



SUPPORT HAZARDOUS WASTE MANAGEMENT

Expert Facility Activity No: EFH-PS-4

Task 2:

Compilation of a Compendium of Best Management Practices for Hazardous Waste



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1. Scope of work

1.1 Foreword

The need for developing a National Strategic Plan for Hazardous Waste Management in Palestine, has become increasingly important since recent years. Under the umbrella of the National Strategy for Solid Waste Management, the Palestinian Authorities have identified the urging need to proceed with the development and implementation of this action, in order to tackle the growing issue of handling this type of waste. The increasing population and the major potential negative impact on public health that Hazardous Waste (HW) pose, has been considered as a major issue for the EPA. Several issues such as improper handling, no separation, no proper treatment and no proper disposal of hazardous waste are evident due to lack of legislative background. The legal and institutional framework under which HW is managed, can be characterized as incomplete and weak in terms of enforcing, monitoring and controlling the whole procedure.

Therefore, a thorough assessment of the existing situation and proposals for a more realistic and firm approach on the issue is required. This has to be facilitated through the involvement of different bodies, from the public as well as from the private sector. For the purposes of the above mentioned issue, an activity under the Horizon 2020 Support Mechanism has been initiated, with main objective the promotion of a National Strategic Plan for Hazardous Waste Management and the support of its implementation and enforcement on the ground.

1.2 Scope of work

The aim of this report is the compilation of a compendium of best management practices on hazardous waste management. More specifically, the report's objective is the recommendation of appropriate best practices to safely dispose of hazardous waste (both solid and liquid) and the introduction of standards for acceptable levels of hazardous substances in the disposed waste.



2. Methodology

Seven types of industry were identified by the Palestinian Authority (EQA) as the major producers of HW. These industries are the following:

- Olive oil mills
- Handling and treatment of used oils
- Bitumen production and handling
- Coating of furniture and wood material
- Dyes and pigments
- Aluminium coating processes
- Pharmaceutical industry

In all seven sectors, there has been a detailed process description based on technical documents from similar facilities in Europe. The origins of the HW within the process will be highlighted and commented. Following the process description, the hazardous waste streams for solid and liquid wastes will be identified and described. The best available techniques for the management of the previously described waste streams have then been described, based on the already implemented technology throughout Europe.



3. Industrial sectors

3.1 Olive mills

Olive oil refers to the product obtained from *Olea europea*. It is composed of about 98% glycerides with the remaining 2% being various components naturally present in olives, some of which play a fundamental role in the olfactory and taste characteristics and which are also important for the stability and quality of the product. Extra virgin oils, virgin oils and ordinary virgin oils are edible; yet only extra virgin oils and virgin oils can be commercialised as they are for direct consumption. Ordinary virgin oils are commonly used mixed with refined olive oils and refined husk oils. Acid oils with an acidity higher than 3.3 degrees are usually refined.

The quality of the olive oil depends on the ripeness of the olives, the type of harvesting, e.g. picking or shaking, the type of intermediate storage, and the type of processing carried out. Olives contain 38 % to 58 % oil and up to 60 % water. Ripe olives should be processed as quickly as possible since lipases in the pulp cause rapid hydrolysis of the oil, impairing its quality for edible purposes. Top-grade oils are made from fresh, handpicked olives by size reduction, pasting, and cold pressing. In the production of olive oil, there are three systems currently in use for the extraction of the oil: traditional, by pressing; three-phase separation; and two-phase separation.

3.1.1 Process description

In traditional production of olive oil, olives are ground into a paste with stone mills, however these days modern milling equipment is also used. Milling is followed by mashing, possibly with the addition of salt. The pulp is then pressed and the press oil is clarified by sedimentation or centrifugation. Traditional open-cage presses are now being replaced by continuous screw expellers. The mashed pulp can also be separated in a horizontal decanter, in which case the crude oil is re-centrifuged after the addition of wash-water. Alternatively, machines can be used to remove the kernels from the pulp and the residue is then separated using self-discharging centrifuges. Cold pressing, which yields virgin grades, is generally followed by a warm pressing at approximately 40 °C. Cold-pressed olive oil is a valuable edible oil.

While the two-phases generate a paste-like waste, both the traditional and the three-phase systems produce a liquid phase, i.e. olive mill waste water, or alpechin and a press cake known as pomace. This latter product may be further treated as husk or pomace oil. The remaining solid husk is dried to 3–6 % of humidity and used as fuel. Olive kernel oil is obtained by pressing and solvent extraction of cleaned kernels. It is similar to olive oil but lacks its typical flavour.

Trade specifications are based primarily on the content of Free Fatty Acids (FFA) and flavour assessment. In some countries, warm-pressed olive oil with a high acidity is refined by neutralisation, bleaching, and deodorisation, and flavoured by blending with cold-pressed oil. The press cake contains 8 % to 15 % of a relatively dark oil, which can be extracted with hexane and is used for technical purposes. After refining, it is also fit for edible consumption.

Olive oil production has traditionally been one of the major sources of industrial pollution in the regions where it is carried out. In traditional olive processing, i.e. the three-phase production, the extraction of the olive seeds has resulted in three streams, i.e. oily, aqueous and solid.

The oily stream is the virgin oil. It is produced at a rate of about 200 kg/t of olives if obtained using continuous separation by decanter centrifuges, or 150 kg/t using olive presses.

The aqueous waste, i.e. waste water, is sometimes called vegetable water and is highly polluted. Its volume depends on the technique applied but, in general, 1 m³ of waste water is produced per tonne of olives processed. The specific pollution is estimated to be about 65 kg BOD₅/t of olives processed.



The solid waste consists of two major parts, i.e. the stones or kernels and the crude oil cake/pomace. The stones accumulate in installations where destoned or stuffed table olives are produced. They can be used as fuel for heating, building materials or for activated charcoal. There is still a small amount of oil in the olive cake from the first pressing of the olives and this can be extracted. Its water content and composition depend on the extraction technique applied. If not going on for further processing, i.e. extraction, this cake is often used as fuel for heating, for animal feed supplement or returned to the olive grove as a mulch to condition the soil.

Water is saved in the extraction part of the two-phase process. The amount of waste water and its contaminant load are also reduced. The water savings are particularly significant because olives are grown and processed in areas of very low rainfall. The rural settings of a significant proportion of the industry also means that there is little access to Municipal Waste Water Treatment Plants (MWWTPs). However, the wetter solid output is also considered as a problem comparable to the waste water produced from the three-phase process.

The solid output, i.e. spent olives or pomace, is produced in greater amounts than from the three-phase process and contains 7–21 % more water. After further hexane extraction, the so-called spent olive cake is generated. This is often used as fuel for heating, for animal feed supplement or returned to the olive grove as a mulch. The spent olive cake is normally dried before disposal. The energy requirement and the cost of the drying is higher and the drying is more difficult due to the higher water, polysaccharides, and polyphenols content of the “alperujo”. The continuous three-phase generates spent olives with humidities of 35–45 %. With the continuous two-phase system, the spent olives present humidities of between 60 % and 70 %.

No water is used in the extraction part of the two-phase process and, in consequence, there is no need to treat it. The energy savings are about 20 %. The amount and the pollution load of the waste water is less. In the traditional process, the processing of 1 tonne of olives resulted in the production of about 0.6 m³ of waste water with a BOD₅ emission level of 120 000–130 000 mg/l. The amount of waste water produced using the two-phase technique is about 0.15 m³/tonne olives, with an average BOD₅ of 45 000–60 000 mg/l. As no water is used in the extraction, there are also savings in water consumption.

There are difficulties associated with the handling of the spent olive cake, which has a higher moisture content than the traditional cake and is not accepted by traditional extraction installations. It is also reportedly less profitable to extract the oil from it, due to its lower oil content, compared to the traditional or three-phase systems. Composting is reported to be an option in all cases. Use as biomass fuel is reported to be an option if a critical mass of spent olive cake is available, so not in cases of individual dispersed and isolated installations.

In two-phase extraction of olive oil it is not necessary to add hot water. The energy consumption for both systems is reported to be <90–117 kWh/t. Also, both systems use the same volume of washing water, i.e. 0.1–0.12 m³/t olives. This water consumption is independent of the extraction process, although, in some cases, it gets mixed with the waste water or wet pomace from the extraction process. Some mills do not use washing water as they collect the olives directly from the trees.

Existing three-phase decanter centrifuges can be modified to two-phase operation. Pomace dryers originally used after three-phase extraction are unsuitable for drying the pomace produced using the two-phase technique.

