
MINI BREF 5

INSTALLATIONS FOR THE PREPARATION OF WASTE TO BE USED AS FUEL

[extract from *BREF for the Waste Treatments Industries* from August 2006]

Note: Text in blue corresponds to references also mentioned in MINI-BREF 1-Common techniques

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NON OFFICIAL FEAD VERSION

1. General information

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.

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 1.1: 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 1.2: 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 1.3)

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 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 1.3: 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 1.3 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 1.4. 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
<p>Note: The data correspond to estimations established in December 2002</p> <p>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.</p> <p>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.</p>		

Table 1.4: Production and site numbers of preparation of waste fuel mainly from hazardous waste in EU-15
[122, Eucopro, 2003], [150, TWG, 2004]

Chapter 3 : economic and institutionnel aspects of waste treatment sector

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 CO₂ 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 recovered 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 1.5.

Fuel	%
Petroleum coke	39
Hard coal	36
Fuel oil	7
Lignite	6

Gas	2
Waste	10

Table 1.5: 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 substitution 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.

NON OFFICIAL FEAD VERSION

2. Applied processes and techniques

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, Milton and Becaude, 1998], [50, Scori, 2002], [52, Ecodeco, 2002], [55, UK EA, 2001], [56, Babbie 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 purposes 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 must need 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 2.1 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 2.1.

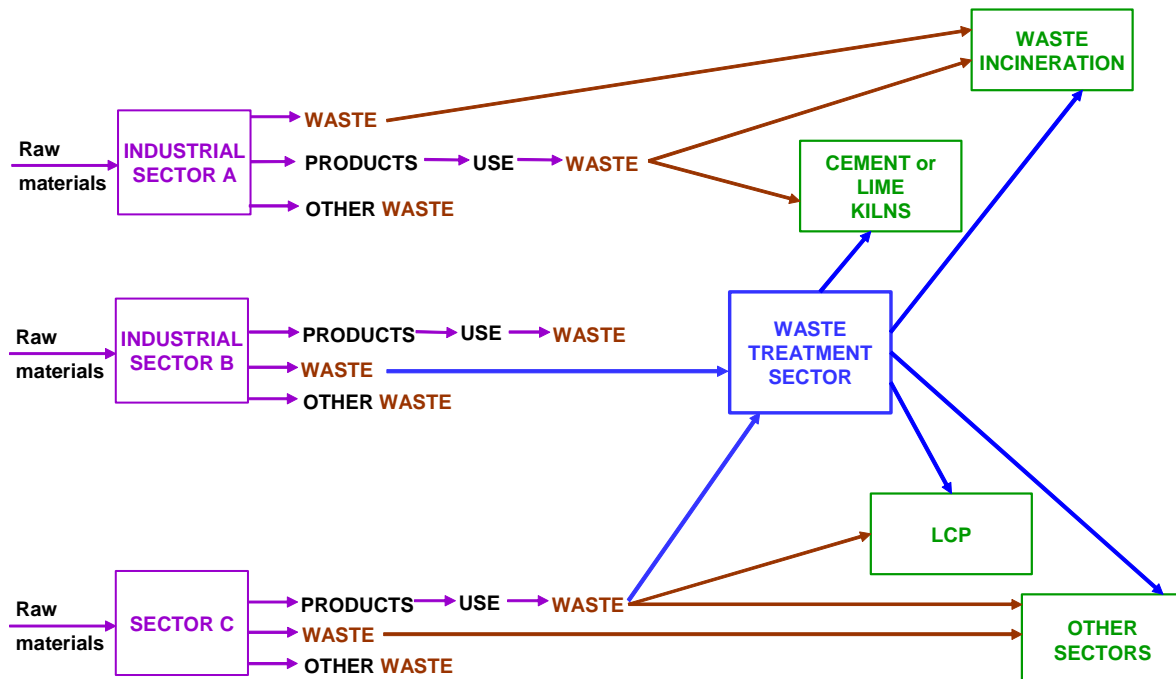


Figure 2.1: Some current possibilities for the use of waste as a fuel in different sectors

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 Error! Reference source not found..

2.1. Preparation of solid waste fuel mainly from solid waste

2.1.1. 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 Error! Reference source not found.. 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 **Error! Reference source not found..** 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-combustible 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 **Error! Reference source not found..** 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 2.2 only shows one main characteristic - automatic picking. Near infrared spectroscopy or metal separation also influences such properties as for example heavy metal contents. Figure 2.2 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.

