselves. Quality assurance systems already exist and further regulations are currently under development.

In the past, SRF was mainly produced from process related wastes as mono-batches which were easier to handle because of their constant qualities. Nowadays high calorific fractions of municipal solid wastes and of other mixed wastes are also used in the production of SRF, which makes the need for a quality assurance system more urgent. The aim of a quality assurance system for SRF is to attain and ensure constant qualities, to increase acceptance of SRF by end users and permitting authorities. The requirements mainly concern product quality. The following sections present the results of a survey about existing quality assurance systems and ongoing developments.

<u>RAL</u>

In early 1999, the German Bundesgütegemeinschaft für Sekundärbrennstoffe e.V. (BGS e.V.) initiated the quality label GZ 724. The label is awarded to SRF producers which comply with certain quality and consistency requirements. The standards initially applied relate to the cement industry and power stations, where SRF now have to fulfil the criteria given in Annexes 1 and 2 of GZ 724. Annex 1 contains a list of all the allowed wastes which can be used as a basis for the SRF. In Annex 2 values are given which have to be met. These values are shown in Table 8.32. Checks are made in two phases in the approval as well as in the supervision procedures.

Phase 1:

Three samples taken by an independent supervisor, and seven samples taken out of a pool of samples resulting from self monitoring are analysed according to certain standards. For the heavy metal contents:

- the median value of the ten samples must not exceed the allowed median values given in Table 8.32
- the "80 the percentile" values in Table 8.32 must not be exceeded by eight out of the ten samples (Application of the '4 out of 5 regulation').

Phase 2:

If in phase 1, the median or the "4 out of 5 regulation" does not comply, another ten samples are chosen out of the sample pool of the self monitoring and examined for the parameter(s) that did not comply. The analysis follows the some procedures as that used in level 1:

- the median values of the 20 samples must not exceed the allowed median values given in Table 8.32 and
- the '80th percentile' values of Table 8.32 must not be exceeded by 16 out of 20 the samples (Application of the "4 out of 5-Regulation").

Further parameters need to be documented as follows: the calorific value, the humidity, the ash content, and the chlorine content.

These values should not be regarded as strict thresholds. The conditions are kept if four of five outliers is still below the 80th percentile. Outliers often appear in waste analysis and this regulation is specific to the character of wastes. The guideline value used is the median because of the obvious low concentrations in waste and environmental analysis. Heavy metal contents are established applying the DIN or DIN EN ISO test methods. The digestion method is applied with aqua regia in a closed microwave system.

	Content of heavy metals 4)	
	median (mg/kgDM)	80th percentile (mg/kgDM)
Cadmium	4	9
Mercury	0.6	1.2
Thallium	1	2
Arsenic	5	13
Cobalt	6	12
Nickel	25 1) 80 2)	50 1) 160 2)
Selenium	3	5
Tellurium	3	5
Antimony	25	60
Lead	70 1) 190 2)	200 1) - 3)
Chromium	40 1) 125 2)	120 1) 250 2)
Copper	120 1) 350 2)	- 3) - 3)
Manganese	50 1) 250 2)	100 1) 500 2)
Vanadium	10	25
Tin	30	70
Beryllium	0.5	2

1) For solid recovered fuel from production specific waste

2) For solid recovered fuel from the high calorific fractions from municipal waste

3) Restricted not until a secured database is given by the fuel processing

4) The mentioned heavy metal contents are valid up to a calorific value NCV_{DM} of ≥ 16 MJ/kg for the high calorific fractions from municipal waste and up to a calorific value NCV_{DM} of ≥ 20 MJ/kg for production specific waste. For calorific values falling below, the mentioned values need to be lowered accordingly, an increase is not allowed.

Table 8.32: Heavy metal contents which have to be complied with according to BGS [126, Pretz, et al., 2003]

Furthermore the BGS e.V. demands an approval procedure (first inspection) and a monitoring procedure, which incorporates self-monitoring and independent supervision. A re-inspection is also scheduled. Moreover, Annex 2 of GZ 724 defines sampling procedures, covering all the analytical examinations and regulations.