3.1.2 Type of hazardous waste

The olive mill waste water is considered as one of the most polluting waste water from the food sector and causes great problems in the olive tree cultivation areas. It has a very high COD, i.e. 200 000 mg/l, a



low pH, i.e. 3–5.9, and a high content of solid matter, i.e. TSS 20 000 mg/l. In addition, the high polyphenol content of olive oil waste water, up to 80 000 mg/l, make bacterial degradation very difficult and give them phytotoxic characteristics.

3.1.3 Best management practices

Oil mill wastewater possesses a double nature. It is a strong pollutant and at the same time a possible source of valuable components, such as polyphenols, flavonoids, anthocyanins, inorganic trace elements, etc., that could be isolated (removed) and economically exploited. A large number of treatments/technologies (physical, chemical, and biological) have been tested in many countries, and these methodologies could be classified in the following categories:

- Detoxification processes (aerobic and anaerobic, physicochemical)
- Processes for production of various products (fertilizers, compost, antioxidants, biopolymers, animal feed)
- Integrated processes aiming at energy recovery (biogas, electricity)
- Combined processes.

Detoxification Processes

They aim at “cleaning” the waste so as to allow its safe, subsequent disposal in water or soil reservoirs. The most important processes are biological and physicochemical.

a. Biological processes: Use of microorganisms to break down the chemicals present in OMW. They are divided into aerobic and anaerobic processes according to the type of the micro-organisms used.

b. Physicochemical Processes:

Neutralization, Precipitation/Flocculation: these involve the use of additional chemicals in order to destabilize the suspended and colloidal matter of OMW and form an insoluble solid that can be removed easily from the waste.

Oxidation processes: Several oxidizing agents have been tested for OMW treatment like hydrogen peroxide, ozone, chlorine, chlorinated derivatives in combination with ultraviolet radiation (Advanced Oxidation Processes).

c. Thermal Processes: Manmade heat sources or a natural source of thermal energy (air, sun) are used. The most important thermal processes are evaporation, lagooning (natural evaporation) and pyrolysis. The main drawback of these processes is related to the post treatment and disposal of the produced emissions.

d. Membrane Processes: Membranes are effective for separation of oil-water mixtures without adding solvents. With ultrafiltration, only a small amount of retentate (waste) is produced (permeate is 90–95% of the volume of the feed) and very high removal of lipids is achieved. Main problems are the high capital costs and the need of qualified personnel, making them non-affordable for small oil mills.

Processes aiming at the production of various products



OMW may be regarded as an inexpensive source of inorganic and organic compounds to be recovered because of their potential economic interest or their potential to be transformed into products for use in agriculture, biotechnology, and the pharmaceutical as well as the food industry.

a. Production of Fertilizers (Recycling of the Waste at Land) Biofertilization or Bioremediation: OMW should not be directly applied on soil and crops because of its phytotoxic properties.

Treating OMW with an enriched aerobic microbial population results in a non-phytotoxic thick liquid that could be characterized as an organic soil-conditioner/ biofertilizer.

Composting refers to the process of controlled aerobic biological degradation of organic substrates (wastes, residues, etc.). In the case of OMW composting, OMW quantities are added to the solid substrate during the thermophilic stage to replace the evaporated water.

b. Recovery of Antioxidants: OMW contains water-soluble compounds with potential antioxidant properties, like polyphenols, flavonoids, anthocyanins, tannins, oleanolic acid, and maslinic acid. The processes of extraction of antioxidants of high added value from OMW are patented.

c. Production of Biopolymers: The production of biopolymers from OMW is a very interesting alternative, studied during the last years due to the high added value and excellent properties of these substances. The two main categories of these substances are: exopolysaccharides and polyhydroxyalkanoates.

d. Production of Animal Feed: Olive cakes or solid residues of various OMW processes could be used in animal feeding, as they are rich in oil, carbohydrates, and proteins. Problems arise from OMW's high concentration of potassium and phenolic compounds which are anti-digestive factors.

Usually, small olive mills, use evaporation lagoons. Allowing their waste water to evaporate in open lagoons for months, leads to stale odours and, in many cases, leakage causes groundwater contamination. The solid residue is then sent for land spreading. Direct deposition in olive groves can result in groundwater contamination. Connection to a MWWTP is not usually possible, as olive mills are normally in rural areas where MWWTPs either do not exist or are not designed to treat such waste water. Thermal concentration/thickening can also be used to treat olive oil waste water.

Olive mill wastewater can also be treated using an anaerobic WWTP, which can reduce COD emission levels by 65–95 %. This has a high investment cost, particularly because olive oil mills have seasonal harvesting. The campaigns are carried out between October and March. The seasonal characteristic of these mills does not affect the treatment as an anaerobic digester can be easily restarted after a dormant state, although it takes some time to re-establish treatment conditions.

The high polyphenol content of the waste water inhibits the growth of aerobic bacteria. In addition, the autoxidation of phenolic compounds during contact of the olive oil wastewater with air leads to the formation of macromolecular polyphenols which are even more difficult to degrade.

A further alternative treatment of waste water from olive mills can involve an effective primary treatment such as sedimentation to remove solids. Using precipitation, with the selection of an optimal flocculation agent, eliminates a very high percentage of the dissolved and particulate organic matter which will then be removed by filtration. The final step consists of applying membrane separation to ensure 95 % reduction of the organic load. This is still under investigation but could be a solution for the future.



Other technologies include soil application:

- Composting (in windrows, in U-lane)
- Electro-coagulation
- Aerobic biological trickling filter + constructed wetland
- Evaporation – Hydrolysis–Oxidation: E.H.O.
- Phytoremediation
- Anaerobic digestion in a WWTP
- Bio-fuel pellets
- Filtration with sawdust & phytoremediation



3.2 Handling and treatment of used oils

3.2.1 Process description

Waste oil (WO) is a term defined as any mineral-based lubrication or industrial oils which have become unfit for the use for which they were originally intended, and in particular used combustion engine oils and gearbox oils, and also mineral lubricating oils, oils for turbines and hydraulic oils. WOs are classified as hazardous waste by European law and should be collected so that they can be safely treated.

WOs cover a wide range of materials, with further differences arising from their previous use under differing conditions. They may end up in used oil collection systems, where they can decrease the value of the used oil. Oil filters and carburetor filters contain around 30 % hydrocarbons.

3.2.2 Type of hazardous waste

Used oils can be categorised according to market considerations as follow:

- (black) engine oils: these represent more than 70 % of used oil. The largest potential source of used oils is from vehicle use, particularly engine oils
- black industrial oils: these represent about 5 % of used oil
- light industrial oils: these represent about 25 % of used oil. They are relatively clean and their market value is high. Their market is very specific and independent from the classical supply routes of regeneration.

Used oil composition is becoming more and more complex due to different factors:

- the increasing use of dispersants, as well as esters and polyalphaolefins, e.g. to increase the life of the oil. However, as a result, the resulting WO has become more complex and dirty over time
- the progressive displacement of conventional mineral based auto lubricants by 'synthetic' products which have enhanced performance characteristics. Whereas some of these synthetic products can be regenerated along with mineral oils, others (those based upon esters for instance) are less suitable to regeneration because they tend to be less stable in the presence of caustic (often used by regeneration processes) and less stable to the hydro-finishing step.

A low proportion of base oil originates from agricultural sources, being produced from either sunflower or rape-seed. These bio-lubricants are used in applications where their characteristics represent a real advantage, in particular:

- their good biodegradability. This is important when lubrication losses into the environmental media, e.g. soil and water, can occur during use (woodcutting with motor saws, boats, cutting oils, etc.)
- their high viscosity index and low volatility for instance.

3.2.3 Best management practices

For most WT plants, the following order is relevant: a) pre-acceptance, b) acceptance, c) storage, d) treatment, and e) storage of residues and emissions. Each of these previous steps requires knowledge and control of the waste as well as specific acceptance and processing management. Knowledge of wastes, before they are accepted and treated, is a key factor for the management of a WT plant. For used oils, the major best management practices are the following:

- Treatment applied mainly to recover materials from the used oils (recycling)
- Treatment primarily aimed at producing material to be used as fuel



There are two main options for the treatment of waste oils. One is the treatment of the waste oil to produce a material that will be used mainly as fuel or for other uses (e.g. absorbent, mould release oil, flotation oil). These include treatments such as cleaning of waste oil, thermal cracking and gasification for example. The other way, is to treat the waste oil to reconvert it to a material that can be used as a base oil to produce lubricants. This latter way is referred to as 're-refining'. A lot of treatment processes exist (or are currently under development) today in Europe. The most significant ones are listed below:

- Reuse (laundering, reclamation)
- Re-refining (pretreatment, cleaning, fractioning, finishing)
- Thermal cracking
- Gasification
- Severe or mild processing (solvent extraction, propane extraction, etc.)