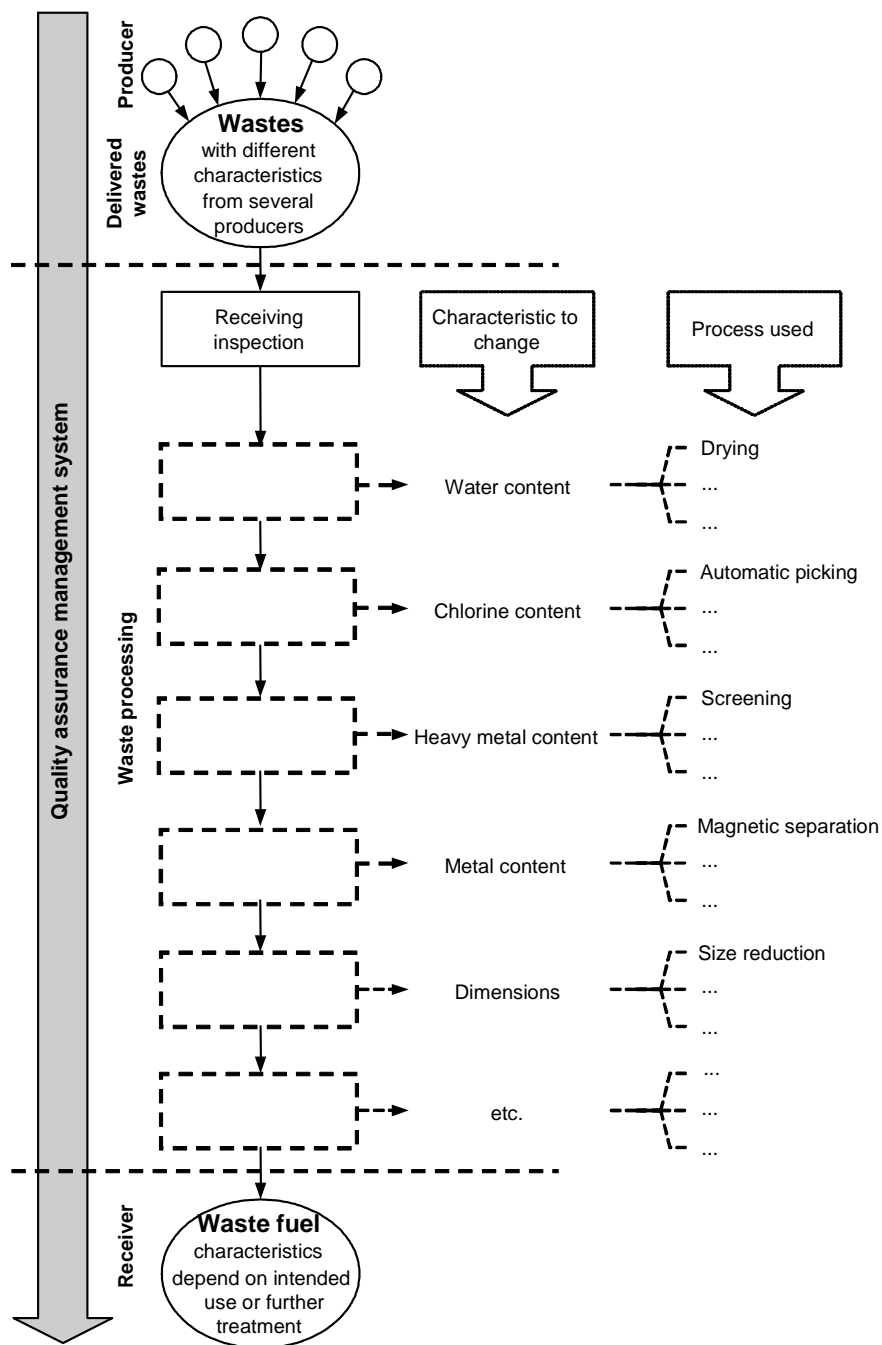


Figure 2.2: Process scheme of solid waste fuel production
 [126, Pretz, et al., 2003]

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 achieved 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 2.1 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 2.1: 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.

2.1.2. 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 2.3. 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.