Acknowledging procedure (first inspection)

To attain the quality label the applicant has to pass the approvals procedure. This first inspection is conducted by a neutral inspection institute which assesses the applied techniques and workforce and facilities. The SRF have to meet the regulations in Annex 2. Furthermore, the applicant has to verify his practice and expert knowledge, reliability and the official permission for operating the plant. Furthermore, he has to prove that he is able to conduct a continuous self-monitoring system. Parts of this self-monitoring can be sub-contracted to a neutral inspection institute in arrangement with the BGS e.V., but this inspection institute is then not allowed to carry out the independent supervision at the same time.

Self-monitoring

The self-monitoring concerns the production process control and is carried out by the enterprise itself or sub-contracted out as explained above. The input material has to be documented using mass balance according to the European Waste List Code (EWL), e.g. also listing mass, derivation, physico-chemical parameters and the output as produced SRFs. The produced SRFs have to be approved in line with the requirements from Annex 2.

Independent supervision

The independent supervision is conducted by a dedicated inspection institute which is nominated by the BGS e.V. The quality of the produced SRF is controlled and the completeness and the reasonableness of the self-monitoring documentation are reviewed. The ascertained personal situation from the approval proceeding is also appraised. The monitoring intervals depend on the amount of SRF produced yearly.

Re-inspection

A re-inspection is carried out within a period of four weeks if, in the framework of the independent supervision, the supervisor detects any faults in the quality assurance. If the re-inspection fails, the enterprise is deemed to have failed the independent supervision as a whole. What further action is needed is laid down in the implementation instructions for awarding and using the BGS e.V quality label.

The BGS e.V. can set penalties depending on the irregularity. This may be an admonishment or even cancellation of the rights to use the label.

SFS 5875

The Finnish waste disposal system is based on a separate collection of wastes for recycling and for SRF production. Different solid wastes are used in Finnish boilers with a high technical standard, ensuring highly efficient energy production together with low emission levels. The application of SRF in the Finnish multifuel boiler is considered to be ‘well suited’. The regulations concern separate collected, dry solid, high calorific fractions or for dry, high calorific fractions derived from household wastes. The regulation defines operations and demands to control the production of SRF. The regulation refers to the complete waste management chain, from the waste recovered paper source up to the disposal. For each part of the disposal chain, the standard requires a person to be in charge and to take responsibility for monitoring the technical and quality requirements.

Similar to the BGS e.V. standard, the annexes of the Finnish standard define concrete requirements concerning the threshold limits for heavy metals, as well as for the framework of the analysis, sampling, etc. The thresholds need to be set and kept to, as well as regulations covering contracts.

Supervision operation

Compliance with the standard needs to be guaranteed by contracts and stipulated delivery specifications between the respective groups within the disposal string. Regulations concerning self-monitoring, independent supervision or approvals procedures are not newly defined in this standard. Therefore, the regulations of the standardisation institute will need to be followed.

Quality requirements and classes

In comparison to the BGS e.V. standard, the Finnish standard is split into three quality classes. For categorisation of SRF in Finland seven elements are analysed. Limiting values for heavy metals are given for cadmium and mercury. Furthermore, the classification into one class requires an analysis for the contents of chlorine, sulphur, nitrogen, potassium and sodium. Table 8.33 presents the criteria for the classification into quality classes. Metallic aluminium is not allowed for in quality class I (1) but is accepted within the limits accuracy (two decimal places). The metallic aluminium content of SRF of quality class II (2) is already reduced by the sorting and further processing steps. For SRF of quality class III (3) it is necessary to satisfy the content of metallic aluminium separately. The given thresholds refer to a volume of SRF of ≤ 1000 m^3 or to the volume which is produced or delivered in one month.

Parameter	Unit	Quality classes		
		I	II	III
Chlorine	weight -%	<0.15	<0.5	<1.5
Sulphur	weight -%	<0.2	<0.3	<0.5
Nitrogen	weight -%	<1.0	<1.5	<2.5
Potassium and sodium	weight -%	<0.2	<0.4	<0.5
Aluminium (metallic)	weight -%	- 1)	- 2)	- 3)
Mercury	mg/kg	<0.1	<0.2	<0.5
Cadmium	mg/kg	<1.0	<4.0	<5.0

1) Metallic aluminium is not allowed, but is accepted within the limits of reporting precision.
2) Metallic aluminium is minimised by source-separation and by the fuel production process.
3) Metallic aluminium content is agreed separately.