Recycling

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

The main processes used in oil recovery plants are shown below:

- Pretreatment of waste oil to dewater (removal of water), de-fuel (removal of light ends and fuel traces such as naphtha, etc.) and remove sediments. This pretreatment process is not compared with the other oil treatment systems because it does not yield an end-product, nor does it achieve the final aim of treatment.
- Cleaning of waste oil includes deasphalting and the removal of asphaltic residues: heavy metals, polymers, additives, other degradation compounds.
- Fractionation of waste oil involves a separation of the base oils using their different boiling temperatures, to produce two or three cuts (distillation fractions).
- Finishing of waste oil Final cleaning of the different cuts (distillation fractions) is carried out to achieve specific product specifications (e.g. improve colour, smell, thermal and oxidation stability, viscosity, etc.). Finishing may also include the removal of PAHs in the case of a severe (high temperature and high pressure) hydrofinishing or solvent extraction (low temperature and low pressure).



3.3 Bitumen production & use and Asphalt Reuse

Bitumen (referred to as asphalt in the US) is used mainly for paving roads but also for a number of other applications, such as materials for roofing. The basic source of bitumen is the residue remaining after vacuum distillation of crude. The residue can also be treated by blowing with air at high temperature (bitumen blowing process) to increase the asphaltene content. Bitumen is a residue derived from certain crude oils (e.g. Middle East, Mexico or South America) after vacuum distillation has removed waxy distillates. Bitumen is normally mixed with other components (e.g. gravel) to produce asphalt that is used in road paving, roof coating and pipe sealing or coating. Bitumen production only appears in some refineries and there are also some refineries that specialise in producing these components.

3.3.1 Process description

In most applications, the hydrocarbon feed stream to a bitumen blowing unit (BBU) is the bottom residue stream from a vacuum unit and in some instances the residue (extract) from a deasphalting unit.

Normally, a number of different grades of bitumen are produced in campaigns and these are further modified by blending with other high-boiling components such as vacuum residue, heavy gas oil or synthetic polymers. In this way, a single blowing unit is able to cater for a wide range of bitumen grades for various applications.

Polymer additives Styrene Butadiene Styrene (SBS), Ethylene Vinyl Acetate (EVA), Natural rubber, etc. are used for heavy duty service bitumen production. They do not change the chemical structure of the bitumen but change its mechanical properties. The polymers modify the bitumen's properties such as the softening or brittleness point, and aim at improving longevity.

The BBU will either operate on a continuous basis or in batch mode depending on the quality of the vacuum residue feedstock and the required bitumen product specification. Continuous processes are the most common in refineries. Where the bitumen feed is received from storage, an additional fired heater may be required to preheat the feed to a temperature of about 200 – 250 °C, but it can be up to 550 °C. With a batch-operated BBU, a feed buffer vessel is usually included to store the hot feed stream from the vacuum unit.

The residue feed stream is pumped into the top of the oxidation vessel. As air is sparged into the base of the vessel, oxidation of the residue takes place, resulting in heat. The temperature in the oxidation vessel, which determines to a certain extent the bitumen grade, is normally controlled between 260 °C and 300 °C. Different options are applied for adjusting the temperature, which include the addition of colder feed to the oxidation vessel, the recirculation of cooled bitumen product from the bitumen run down cooler, and in older units direct water quenching. The blown bitumen is removed from the bottom of the oxidation vessel and cooled by rising steam, before being sent to storage.

The air rate is normally well in excess of stoichiometric requirements and so a considerable quantity of oxygen is present in the upper vapour space of the oxidation vessel. To avoid an explosion in the vapour space, in most units, steam is injected at a rate necessary to keep the oxygen concentration below the lower flammable limit (5 – 6 % v/v). In some units, a small amount of water is also injected into the vapour outlet of the oxidation vessel to reduce the vapour temperature. This is sometimes considered necessary to prevent afterburning in the overhead system which could otherwise lead to severe coke formation.

The overhead vapours are first passed through a vent gas scrubber to remove oil and other oxidation products. In most cases, gas oil is used as once-through scrubbing liquid. The vent gas from the scrubber is subsequently cooled to condense light hydrocarbons and sour water, sometimes in a water spray contact condenser or scrubber. The remaining gas, consisting mainly of light hydrocarbons, N₂, O₂, CO₂ and SO₂, is incinerated at high temperatures (~800 °C) to ensure complete destruction of minor



components such as H₂S, complex aldehydes and organic acids and phenolic compounds, which have a highly unpleasant odour.

The majority of the BBUs produce the higher grades of bitumen (roof and pipe coatings) and normally operate continuously throughout the year. The BBUs which are used to produce road bitumens operate only when the demand for road asphalt is high.

3.3.2 Type of hazardous waste

Process waste water from the production of bitumen, consist of sour water produced in the oxidiser overhead waste water. It contains H₂S, oil, aromatics, PAH, sulphuric acid, odorous oxidation products (ketones, aldehydes, fatty acids) and particulates. Other potential releases into water are of hydrocarbons and sulphur compounds from spillages and leakages. Regarding solid waste, slop oil emulsions are formed in the oxidiser overhead slop oil. It consists of an emulsion of light oil, water and particulates.

3.3.3 Best management practices

Bitumen best handling practices

The most important issue for Palestine is the proper storage and handling of bitumen to avoid fire, health and environmental risks.

As described by the European Best Available Technique Reference Documents, bitumen should be kept in proper storage tanks normally under heating conditions and insulated. Bitumen is generally not handled as a solid.

For preventing fire due to auto ignition of condensed vapours, tanks containing oxidised bitumen are equipped with nitrogen blanketing and pressure/vacuum safety valves. These valves need maintenance due to the slime. In some cases, these valves may be removed and a gaseous overhead treatment scheme is used.

Hydrocarbons and sulphur compounds may emanate from leakages (particularly in overhead systems) and pressure relief valves and in the form of liquid droplet-containing aerosols from the venting of tanker top-loading operations.

Loading and unloading of the tank is typically done as follows: when the tank is filled, nitrogen does not flow to the tank, and the pressure is lowered by letting part of the gas go to the atmosphere; when the tank is unloaded at a low speed, a small amount of nitrogen is led to the tank; however, when the speed of unloading is higher, higher amounts of nitrogen must be used. If the tank is equipped with a cleaning system, it is mechanically very simple and easy to clean.

Asphalt reuse best management practices

Recycling or reuse of asphalt pavement material, in situ (in place), by employing movable asphalt/sand reworking machinery is a very simple but powerful concept. Recycling of existing/damaged asphalt pavement materials to produce new asphalt pavement materials, results in considerable savings of material, energy and money. At the same time, recycling of existing material also helps to solve operational, transport and disposal problems. Because of the reuse of existing material, asphalt pavement geometrics and thickness can also be maintained or adjusted accordingly during construction. In some cases, traffic disruption is considerably less than that for other rehabilitation techniques. The specific benefits of recycling can be summarized as follows:

1. Reduced costs of construction.
2. Conservation of aggregate and binders.
3. Preservation of the existing pavement geometrics.



4. Protection of the environment.
5. Conservation of energy.
6. Less user delay.
7. Considerable reduction in transport of material.
8. Zero or minimal disposal of waste.

Reduction of asphalt waste is directly linked to the issue of proper road maintenance. Several studies have shown that it costs highway agencies less if the pavements are kept at a certain acceptable level of serviceability. According to World Bank Sources, each \$1.00 spent during the first 40 percent drop in quality will avoid much higher costs needed (\$4.00 to \$5.00) if the maintenance is delayed until the pavement loses 80 percent of its original quality. Rehabilitation is needed to maintain the pavement at a certain condition ensuring adequate road safety. Rehabilitation of pavement is also needed due to the following reasons:

1. Inadequate ride quality.
2. Excessive pavement distress.
3. Reduced surface friction.
4. Excessive maintenance requirement.
5. Unacceptable user costs.
6. Inadequate structural capacity for planned use or projected traffic.

Recycling is only one of the several rehabilitation alternatives available for asphalt pavements. Some of the other common methods are thick or thin hot mix asphalt (HMA) overlay. The choice of rehabilitation alternative depends on observed pavement distress, laboratory and field evaluation of existing material, and design parameters. Also, maintenance of geometrics and original thickness of pavements, especially in underpasses, influence the choice of rehabilitation method, among which recycling has some unique advantages which are not available with other types of rehabilitation techniques.