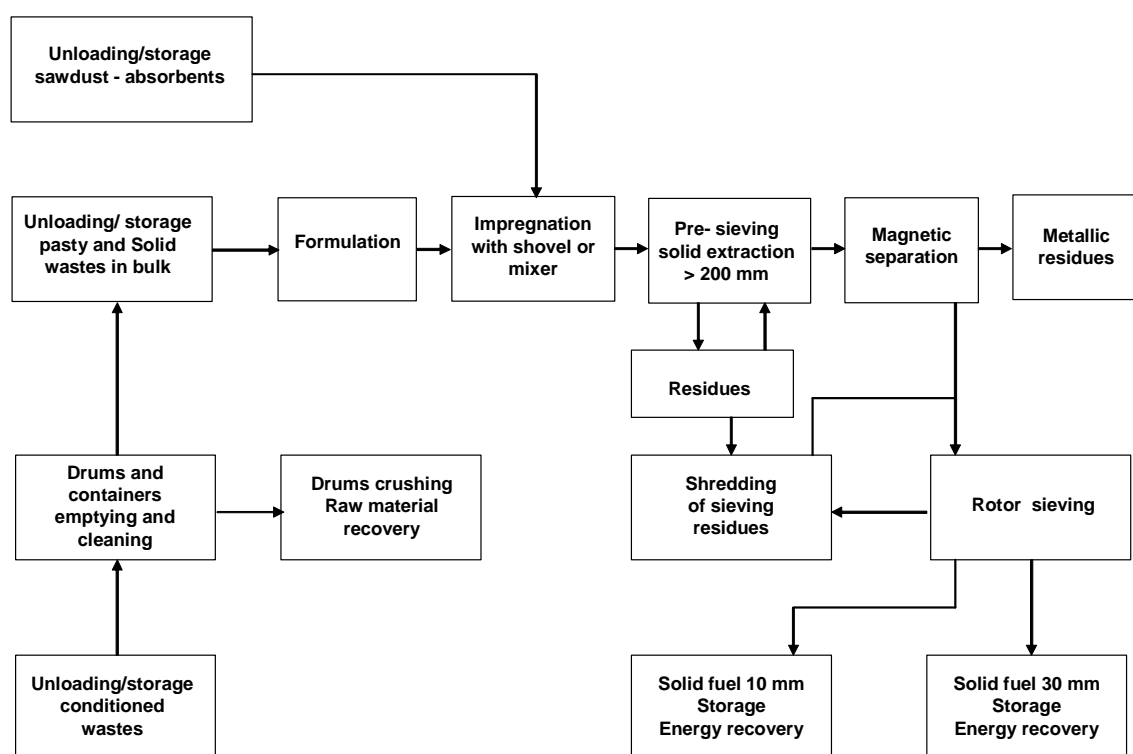


Figure 2.3: An example of the production of solid fuel from liquid or semi-liquid hazardous waste [122, Eucopro, 2003]

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).

2.1.3. 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.

2.2. 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 2.1.2.

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.

2.2.1. 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 2.4.

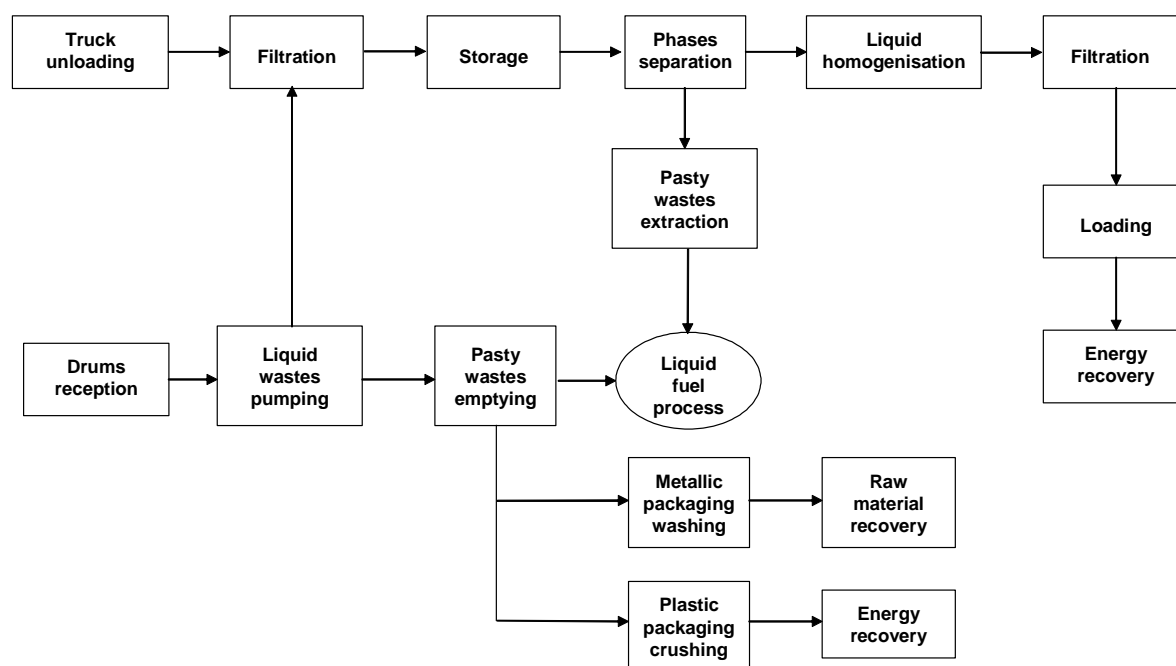


Figure 2.4: An example of the process layout for the preparation of organic liquid waste fuel [122, Eucopro, 2003], [150, TWG, 2004]

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).

2.2.2. 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

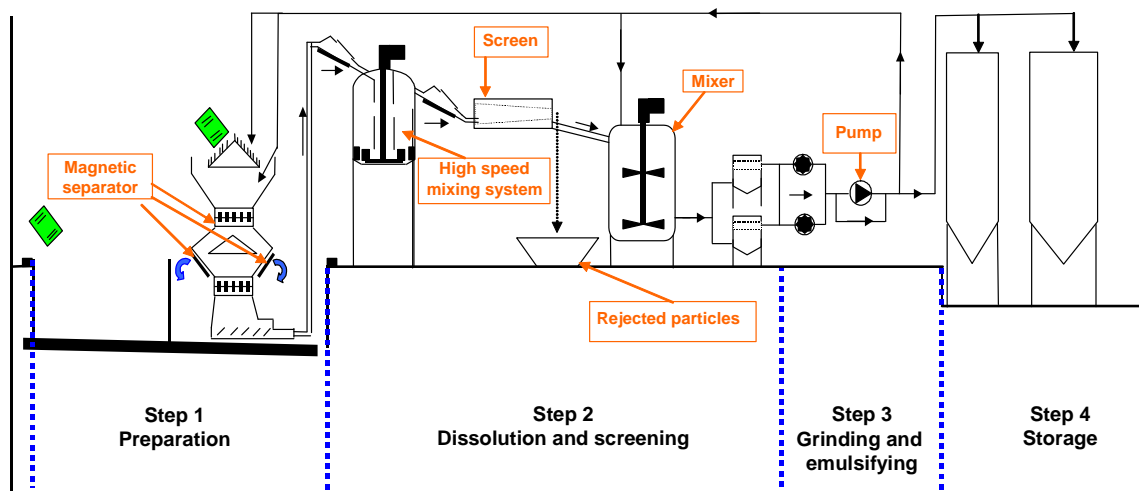


Figure 2.5: An example of the process layout for the production of liquid waste fuel by fluidification [122, Eucopro, 2003]

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 transferring 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 shredding 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).