Table 8.33: Quality classes according to SFS 5875/13/ [126, Pretz, et al., 2003]

In principle, the SRF quality is specified by means of Table 8.33 above. A second possibility for an arrangement about the characteristics of SRF is the possibility of fixing it on the content and amount of parameters. The amount of parameters may need further thresholds and characters to extend to the defined quality classes. Concerning the analysis of the physico-chemical parameters, the respective ISO standards apply.

CEN/BT/TF 118

The CEN Task Force 118 'Solid Recovered Fuels' was established in April 2000. It was set up to prepare a technical report about the production and application of SRF within the EU, as well as to develop a work programme as a basis for a future European standard. The European classification model will be based on SRF characteristics, source material and origin.

The report concluded that it was indeed necessary to develop a European standard. CEN has been given the mandate to develop, as a first step, a set of technical specifications concerning the use of SRF for energy recovery in waste incineration or co-incineration plants. Secondly, CEN has been given a mandate to transform this set of technical specifications into European Standards.

ÖG SET

In a joint project of the 'Österreichische Gütegemeinschaft für Sekundärenergieträger (ÖG SET)', a quality assurance concept has been worked out. The work started in May 2001 and it was finished on May 2003. The result ought to be a basis for a label like the one generated by the BGS e.V.

Others

Internal quality assurance systems already exist, e.g. the generated quality assurance system used by Trienekens AG whose successor is RWE Umwelt AG. Table 8.34 gives an overview about this system.

Process step	Measures	Supplementary measures
Origin (waste producer, sorting plant, mechanical biological processing)	Collection of wastes, avoidance of impurities, contractual arrangements about allowed qualities of wastes, declaration analysis, documentation of disposed amounts	Instruction courses for waste producers, periodic controls of the waste producing company by the disposer
Processing plant (delivery)	(Regular) sampling and analysis, reserve samples, documentation of input and processed amounts	Regular sampling and analysis of the outgoing materials by a external official expert
Processing plant (output)	Regular sampling and analysis, reserve samples, documentation of the delivered amounts	
Cement and lime kilns, power plants	Regular sampling and analysis, reserve samples, documentation of the input amounts	

Table 8.34: Quality assurance system of RWE Umwelt AG
[126, Pretz, et al., 2003]

Comparison of quality assurance systems

The regulations of the German Bundesgütegemeinschaft für Sekundärbrennstoffe e.V. should complement internal quality assurance systems. The regulations according to RAL-GZ 724 are a completion of ISO 9000 and are specific to SRF. The Finnish regulation aims at incorporation of existing systems, opening the possibility for agreements to be made concerning the SRF quality between the producer and the consumer. The BGS e.V. actually defines two classes, whereas the Finnish system separates into three different quality classes. It has already been decided for the new EU regulations that the quality classes will be expanded. The result may be a classification system as shown in Table 8.35, with additional parameters for fuel technology and process engineering.

		Codification of the columns				
Parameter	Units	A	B	C	.....	X
NCV	MJ/kg					
H_2O	% o.s.					
Chlorine	% o.s.					
Ash	% o.s.					
Hg	mg/MJ					
Cd	mg/MJ					
Sum of As, Co, Cr, Cu, Mn, Ni, Pb, Sb, V	mg/MJ					
Biogenic part	% o.s.					

Table 8.35: Classification system
[126, Pretz, et al., 2003]

The BGS e.V. standard requires documentation of the chlorine content whereas the Finnish standard defines thresholds for each quality class.

The Finnish standard seems to be less widely applied in practice than the German quality label GZ 724. The approach of the Finnish standard is quite different in comparison to the German quality label. The German system is based upon an extensive data basis and considers the complete process chain. The Finnish standard regulates high calorific fractions derived from separate collected wastes and defines procedures and requirements for SRF quality control.