The Asphalt Recycling and Reclaiming Association defines four different types of recycling methods: (1) hot recycling; (2) hot in-place recycling; (3) cold in-place recycling; and (4) full depth reclamation.

1. Hot mix asphalt recycling is the process in which reclaimed asphalt pavement (RAP) materials are combined with new materials, sometimes along with a recycling agent, to produce hot mix asphalt (HMA) mixtures. Both batch and drum type hot mix plants are used to produce recycled mix. The RAP material can be obtained by milling or ripping and crushing operation. The mix placement and compaction equipment and procedures are the same as for regular HMA. Typically, 10 to 30 percent RAP is used in recycled hot mixes. The advantages of hot mix recycling include equal or better performance compared to conventional HMA, and capability to correct most surface defects, deformation, and cracking.

2. Hot in-place recycling (HIR) consists of a method in which the existing pavement is heated and softened, and then scarified/milled to a specified depth. New HMA (with/without RAP) and/or recycling agent may be added to the scarified RAP material during the recycling process. HIR can be performed either as a single pass or as a multiple pass operation. In single pass operation, the scarified in-place material can be combined with new material if needed or desired. In multiple pass operation, the restored RAP material is recompacted first, and a new wearing surface is applied later. The depth of treatment varies between 20 to 50 mm ($\frac{3}{4}$ in to 2 in). There are three HIR processes; (a) surface recycling, (b) repaving, and (c) remixing. This is a type of HIR operation in which the existing asphalt surface is heated



and scarified to a specified depth. The scarified material is combined with aggregate and/or recycling agent. The mix is then compacted. A new overlay may or may not be placed in the recycled mix. In the second type of HIR method, repaving, the surface recycling method is combined with a simultaneous overlay of new hot mix asphalt (HMA). Both the scarified mix and the new HMA are rolled at the same time. In the case of remixing, the scarified RAP material is mixed with virgin HMA in a pugmill, and the recycled mix is laid down as a single mix. The advantages of hot in-place recycling are that surface cracks can be eliminated, ruts and shoves and bumps can be corrected, aged asphalt is rejuvenated, aggregate gradation and asphalt content can be modified, traffic interruption is minimal, and hauling costs are minimized.

3. Cold in-place recycling (CIR) involves reuse of the existing pavement material without the application of heat. Except for any recycling agent, no transportation of materials is usually required, and aggregate can be added, therefore hauling cost is very low. Normally, an asphalt emulsion is added as a recycling agent or binder. The emulsion is proportioned as a percentage by weight of the RAP. Fly ash or cement or quicklime may also be added. These additives are effective for over asphalted and low stability mixes. The process includes pulverizing the existing pavement, sizing of the RAP, application of recycling agent, placement, and compaction. The use of a recycling train, which consists of pulverizing, screening, crushing and mixing units, is quite common. The processed material is deposited in a windrow from the mixing device, where it is picked up, placed, and compacted with conventional hot mix asphalt laydown and rolling equipment. The depth of treatment is typically from 75 to 100 mm (3 to 4 in). The advantages of cold in-place recycling include significant structural treatment of most pavement distress, improvement of ride quality, minimum hauling and air quality problems, and capability of pavement widening.

Full depth reclamation (FDR) has been defined as a recycling method where all of the asphalt pavement section and a predetermined amount of underlying base material is treated to produce a stabilized base course. It is basically a cold mix recycling process in which different types of additives such as asphalt emulsions and chemical agents such as calcium chloride, portland cement, fly ash, and lime, are added to obtain an improved base. The four main steps in this process are pulverization, introduction of additive, compaction, and application of a surface or a wearing course. If the in-place material is not sufficient to provide the desired depth of the treated base, new materials may be imported and included in the processing. New aggregates can also be added to the in-place material to obtain a particular gradation of material. This method of recycling is normally performed to a depth of 100 mm to 300 mm (4 to 12 in). The train consists of a recycling machine hooked to a water tanker and steel drum roller with pad foot shell. The advantages of full depth reclamation are that most pavement distresses are treated, hauling costs are minimized, significant structural improvements can be made (especially in base), material disposal problems are eliminated, and ride quality is improved.



3.4 Coating of furniture and wood material

Wood is a natural raw material characterised by its inhomogeneity and anisotropy, which displays irregular properties in terms of surface structures, the varying contents of different substances (e.g. waxes, water, resins), and variable electrical resistance. Wood fibres often have the characteristic that they swell-up and become erect under the influence of liquids (in particular, with water). Wooden surfaces are coated, in order to conserve or strengthen the colour, surface structure and/or porosity. The coating is applied to provide, for example, resistance against:

- chemical impacts;
- mechanical stress;
- climatic impacts;
- staining.

3.4.1 Process description

The application of coating materials for wood and wood materials involves:

- pretreatment of the wood surface;
- application of a base coat;
- application of a topcoat;
- application of the paint;
- flashing-off and drying/curing.

Depending on the desired surface structure (i.e. open or closed cell pore structure), different paint systems may be used. If the wooden grains need to be visible, e.g. for solid wood or veneer, uncoloured paints (i.e. clear coats), oils and waxes are used. For example, medium dense fibre (MDF) panels are coated with pigment paints of the desired colour. If pigment paint systems are used, a barrier layer is applied before the base coat, which restricts permeation of paint to the wooden sub-surface and allows a more uniform paint layer to be applied.

Pretreatment of the wood surface

Due to irregular growth and the varying surface structure, and because of the differing content of certain substances such as resin or wax, proper pretreatment of the surface to be coated is essential. This pretreatment can address different aspects of the wood, such as the existing surface flatness, removal of working marks, treatment of colour differences, unevenness, fibre erections, cracks, boughs, as well as wood moisture. Typical pretreatment techniques include:

- mechanical pretreatment, e.g. sanding;
- colouring methods (staining, glazing, bleaching).

For some special kinds of wood, it is necessary to use chemical cleaning processes which utilize soap solutions, ammonia or organic solvents, together with a sanding technique for the disposal of paint incompatible wood substances such as resin and wax.

Application of a base coat

Base coat material needs to be suitable for sanding down. Application techniques include:

- spraying (manually or automatically; conventional, airless, air-assisted airless (so-called 'airmix') and electrostatically assisted);



- casting;
- rolling (e.g. using a UV curing lacquer suitable for rolling);
- dipping (only for special workpieces).

After drying of the pretreatment stage, sanding (with material of an appropriate grain size) takes place before a colourless base coat is applied. Afterwards the surface is sanded again before a topcoat is applied. In some cases, a wooden structure is printed directly onto the base coat. As the substrate, mainly simple veneers are used or alternatively, the surface to be coated may already incorporate a coloured base coat/stopper.

Application of a topcoat

For the coating of wood and wood materials, paints, foils or other panel-like coating materials, as well as textiles or leathers are used. Some specific coatings are:

- nitro cellulose paint (NC) sometimes called cellulose nitrate paint (CN);
- acid curing paints;
- polyurethane paints (PUR);
- unsaturated polyester paints (UP)
- water-based paints;
- powder coatings;
- alkyd paints/glazes;
- combined/mixed paint systems;
- waterborne UV lacquers;
- 100 % UV lacquers.

Application of the paint

The following application techniques are used for wood and wood materials:

- painting, rolling;
- manual spraying (partly also using electrostatically assisted processes);
- automated spraying (partly also using electrostatically assisted processes);
- automated spraying with or without the recycling of overspray (partly also using electrostatically assisted processes);
- rolling;
- vacumat technique;
- filling with stoppers;
- curtain coating;
- dipping/flooding;
- printing.

Besides manual spray applications, spraying installations or spraying machines equipped with two-component dispensing units are in use in the furniture industry.



Flashing off and drying/curing

Drying/curing of the paint layer requires an intense flashing-off. The flashing-off takes place in special installations that are generally located upstream of the dryers. For water-based paints, the humidity of the evaporating air needs to be taken into account to enable a sufficient drying. Some specific drying processes applied (some more commonly applied than others) are:

- through-circulation dryer with dehumidification;
- convection dryers;
- infrared systems
- UV radiation drying;
- microwave;
- high frequency dryers (HF dryers);
- X-ray curing.