2.2.3. 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.

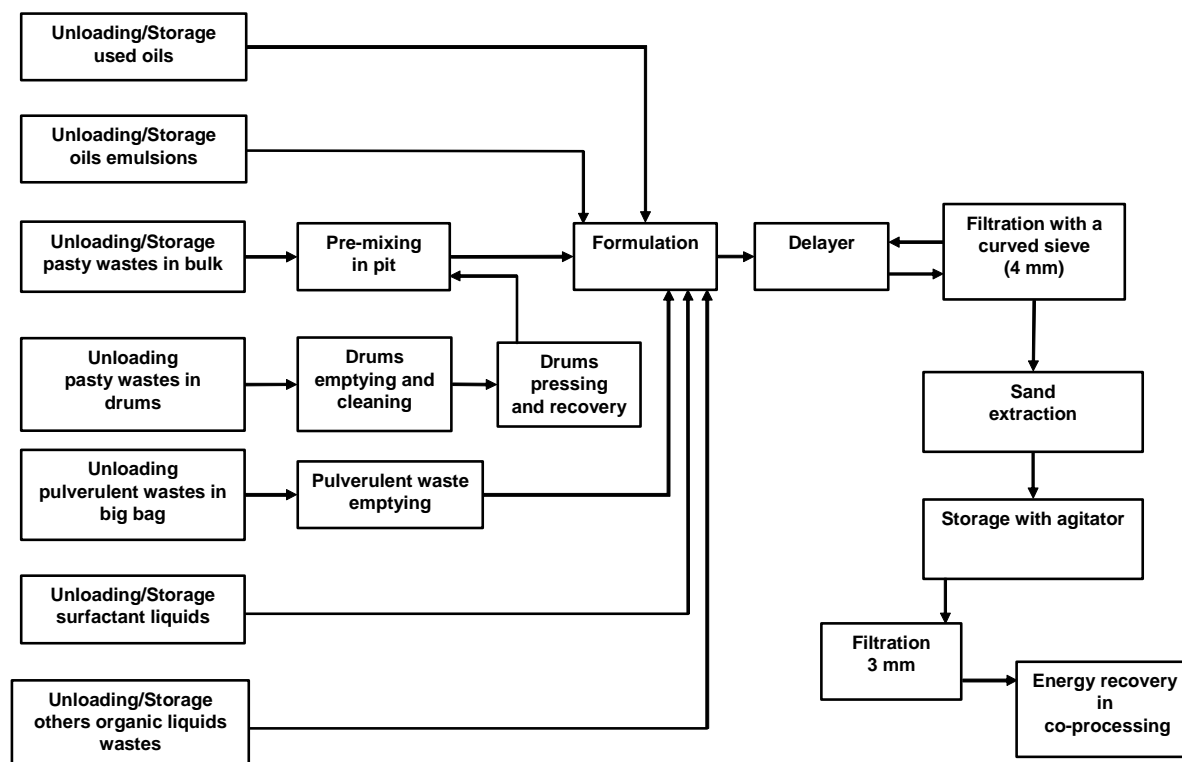


Figure 2.6: An example of the process layout out for the preparation of emulsions [122, Eucopro, 2003], [150, TWG, 2004]

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 m³/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).

2.2.4. 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 **Error! Reference source not found.** in Section **Error! Reference source not found.**). 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 **Error! Reference source not found.**. 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 2.2.

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 2.3			

Table 2.2: Treatments applied to waste oils before their use as fuel
[5, Concawe, 1996], [7, Monier and Labouze, 2001], [86, TWG, 2003], [150, TWG, 2004]

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.