3.4.2 Type of hazardous waste

Especially for the coating of profiled, wooden workpieces, the base and topcoat are applied via spray applications. Thereby, losses via overspray are generated within the spraying booths in one of two waste forms:

- If wet separation is applied, the overspray forms paint sludge. The paint sludge then consists of paint particles, small amounts of organic solvents, coagulation agents and water. Paint sludge is generally regarded as a waste that needs monitoring. In general, the material is used as a fuel in special refuse combustors.
- If the overspray is separated dry, contaminated glass fibre filter mats have to be disposed of.

As soon as a specific minimum velocity of the airflow is reached, the filter mats have to be replaced. The filter mats, now contaminated with dried paint particles, generally do not need monitoring and can be used as a fuel in regular waste incineration plants. Mixed two-component paints cannot be recycled and are disposed of. The solvents are recovered from non-cured paints. In addition, contaminated solvents are generated from the cleaning of application devices, conveyor systems, paint pipelines, spray booths and others. In general, cleaning agents used in the wood industry are recycled via distillation and can be used as recycled cleaning agents. The distillation generates paint leftovers in solid, liquid or pastelike forms. Contaminated solvent, solids from distillation, dried 2K paint and other residues and leftovers that are not reused are disposed of, usually as hazardous waste.

Hazardous properties of paint sludge from paint overspray have been analysed and in many cases, there is a lack of overall background data on wastes. Therefore, co-operation between paint or lacquer producers, waste producers, environmental authorities, and waste researchers and laboratories is very important. For example, in one study, the formaldehyde concentrations were analysed based on information received from the producers of paints and lacquers. This provided the essential information for overall assessment of the chemical and ecotoxicological hazard of residues studied. The results confirmed the benefit of combining chemical and ecotoxicological assays in assessing the potential environmental hazard of complex organic mixtures found in paint residue wastes. The pretreatment studies showed that the amount of residues could be minimised by reducing the liquid content of water-curtainbooth residues, and the hazard was decreased by changing the raw materials in the spray painting process to paints and lacquers that contain less harmful solvents. The results also proved that landfilling is not a suitable method of disposal for the paint residues produced in the furniture industry. For these



types of organic wastes, a better alternative method of treatment could be incineration. The information of the ecotoxicological and leaching properties of excess paint residues produced in different spray painting processes helped paint producers to develop their products and makes it possible for furniture producers to choose environmentally safer products. Furthermore, this hazard-screening approach will help furniture producers to improve the surface paint process of furniture making in order to minimise the amount and hazard of the wastes produced.

3.4.3 Best management practices

- Minimisation of raw material consumption

Batch painting/colour grouping

Pig cleaning systems

Online mixing system for two-component products

- Replacement of solvent-based material

Water-based coatings

Powder coating – conventionally dried

UV radiation curing paints

- Paint application techniques and equipment

Rolling and filling by using reverse coaters

Curtain coating (casting)

Flooding

High-volume low-pressure spraying (HVLP)

Electrostatically assisted compressed air, airless and air-assisted spraying

Powder coatings – electrostatically assisted spraying

- Spray booths

Wet separation booth

- Drying

Microwave dryer

High-frequency dryers

Infrared radiation curing

Near-infrared radiation curing

Ultraviolet (UV) radiation

Electron beam curing

Combined convection/radiation drying (thermal reactor)

- Waste gas treatment

Dry particle filter systems

Electrostatic filter



Venturi particle separation

Scrubber

Biological treatment

Thermal oxidation

- Waste water treatment

Waste water treatment for wet separation paint spray booths

Ultra and nanofiltration

- Waste treatment

Recovery of used solvents by applying distillation



3.5 Dyes and Pigments

Pigments are defined as colouring agents that are practically insoluble in the application medium, whereas dyes are colouring agents that are soluble in the application medium. In colouring, the crystalline pigment is applied in the solid state, not in the dissolved form, to the medium being coloured. Both the chemical and the physical properties of the pigments (e.g. particulate size, particulate size distribution, special types of surface and specific surface area, crystal modification, and crystal form) are important for their industrial application.

Many organic pigments and dyes have the same basic chemical structure. The insolubility required in pigments can be obtained by excluding solubilising groups, by forming insoluble salts (lake formation) of carboxylic or sulphonic acids, by metal complex formation in compounds without solubilising groups, and particularly by incorporating groups that reduce solubility (e.g. amide groups). The remaining organic pigments (“Other”) are used in textile printing and a number of smaller sectors, including contactless printing processes, office articles and accessories (e.g. coloured pencils, crayons, chalks), and the colouring of wood, cosmetics, and paper.

3.5.1 Process description

Making the paste

1 Pigment manufacturers send bags of fine grain pigments to paint plants. There, the pigment is premixed with resin (a wetting agent that assists in moistening the pigment), one or more solvents, and additives to form a paste.

Dispersing the pigment

2 The paste mixture for most industrial and some consumer paints is now routed into a sand mill, a large cylinder that agitates tiny particles of sand or silica to grind the pigment particles, making them smaller and dispersing them throughout the mixture. The mixture is then filtered to remove the sand particles.

3 Instead of being processed in sand mills, up to 90 percent of the water-based latex paints designed for use by individual homeowners are (instead) processed in a high-speed dispersion tank. There, the premixed paste is subjected to high-speed agitation by a circular, toothed blade attached to a rotating shaft. This process blends the pigment into the solvent.

Thinning the paste

4 Whether created by a sand mill or a dispersion tank, the paste must now be thinned to produce the final product. Transferred to large kettles, it is agitated with the proper amount of solvent for the type of paint desired.

Canning the paint

5 The finished paint product is then pumped into the canning room. For the standard 8 pint (3.78 liter) paint can be available to consumers, empty cans are first rolled horizontally onto labels, then set upright so that the paint can be pumped into them. A machine places lids onto the filled cans, and a second machine presses on the lids to seal them. From wire that is fed into it from coils, a bailometer cuts and shapes the handles before hooking them into holes pre-cut in the cans. A certain number of cans (usually four) are then boxed and stacked before being sent to the warehouse.

Quality Control

Paint manufacturers utilize an extensive array of quality control measures. The ingredients and the manufacturing process undergo stringent tests, and the finished product is checked to insure that it is of



high quality. A finished paint is inspected for its density, fineness of grind, dispersion, and viscosity. Paint is then applied to a surface and studied for bleed resistance, rate of drying, and texture.

In terms of the paint's aesthetic components, color is checked by an experienced observer and by spectral analysis to see if it matches a standard desired color. Resistance of the color to fading caused by the elements is determined by exposing a portion of a painted surface to an arc light and comparing the amount of fading to a painted surface that was not so exposed. The paint's hiding power is measured by painting it over a black surface and a white surface. The ratio of coverage on the black surface to coverage on the white surface is then determined, with .98 being high-quality paint. Gloss is measured by determining the amount of reflected light given off a painted surface.

Tests to measure the paint's more functional qualities include one for mar resistance, which entails scratching or abrading a dried coat of paint. Adhesion is tested by making a crosshatch, calibrated to .07 inch (2 millimeters), on a dried paint surface. A piece of tape is applied to the crosshatch, then pulled off; good paint will remain on the surface. Scrubbability is tested by a machine that rubs a soapy brush over the paint's surface. A system also exists to rate settling. An excellent paint can sit for six months with no settling and rate a ten. Poor paint, however, will settle into an immiscible lump of pigment on the bottom of the can and rate a zero. Weathering is tested by exposing the paint to outdoor conditions. Artificial weathering exposes a painted surface to sun, water, extreme temperature, humidity, or sulfuric gases. Fire retardancy is checked by burning the paint and determining its weight loss. If the amount lost is more than 10 percent, the paint is not considered fire-resistant.

3.5.2 Type of hazardous waste

Major solid wastes of concern include filtration sludges, process and effluent treatment sludges, and container residues. Examples of wastes considered toxic include, wastewater treatment sludges, spent acids, and process residues from the manufacture of chrome yellow and orange pigments, molybdate orange pigments, zinc yellow pigments, chrome and chrome oxide green pigments, iron blue pigments, and azo dyes.

3.5.3 Best management practices

Major solid wastes of concern include filtration sludges, process and effluent treatment sludges, and container residues. Examples of wastes considered toxic include wastewater treatment sludges, spent acids, and process residues from the manufacture of chrome yellow and orange pigments, molybdate orange pigments, zinc yellow pigments, chrome and chrome oxide green pigments, iron blue pigments, and azo dyes.

Liquid Effluents

Effluent treatment normally includes neutralization, flocculation, coagulation, settling, carbon adsorption, detoxification of organics by oxidation (using ultraviolet systems or peroxide solutions), and biological treatment. Exhausted carbon from adsorption processes may be sent for regeneration or combustion. Reverse osmosis, ultrafiltration, and other filtration techniques are used to recover and concentrate process intermediates.