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

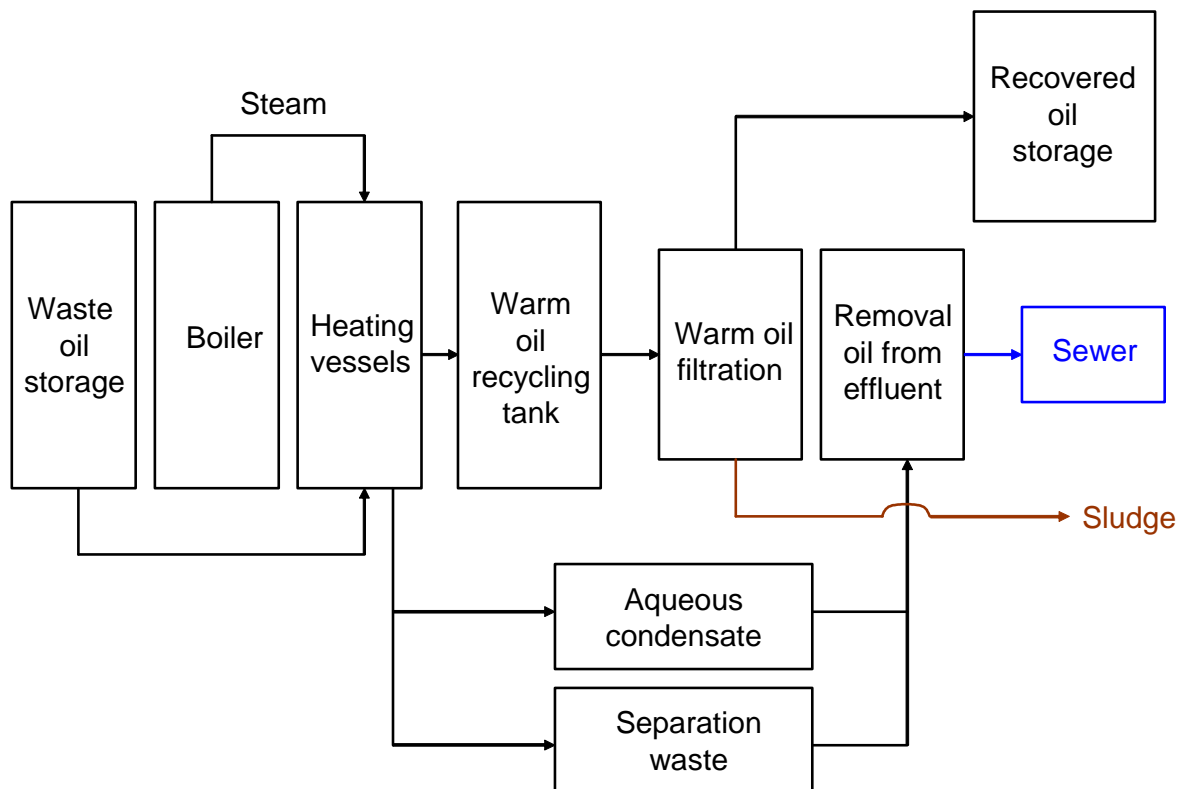


Figure 2.7: An example of a mild reprocessing of waste oil
[55, UK EA, 2001]

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 (although 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 2.3 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 Error! Reference source not found.) 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 2.3: Use of mild reprocessed waste oil (WO) as fuel
[55, UK EA, 2001], [86, TWG, 2003]

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 exist (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.

Waste OUT from the 'Trailblazer' process (see process description below)

- 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.

Waste OUT from the propane de-asphalting process (see description below)

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 **Error! Reference source not found..**

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:

'Vaxon' process

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 **Error! Reference source not found.**).

'Trailblazer' process

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.

Propane de-asphalting process (PDA)

Two types of process exist. These are called 'single-stage' and 'two-stages'. More information can be found in **Error! Reference source not found..** 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 2.4:

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 2.4: 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.

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 2.5).

Plant configuration	Outputs	%
1	Off-gases	5
	Naphtha	8
	Demetallised heavy fuel oil or marine gasoil	77
	Heavy residues	10
2	Off-gases	10
	Naphtha	15
	Gasoil (also called diesel fuels, heating oil, furnace oil)	65
	Light lube oil	Small fraction
	Heavy residues	10
3	Off-gases	5
	Naphtha	10
	Gasoil	30
	Re-refined light lube oil ¹	45
	Heavy residues	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 2.5: 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.

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).

2.2.5. 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.

2.3. 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 **Error! Reference source not found.**).

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.

3. Current consumption and emission levels

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 Committee, 2002], [37, Woodward-Clyde, 2000], [52, Ecodeco, 2002], [55, UK EA, 2001], [56, Babbie 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.

3.1. Waste IN for the preparation of waste fuels

Table 3.1 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 3.1: 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 3.2 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 3.2: 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 3.3.

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	Waste woods					

	Wood chips Biomass pellets/briquettes						
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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 3.3: 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 3.4 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 3.4: Important characteristics of MSW, and some of its fractions, for use as fuel
[4, Langenkamp, 1997], [8, Krajenbrink, et al., 1999], [16, ÖWAV Working Committee, 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 construction
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 3.5: 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 **Error! Reference source not found..** 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 3.6 below.

	Normal carbon chain length	Boiling point range (°C)	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 (N ^o 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, naphthalenes (0.22 %) and PAHs, nickel 0.00005 %
Fuel oil (N ^o 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 3.6: Typical composition of fuel oils and lube oils
[56, Babbie Group Ltd, 2002]

Rubber

Table 3.7 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 3.7: 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 3.8.

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 3.8: Metals' content of scrap wood
[4, Langenkamp, 1997], [81, VDI and Dechema, 2002]

3.2. 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 3.9: 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 H₂SO₄)
- 2 Many of them are waste fuels generated during the process

Table 3.10: 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 3.11: 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 3.12: Consumptions in the preparation of hazardous waste to be used as fuel
[122, Eucopro, 2003]

NON OFFICIAL FEAD VERSION

Consumptions in the preparation of waste fuel from municipal solid waste

Table 3.13 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 3.13: 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 3.14: 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.