Solid Hazardous Wastes

Contaminated solid wastes are generally incinerated, and the flue gases, when acidic, are scrubbed.



3.6 Aluminium coating processes

Aluminium alloys are anodized to increase corrosion resistance and to allow dyeing (coloring), improved lubrication, or improved adhesion. However, anodizing does not increase the strength of the aluminium object. The anodic layer is non-conductive.

When exposed to air at room temperature, or any other gas containing oxygen, pure aluminum self-passivates by forming a surface layer of amorphous aluminum oxide 2 to 3 nm thick, which provides very effective protection against corrosion. Aluminum alloys typically form a thicker oxide layer, 5–15 nm thick, but tend to be more susceptible to corrosion. Aluminium alloy parts are anodized to greatly increase the thickness of this layer for corrosion resistance. The corrosion resistance of aluminium alloys is significantly decreased by certain alloying elements or impurities: copper, iron, and silicon, so 2000-, 4000-, and 6000-series Al alloys tend to be most susceptible.

Although anodizing produces a very regular and uniform coating, microscopic fissures in the coating can lead to corrosion. Further, the coating is susceptible to chemical dissolution in the presence of high- and low-pH chemistry, which results in stripping the coating and corrosion of the substrate. To combat this, various techniques have been developed either to reduce the number of fissures, to insert more chemically stable compounds into the oxide, or both. For instance, sulfuric-anodized articles are normally sealed, either through hydro-thermal sealing or precipitating sealing, to reduce porosity and interstitial pathways that allow corrosive ion exchange between the surface and the substrate. Precipitating seals enhance chemical stability but are less effective in eliminating ion exchange pathways. Most recently, new techniques to partially convert the amorphous oxide coating into more stable micro-crystalline compounds have been developed that have shown significant improvement based on shorter bond lengths.

Some aluminium aircraft parts, architectural materials, and consumer products are anodized. Anodized aluminium can be found on MP3 players, smartphones, multi-tools, flashlights, cookware, cameras, sporting goods, firearms, window frames, roofs, in electrolytic capacitors, and on many other products both for corrosion resistance and the ability to retain dye. Although anodizing only has moderate wear resistance, the deeper pores can better retain a lubricating film than a smooth surface would.

Anodized coatings have a much lower thermal conductivity and coefficient of linear expansion than aluminium. As a result, the coating will crack from thermal stress if exposed to temperatures above 80 °C (353 K). The coating can crack, but it will not peel. The melting point of aluminium oxide is 2050 °C (2323 K), much higher than pure aluminium's 658 °C (931 K). This and the non-conductivity of aluminum oxide can make welding more difficult.

In typical commercial aluminium anodizing processes, the aluminium oxide is grown down into the surface and out from the surface by equal amounts. So, anodizing will increase the part dimensions on each surface by half the oxide thickness. For example, a coating that is 2 µm thick will increase the part dimensions by 1 µm per surface. If the part is anodized on all sides, then all linear dimensions will increase by the oxide thickness. Anodized aluminium surfaces are harder than aluminium but have low to moderate wear resistance, although this can be improved with thickness and sealing.

3.6.1 Process description

The anodized aluminium layer is grown by passing a direct current through an electrolytic solution, with the aluminium object serving as the anode (the positive electrode). The current releases hydrogen at the cathode (the negative electrode) and oxygen at the surface of the aluminium anode, creating a build-up of aluminium oxide. Alternating current and pulsed current is also possible but rarely used. The voltage required by various solutions may range from 1 to 300 V DC, although most fall in the range of 15 to 21 V.



Higher voltages are typically required for thicker coatings formed in sulfuric and organic acid. The anodizing current varies with the area of aluminium being anodized and typically ranges from 30 to 300 A/m² (2.8 to 28 A/ft²).

Aluminium anodizing is usually performed in an acid solution, which slowly dissolves the aluminium oxide. The acid action is balanced with the oxidation rate to form a coating with nanopores, 10–150 nm in diameter. These pores are what allow the electrolyte solution and current to reach the aluminium substrate and continue growing the coating to greater thickness beyond what is produced by autopassivation. However, these same pores will later permit air or water to reach the substrate and initiate corrosion if not sealed. They are often filled with colored dyes and/or corrosion inhibitors before sealing. Because the dye is only superficial, the underlying oxide may continue to provide corrosion protection even if minor wear and scratches may break through the dyed layer.

Conditions such as electrolyte concentration, acidity, solution temperature, and current must be controlled to allow the formation of a consistent oxide layer. Harder, thicker films tend to be produced by more dilute solutions at lower temperatures with higher voltages and currents. The film thickness can range from under 0.5 micrometers for bright decorative work up to 150 micrometers for architectural applications.

Dual-finishing aluminium

Anodizing can be performed in combination with chromate conversion coating. Each process provides corrosion resistance, with anodizing offering a significant advantage when it comes to ruggedness or physical wear resistance. The reason for combining the processes can vary, however, the significant difference between anodizing and chromate conversion coating is the electrical conductivity of the films produced. Although both stable compounds, chromate conversion coating has a greatly increased electrical conductivity. Applications where this may be useful are varied, however, the issue of grounding components as part of a larger system is an obvious one.

The dual finishing process uses the best each process has to offer, anodizing with its hard wear resistance and chromate conversion coating with its electrical conductivity.

The process steps can typically involve chromate conversion coating the entire component, followed by a masking of the surface in areas where the chromate coating must remain intact. Beyond that, the chromate coating is then dissolved in unmasked areas. The component can then be anodized, with anodizing taking to the unmasked areas. The exact process will vary dependent on service provider, component geometry and required outcome.

3.6.2 Type of hazardous waste

Liquid waste

The production of aluminium from secondary raw materials is essentially a dry process. Any discharge of waste water is usually limited to cooling water, which is often recirculated, and rainwater run-off from surfaces and roofs. A closed water circuit returns the used water to the process; only water used to cool the metal is evaporated to the atmosphere and is regarded as lost and must be replaced. Sometimes fresh water is added to maintain the cooling water below a certain temperature for safety reasons. The cooling water basin of a closed loop system will collect some contaminants due to abrasion in the equipment and as precipitation products originating from water conditioning. These contaminants collect in the basin and have to be discharged from time to time. As they are not toxic or otherwise harmful to the environment they are usually passed on to public waste water treatment plants. Similarly, considerable amounts of water are used when wet systems are used for air pollution control. However, the waste water is often purified and recirculated within the system.



The rainwater run-off can be contaminated by the open storage of raw materials such as oily scrap and deposited solids. Typical values for this contamination are < 0.03 kg/tonne of aluminium for suspended solids. In addition, considerable amounts of waste water can be discharged when wet systems are used for air pollution control. Waste water from swarf washing is also recirculated inside the plant.

The main sources of the waste water in secondary aluminium production are:

- surface water;
- water from swarf washing (usually completely reused);
- waste water from gas treatment;
- cooling water from casting (0.15–0.3 m³/t Al).

Solid waste

Typical residues from secondary aluminium production are shown below:

Residue	Origin	Volume	Treatment	Driving force
Salt slag	Melting in rotary furnaces	Up to 500 kg/t Al	Recovery via dissolution and crystallisation techniques. Production of reusable substances: Al metal granulate, mixed salt, non-metallic oxidic products	Salt is not used in all furnaces. Ban on landfill
Filter dust	Exhaust gas cleaning	Up to 35 kg/t Al 0.1 to 10 kg/t Al (1)	Disposal with pretreatment or to underground site, partly reconditioned with salt slag or used in the steel industry	Ban on surface disposal in some countries, thermal treatment possible (neutralisation with NaHCO ₃ or Na ₂ CO ₃ → use with salt slag)
Furnace lining	Melting furnace	Up to 4 kg/t Al	Potential for reconditioning with skimmings/dross, otherwise leaching and landfill	Aim to prevent landfill. Recycle to produce moulds
Skimmings or dross	Cleaning of smelter and foundries	Up to 80 kg/t Al (2)	Smelting in rotary furnace. Recovery, pellets used in rotary drum furnace, dross dust used in the recovery of salt slag	Ban on landfill
Grease/oil	Swarf washing/centrifugation		Collection and separation	Oil recycling

(1) Non-metallic products (oxide compounds from Al scrap).
 (2) Using a closed well furnace provided no external scrap is melted.
 Source: [142, Boin, U. et al. 1998], [234, UBA (D) 2007], [256, Winter 2007].