3.3. 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 53 ¹		20	5	20 – 25	
		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 3.15: Examples of the emissions from the production of RDF from MSW [52, Ecodeco, 2002], [81, VDI and Dechema, 2002]

Table 3.16 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 3.16: 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 ₂ O	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 3.17: 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 3.18: 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 3.16, 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 3.19: 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 3.20 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 3.20: 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	0 – 3
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	
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 3.21: 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 3.22 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 3.22: Emissions generated from the preparation of waste oils to be used as fuel
[55, UK EA, 2001]

Table 3.23 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 3.23: Inputs and outputs for waste oil treatment plants producing a material to be used as fuel [56, Babbie 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 3.24: Example of emissions from an oil recycling plant that heats the oil during the process

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 ₂ H 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 H₂SO₄)

² Thermal cracking adjusted to produce primarily gasoil. Finishing with purification and stabilisation stages

³ Many are waste fuels generated during the process

Table 3.25: 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 ₂ H ₄
Phosphates	0.0079	kg eq phosphates in water
Waste to eliminate	1	kg
Waste to recover	36	kg

Table 3.26: 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 3.27).

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 3.27: 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, Babbie Group Ltd, 2002]

Emissions to water

Waste oil preparation may give rise to miscible or dissolved organic substances, for example, demulsifiers and detergents, within the effluent.

3.4. 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.

3.4.1. Solid waste fuel prepared from municipal solid waste

The range of compositions of solid waste fuel in Europe is shown in Table 3.28 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 3.28: 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	80 th 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 3.29: 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 3.30: Recovered fuel produced from source-separated fractions from MSW and other combustible waste (Finland)
[21, Langenkamp and Nieman, 2001]

Parameter	Units	Median	80 th 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 3.31: 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 3.32 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 3.32: 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.

3.4.2. Specifications of waste fuel to be used in cement kilns

The two tables below (Table 3.33 and Table 3.34) 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 3.33.

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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 3.33: 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 3.34 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 ₂ O ₃ + Al ₂ O ₃	%	>80 *					
Water	%	<10	40 – 70				<15
Alkalies (Na ₂ O + K ₂ O)	%	<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 ₂ O 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
<p>Notes:</p> <p>* on a dry basis</p> <p>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.</p> <p>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.</p> <p>Some substances mentioned here have an impact on the cement kiln process or product (e.g. alkalies, phosphorous, viscosity). For more information see the Cement and Lime BREF.</p>							

Table 3.34: 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 column 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 3.35: Standard values for pollutant content of waste used in the cement kilns used in Switzerland [150, TWG, 2004]

3.4.3. 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 3.36 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 3.36: Typical specification for recovered fuel oil supplied to UK power stations
[56, Babbie 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 3.37 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 3.37: 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 ₂ SO 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 3.38: 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 3.39: Outputs generated by the gasification of waste oils
[7, Monier and Labouze, 2001]

3.4.4. 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 3.40. 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.

Parameter	Content of heavy metals ⁴⁾	
	Median (mg/kgDM)	80 th 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 3.40: 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 3.41 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 3.41: 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, steel 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 3.42 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 3.42: Quality assurance system of RWE Umwelt AG (Germany)
[126, Pretz, et al., 2003]

3.5. Monitoring

Monitoring and sampling practices applied to the preparation of waste fuel from hazardous waste

More information on sampling is available in Section [Error! Reference source not found.](#). 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
Alkalís	ICP, fluorescence X, atomic absorption
Compatibility test	Function of waste received

Table 3.43: 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.

NON OFFICIAL FEAD VERSION

4. Techniques to consider in the determination of BAT

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.

4.1. To improve the knowledge of the waste fuel prepared

Description

This technique is related to the one described in Section **Error! Reference source not found.** on **Error! Reference source not found.** and related to Quality Management System (QMS). Mixing and blending (see Section **Error! Reference source not found.**) 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, thallium, 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]

4.2. 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]

4.3. 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 4.3.1 to 4.3.5 are relevant for any type of waste. Techniques in Sections 4.3.6 to 4.3.11 are mainly applicable to non-hazardous waste. Only one technique specifically for hazardous waste has been included and is in Section 4.3.12.

4.3.1. 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]

4.3.2. 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]

4.3.3. 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 abrasion 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

4.3.4. 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 centrally. 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]

4.3.5. 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]

4.3.6. 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 stream 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 further 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]

4.3.7. 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]

Drum screens

Description

Depending on the velocity of the drum, different operating modes may be utilised: cascade or cataract. Figure 4.1 shows these modes.