Source: Non ferrous Metals industries, Intergated pollution prevention and control, European Commission, Aug. 2017

Skimmings/dross from the holding and treatment processes occur in amounts of 15–30 kg per tonne of aluminium produced, and contain a significant amount of aluminium, around 20–80 %.



Skimmings/dross are used as a raw material in parts of the secondary aluminium industry. Sometimes hot skimmings/dross are directly charged to the furnaces for recovery of aluminium metal. Mostly, they are cooled and pretreated as soon as they are removed from the furnace, to reduce emissions and prevent further oxidation of the metal present and to separate aluminium from aluminium oxide. Methods include inert gas cooling, hot pressing to remove molten aluminium, and cooling in purpose-built coolers.

During storage, skimmings/dross can react with moisture (from the air) to produce ammonia and other gases.

Cold skimmings/dross are further treated by a number of processes to recover aluminium. Rotary or tilting rotary furnaces, are used to recover aluminium from skimmings/dross and the metallic fraction produced from it. Salt flux is usually used to facilitate this process, as it reduces oxidation and promotes the removal of some impurities (e.g. Mg, Ca, Li). Salt slag is generated and treated in salt slag recovery processes. Another further treatment is the use of separation techniques such as milling and processing, e.g. air classification, to separate oxide from the metal using the separation techniques, the metal can be remelted in relevant furnaces and the fine fraction can be further processed, e.g. recycled in the steel industry or in the salt slag recovery process. It has been reported that the final generation of salt slag and waste is reduced and the use of energy is lower due to a lower burden of inert material in the furnace.

Spent filters from metal treatment are usually disposed of. In some cases, when sodium bicarbonate is used for gas cleaning, solid residues can be recovered with the salt cover.

Furnace linings and dust can be recovered in salt slag treatment processes or disposed of.

When used salt flux is tapped from the furnace it contains large amounts of aluminium oxide, which the flux has separated from the raw materials. Of the total weight of the salt slag, 4–10 % is metallic aluminium. The sodium and potassium chlorides can be recovered for further use, using separation and crystallisation processes. In most salt slag recycling plants the oxide portion is sold, after a washing stage, to the cement or mineral wool industry.

Both filter dust and salt slag are recycled, which means that all the solid wastes generated by the secondary aluminium industry can be recovered, avoiding the need for landfill.

3.6.3 Best management practices

Anodizing is one of the more environmentally friendly metal finishing processes. With the exception of organic (aka integral color) anodizing, the by-products contain only small amounts of heavy metals, halogens, or volatile organic compounds. Integral color anodizing produces no VOCs, heavy metals, or halogens as all of the byproducts found in the effluent streams of other processes come from their dyes or plating materials.

The first step in dealing with wastewater is to produce less of it; this is the idea behind electro dialysis. Electro dialysis is a process of extending the life of the anodizing electrolyte by removing the aluminum ions from the bath. Electricity charges the ions that are then driven through an ionic sensitive membrane on their way to an oppositely charged electrode. The membrane picks up the aluminum and allows the acid electrolyte to pass through and continue back to the bath. The collected aluminum hydroxide is sludge, and the acid bath is then cleaned.

In another process called acid sorption, the exact opposite takes place. In acid sorption, ion exchange resins absorb the sulfuric acid while the metals pass by. The resins then release the acids in a water wash, and the metals are collected for disposal.

In another method, flocculating agents separate the aluminum from the electrolyte. These polymer additives combine with the aluminum hydroxide and congeal, creating a woolly mass that is skimmed



away. The only equipment needed is the agents themselves—this makes it an attractive process to both large and small businesses.

In all of the above processes, heavy aluminum hydroxide sludge is left. Presses can squeeze out water, and sludge dryers further concentrate the sludge making it up to 75 percent solid. Small producers (less than 100 kilograms per month) are exempt from the authorities' guidelines in the disposal of hazardous waste and may take it to a general municipal landfill. Larger producers, though, must adhere to the regulations in the storage, transportation, and disposal of their waste.

Other Pollutants

Air pollution is a concern in the anodizing shop. In the anodizing bath, sulfuric acid fumes are released that can be hazardous not only to the air, but to employees in the plant. Local exhaust ventilation removes the fumes at the source point and a scrubber provides additional cleaning before release into the atmosphere. The concentration in the electrolyte bath may be only 10 to 20 percent, but long-term exposure causes permanent health problems if precautions are not taken. In the atmosphere, released sulfuric acid subsequently falls back to the ground as acid rain, which adversely affects flora, fauna, soils and surface waters. The Clean Air Act regulates the release of sulfuric acid into the atmosphere, not only controls its release, but also record keeping and reporting.

Besides the electrolyte bearing sludge, other wastes are generated in the anodizing process. The solvents and cleaners used in the pre-treating process, as well as the materials removed from the aluminum, must be collected and properly disposed of. After anodizing, there are also dyes and sealants that need additional disposal.

Hazardous waste contractors are an expensive way to deal with disposal, but save the anodizer from compliance errors that can be even more costly. Hazardous disposal contractor's services range from simple consulting to complete handling of the waste. Once in hand, the waste is recycled, incinerated, or taken to a landfill.

If sludge contains high enough levels of aluminum, it can be removed from sludge and sent off for use in the manufacturing of bricks and clays, cosmetics, and paper products. This process often proves unfeasible due either to the contaminants in the sludge or its low metal content per volume.

Incineration is another option for sludge disposal. It has the advantages of reducing both the volume and toxicity of the sludge, but is an expensive process.

3.7 Pharmaceutical industry

Pharmaceutical waste includes expired, unused, spilt and contaminated pharmaceutical products, prescribed and proprietary drugs, vaccines and sera that are no longer required, and, due to their chemical or biological nature, need to be disposed of carefully. The category also includes discarded items heavily contaminated during the handling of pharmaceuticals, such as bottles, vials and boxes containing pharmaceutical residues, gloves, masks and connecting tubing.

3.7.1 Type of hazardous waste

Genotoxic waste is highly hazardous and may have mutagenic (capable of inducing a genetic mutation), teratogenic (capable of causing defects in an embryo or fetus) or carcinogenic (cancer-causing) properties. The disposal of genotoxic waste raises serious safety problems, both inside hospitals and after disposal, and should be given special attention. Genotoxic waste may include certain cytostatic



drugs, vomit, urine or faeces from patients treated with cytostatic drugs, chemicals and radioactive material.

Technically, genotoxic means toxic to the deoxyribonucleic acid (DNA); cytotoxic means toxic to the cell; cytostatic means suppressing the growth and multiplication of the cell; antineoplastic means inhibiting the development of abnormal tissue growth; and chemotherapeutic means the use of chemicals for treatment, including cancer therapy.

Cytotoxic (chemotherapeutic or antineoplastic) drugs, the principal substances in this category, have the ability to kill or stop the growth of certain living cells and are used in chemotherapy of cancer. They play an important role in the therapy of various neoplastic conditions but are also finding wider application as immunosuppressive agents in organ transplantation and in treating various diseases with an immunological basis. Cytotoxic drugs are most often used in specialized departments, such as oncology and radiotherapy units, whose main role is cancer treatment. Their use in other hospital departments and outside the hospital in clinics and elsewhere is also increasing.

Cytostatic drugs can be categorized as follows:

- alkylating agents: cause alkylation of DNA nucleotides, which leads to cross-linking and miscoding of the genetic stock;
- antimetabolites: inhibit the biosynthesis of nucleic acids in the cell;
- mitotic inhibitors: prevent cell replication.

Cytotoxic wastes are generated from several sources and can include the following:

- contaminated materials from drug preparation and administration, such as syringes, needles, gauzes, vials, packaging;
- outdated drugs, excess (leftover) solutions, drugs returned from the wards;
- urine, faeces and vomit from patients, which may contain potentially hazardous amounts of the administered cytostatic drugs or of their metabolites, and which should be considered genotoxic for at least 48 hours and sometimes up to 1 week after drug administration.