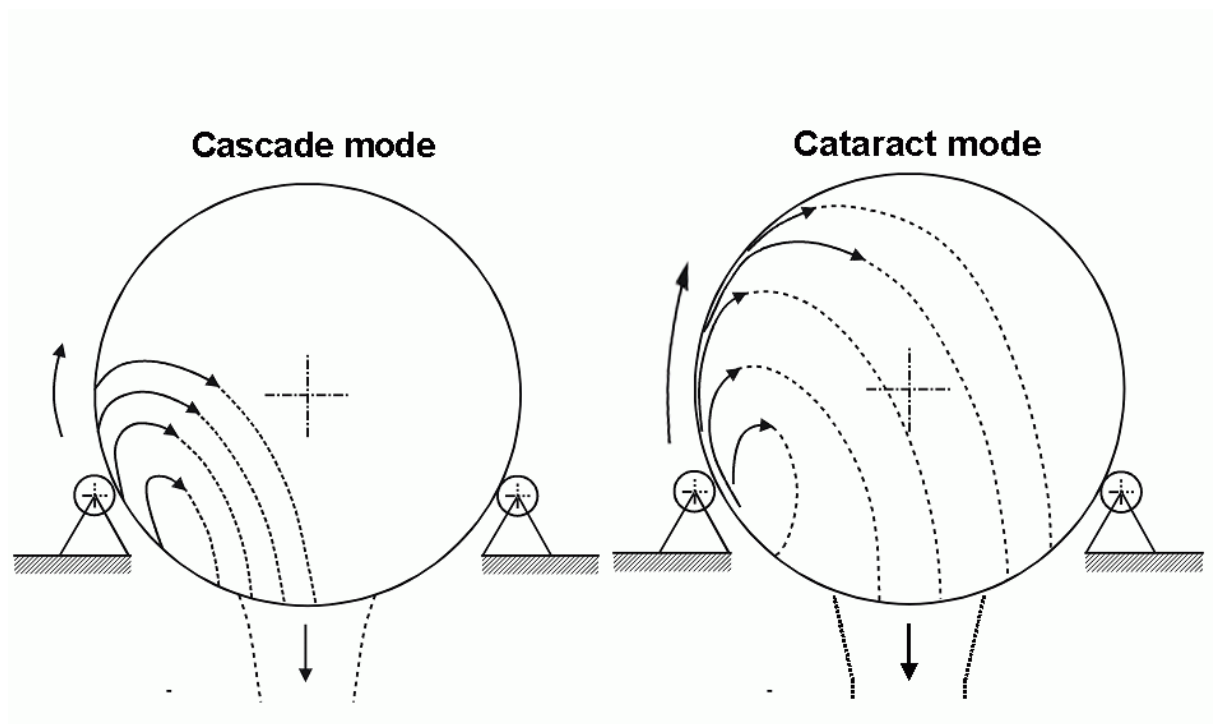


Figure 4.1: Drum screeners
[126, Pretz, et al., 2003], [150, TWG, 2004]

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]

4.3.8. 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/(m³air · h).

Reference literature

[126, Pretz, et al., 2003], [150, TWG, 2004]

4.3.9. 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]

4.3.10. 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]

4.3.11. 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]

4.3.12. 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:

- comminution in a shredder and addition of nitrogen for inertisation of the atmosphere. The liquid fraction (e.g. paint sludge) is separated by sieving
- cryogenic (deep cooling) treatment with liquid nitrogen (-196 °C). Through this treatment, the material hardens and, due to the different coefficients of components expansion, the binding reduces
- separation of the packaging (e.g. metal and plastic) and the content (e.g. paint sludge) by means of a hammer mill and a vibrating sieve
- collection of the metal fraction by ferromagnetic separation for re-use
- 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]

4.4. Techniques for preparation of liquid waste fuel

4.4.1. 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]

4.4.2. Thermal cracking of waste oils

Description

See Section 0.

Achieved environmental benefits

The use of thermal cracking in a refinery reduces the CO₂ 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 4.1: 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]

4.4.3. 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. 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]

4.6. Prevention and abatement techniques applied for the preparation of waste fuel from hazardous waste

Technique	Cross reference in this document	Applicability
<i>Dust preventive measures</i>		
Applying closing and underpressure	Error! Reference	

for all the reception, production and storage areas	source not found.	
Applying an overpressure of the working places (control room, vehicles cabin, etc.) ensures that no dust reaches the workers	Error! Reference source not found.	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	Error! Reference source not found.	
Handling pulverulent wastes in closed areas	Error! Reference source not found.	Can be applied to existing facilities without a complete redesign of the facility
Using closed vessels/mixers/filters/screens/magnetic separators/homogenising equipment	Error! Reference source not found.	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.	Error! Reference source not found.	
Ensuring that before transport, loads of fresh sawdust, pulverulent waste or solid waste fuel are efficiently covered	Error! Reference source not found.	Can be applied to existing facilities without a complete redesign of the facility
Applying a dust retention net	4.7.2	Can be applied to existing facilities without a complete redesign of the facility
<i>Dust abatement techniques</i>		
Wet scrubber	4.7.5	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	4.7.1	Not commonly used in the sector. This technique may only be used in combination with a bag filter
Bag filters	4.7.2	Widely used in the sector
Electrostatic precipitator	Error! Reference source not found.	
<i>Waste water treatment</i>		
Activated carbon treatment	Error! Reference source not found.	Low contaminated waste waters
Thermal treatment	Error! Reference source not found.	High contaminated waste waters

Table 4.2: Prevention and abatement techniques applied to the production of waste fuel from hazardous waste
[122, Eucopro, 2003], [152, TWG, 2004]

4.7. Waste gas treatments

4.7.1. 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 $>10\text{ }\mu\text{m}$. They are not effective against particle sizes $<10\text{ }\mu\text{m}$, 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]

4.7.2. 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 4.3: 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]

4.7.3. 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 °C). 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/Nm³. 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 4.4: 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 Nm³/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 condenser.

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 4.5: 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, Babbie Group Ltd, 2002], [66, TWG, 2003], [122, Eucopro, 2003], [150, TWG, 2004], [152, TWG, 2004]

4.7.4. 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 4.6.

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·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 4.6: 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 m², can treat an exhaust air stream of approximately 200000 m³/h, which results in a specific filter load area of 111 m³/m²/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. H₂S and NH₃), 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 Nm³/h/m² 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 4.7: 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 H₂S (>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/Nm³.

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/m³ and 1000 – 6000 ouE/m³ (90 % reduction), respectively.

Table 4.8 and Table 4.9 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
Acetaldehyde	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
Limonene	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 4.8: 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 4.9 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-Dichlorobenzene	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 4.9: Separation efficiency of organic compounds in the biofilter
[132, UBA, 2003]

Table 4.10 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 4.10: Raw gas and treated gas by a biofilter in an aerosol can treatment facility
[157, UBA, 2004]

Cross-media effects

N₂O and NO emissions are typically increased. However, it has been demonstrated that the use of an acid scrubber for ammonia (NH₃) removal prior to biofiltration can reduce potential N₂O and NO emissions. Methane is neither biodegraded 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 $\text{Nm}^3/\text{m}^2 \times \text{h}$.

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/Nm³) 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 Nm³/h are considered cost-effective. Investment cost of EUR 550000 for a biofilter applied to treatment of WWTP odours with a flow of 1800 Nm³/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 4.11: 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/Nm³).

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, Babbie 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]

4.7.5. Scrubbing

Description

Absorption techniques are typically called scrubbers. Some techniques include:

- having in place a scrubber system for the major inorganic gaseous releases (e.g. Cl₂, ClCN, HCl, H₂S, NH₃, 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
- 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/Nm³ 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 4.12 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 4.12: 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, Babbie Group Ltd, 2002], [86, TWG, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004]

4.7.6. 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 H₂O₂, 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]

4.7.7. Incineration

Description

In the decontamination of thermal exhaust air, the exhaust air is treated in a combustion chamber at temperatures of up to 850 °C 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 Nm³/h and the operating temperature is 1050 – 1200 °C. The specification of 850 °C 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 °C with 2 seconds residence time) to completely destroy some odorous and VOC components as well as destroy dioxins and dioxin pre-cursors.

Table 4.13 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 4.13: 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 4.14 and Table 4.15) 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 4.14: 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 4.15: 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]

4.7.8. 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 4.16 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 4.16: 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]

4.7.9. 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 °C 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/Nm³ are achievable. The actual range depends on the type of compound and the input concentration.

Table 4.17 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)	1 – 3
Electricity	1 – 2
Fuel/gas	
Maintenance costs (EUR/t waste fuel produced)	<1

Table 4.17: 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 CO₂ only under certain conditions. High temperatures of over 600 °C 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 4.18 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 4.18: 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 4.19 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 4.19: 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]

4.7.10. 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 CO₂ 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/Nm³), 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 4.20 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 4.20: 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/Nm³.

Table 4.21 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 4.21: 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]

4.7.11. 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:

$$\text{Performance} = 1 - \frac{T_{\text{scrubbed gas}} - T_{\text{crude gas}}}{T_{\text{combustion chamber}}} \quad T = \text{temperature}$$

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 approx. 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/Nm³.

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 Nm³ 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/Nm³), 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]

4.7.12. Some examples of abatement techniques comparisons applied to the preparation of waste fuel from hazardous waste

Table 4.22 and Table 4.23 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 4.22: 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 4.23: Comparison of VOC abatement techniques
[122, Eucopro, 2003]

5. Best available techniques

Preparation of waste to be used as fuel

For the preparation of waste to be used as fuel, BAT is to:

1. 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 4.1)
2. have a quality assurance system to guarantee the characteristics of the waste fuel produced (see Section 4.1)
3. 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 4.2)
4. *when producing waste fuel from hazardous waste, use activated carbon treatment for low contaminated water and thermal treatment for highly polluted water (see Sections 4.6 and **Error! Reference source not found.**). In this context, thermal treatment relates to any thermal treatment in Section **Error! Reference source not found.** or incineration which is not covered in this document*
5. *when producing waste fuel from hazardous waste, ensure correct follow-up of the rules concerning electrostatic and flammability hazards for safety reasons (see Sections **Error! Reference source not found.** and **Error! Reference source not found.**)*

For the preparation of solid waste fuels from non-hazardous waste, BAT is to:

6. 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 **Error! Reference source not found.** and this is also related to BAT **Error! Reference source not found.****Error! Reference source not found.**)
7. 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 4.3.3 and 4.3.4)
8. 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 4.3.9)
9. use a combination of shredder systems and pelletisers suitable for the preparation of the specified size waste fuel (see Sections 4.3.1 and 4.3.11)

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 4.3.1)

For the preparation of solid waste fuel from hazardous waste, BAT is to:

10. *consider emissions and flammability hazards in case a drying or heating operation is required (see Sections **Error! Reference source not found.** and 4.4.1)*
11. *consider carrying out the mixing and blending operations in closed areas with appropriate atmosphere control systems (see Sections **Error! Reference source not found.**, 4.4.1 and **Error! Reference source not found.**)*
12. *use bags filters for the abatement of particulates (see Section 4.7.12)*

For the preparation of liquid waste fuels from hazardous waste, BAT is to:

13. *use heat-exchange units external to the vessel if heating of the liquid fuel is required (Section 4.4.1)*
14. *adapt the suspended solid content to ensure the homogeneity of the liquid fuel (see Section 4.4.1)*

NON OFFICIAL FEAD VERSION

6. Emerging techniques

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.

NON OFFICIAL FEAD VERSION