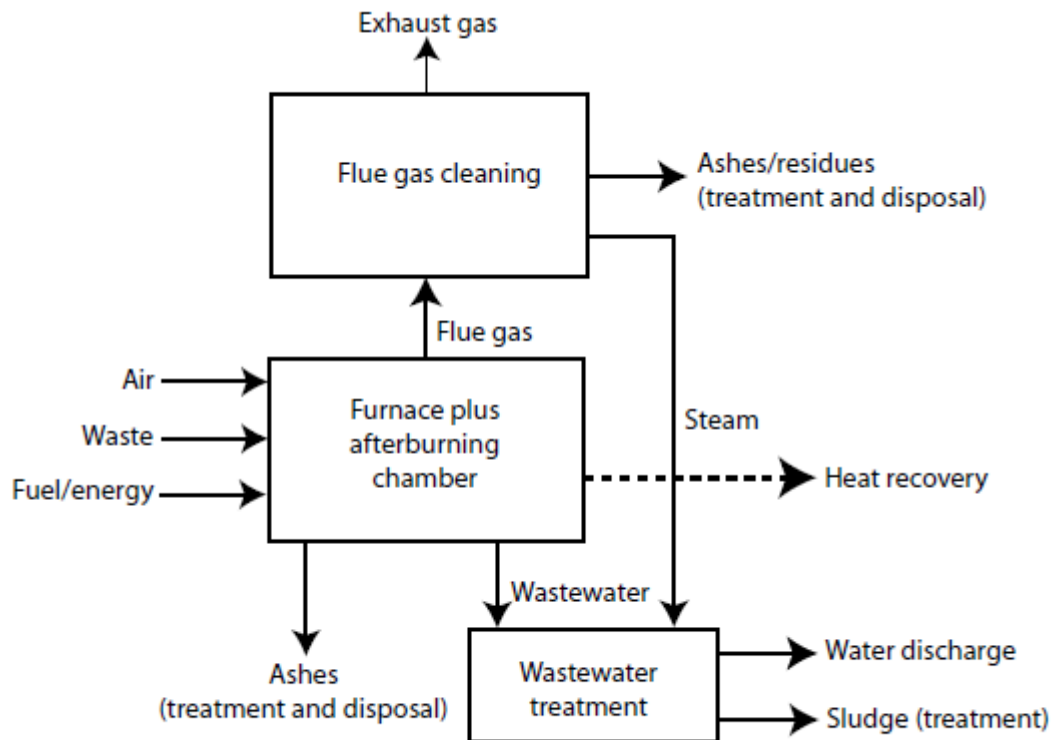
In specialized oncological hospitals, genotoxic waste (containing cytostatic or radioactive substances) may constitute as much as 1% of the total health-care wastes.

3.7.2 Pharmaceutical industry best environmental management practices

Incineration is a high-temperature, dry oxidation process that reduces organic and combustible waste to inorganic, incombustible matter and results in a significant reduction of waste volume and weight. High-heat thermal processes take place at temperatures from about 200 °C to more than 1000 °C. They involve the chemical and physical breakdown of organic material through the processes of combustion, pyrolysis or gasification. A disadvantage of these technologies is the release of combustion by-products into the atmosphere and the generation of residual ash. The combustion of health-care waste produces mainly gaseous emissions, including steam, carbon dioxide, nitrogen oxides, a range of volatile substances (e.g. metals, halogenic acids, products of incomplete combustion) and particulate matter, plus



solid residues in the form of ashes. The figure below shows a simple schematic of the incineration process.



Source: Adapted by Jorge Emmanuel from UNEP (2006)

The Stockholm Convention guidance on best available techniques and best environmental practices states: “If medical waste is incinerated in conditions that do not constitute best available techniques or best environmental practices, there is potential for the release of PCDD [polychlorinated dibenzodioxins] and PCDF [polychlorinated dibenzofurans] in relatively high concentrations” (Secretariat of the Stockholm Convention, 2006).

The World Health Organization (WHO) has reviewed small-scale health-care incinerators and reported “significant problems regarding the siting, operation, maintenance and management of these incinerators” (Batterman, 2004). As a result of these and other concerns, together with the very high costs for modern incineration to meet best available technique (BAT) standards, the WHO report concluded that “small-scale incineration is viewed as a transitional means of disposal for health care waste”

Required waste characteristics

Incineration of waste is affordable and feasible only if the “heating” (or “calorific”) value of the waste reaches at least 2000 kcal/kg (8370 kJ/kg). While the value for hospital wastes containing high levels of plastics can exceed 4000 kcal/kg (16740 kJ/kg), some health-care waste may contain a high proportion of



wet waste and have much lower calorific values. The basic characteristics necessary for incineration include:

- heating value above 2000 kcal/kg (8370 kJ/kg);
- calorific values within the regulatory and design requirements (e.g. the desired residence time, system operating temperature and excess air levels);
- content of combustible matter above 60%;
- content of non-combustible solids below 5%;
- content of non-combustible fines below 20%;
- moisture content below 30%.

Incineration requires no pretreatment, provided the following waste types are not included or are kept to an absolute minimum:

- pressurized gas containers;
- large amounts of reactive chemical waste;
- silver salts and photographic or radiographic wastes;
- halogenated materials such as polyvinyl chloride (PVC) plastics (waste and packaging of waste should not contain PVC material);
- waste containing mercury, cadmium and other heavy metals, such as broken thermometers, used batteries and lead-lined wooden panels;
- sealed ampoules or vials that may implode during the combustion process;
- radioactive materials;
- pharmaceuticals thermally stable in conditions below 1200 °C (e.g. 5-fluorouracil).

Energy recovery

Many modern large incineration facilities can reuse the heat generated from the combustion of waste, so energy recovery seems an attractive proposition. However, there are characteristics that need to be taken into consideration. Most health-care waste incinerators are too small for energy recovery to be effective. Whenever energy recovery is considered, it requires specialized advice on whether the proposition is technically and financially feasible for the local circumstances.

Types of incinerators for health-care waste

Incinerators range from extremely sophisticated, high-temperature operating plants to very basic combustion units. All types of incinerators, if operated properly, should eliminate pathogens from waste and reduce waste to a small volume of ash. Incineration equipment should be chosen on the basis of the available resources and the local situation, balancing the public health benefits of pathogen elimination against the technical requirements needed to avoid the health impacts of air or groundwater pollution from the by-products of waste combustion.

Three generic kinds of incineration technologies are commonly used for treating health-care waste:



- dual-chamber starved-air incinerators, which operate in the starved-air mode (below stoichiometric conditions) in the primary chamber and are designed to burn infectious health-care waste;
- multiple chamber incinerators, including in-line incinerators and retort incinerators used for pathological waste, which operate in the excess-air mode (above stoichiometric conditions);
- rotary kilns, normally capable of reaching temperatures that break down genotoxic substances and heat-resistant chemicals.

Starved-air incinerators

Starved-air incineration is a commonly used incineration process for health-care waste. The process is also known as controlled-air incineration, pyrolytic incineration, two-stage incineration or static hearth incineration. The combustion air used for incineration is less than stoichiometric (that is, the amount of oxygen is less than the ideal proportion needed for burning the carbon and hydrogen).

A starved-air incinerator comprises a primary chamber and a post-combustion secondary chamber. In the primary chamber, the waste is thermally decomposed through an oxygen-deficient, medium-temperature combustion process (800 to 900 °C), producing solid ashes and gases. The primary chamber includes a fuel burner, used to start the process. Waste residence time can vary from 1 to 4 hours, depending on the size of the installation. The gases produced in the primary chamber are burned at high temperature (ranging from 1100 to 1600 °C) in the secondary chamber, using an excess of air to minimize smoke, carbon monoxide and odours. If the temperature drops below 1100 °C (the minimum requirement specified in the European Union's Waste incineration directive 2000/76/EC), additional energy should be provided by a gas or fuel burner.

Larger pyrolytic incinerators (capacity >20 tonnes/day) are usually designed to function on a continuous basis. They are also capable of automatic operation, including loading of waste, removal of ashes and internal movement of burning waste.

Multiple chamber incinerators

Multiple chamber incinerators were more common in the past and are still used in some countries for pathological waste. There are two major types: in-line incinerators and retort incinerators. In-line incinerators are rectangular in design and have a large primary chamber with a moving grate, a secondary chamber to burn off volatile organic compounds in the flue gas, and additional chambers that force the gas to turn in different directions to remove particulate matter as ash residues.

Retort incinerators have a primary and a secondary chamber arranged in a "U" shape. Flue gas from the primary chamber (hearth) is generally passed under the primary chamber to add heat to the hearth. Both types of incinerators operate in the excess-air mode and use supplementary fuel to reach temperatures of around 800–1000 °C. These designs are not commonly used because of their high volumes of airborne emissions.

Rotary kilns



A rotary kiln has a rotating oven and a post-combustion chamber. They can be specifically designed to burn chemical wastes and may also be suitable as a large-scale regional health-care waste incinerator if appropriate temperatures and scrubbing (flue gas cleaning) equipment are used. The main characteristics of rotary kilns are:

- incineration temperatures between 900 and 1200 °C are possible;
- incinerator capacities up to 10 tonnes per hour are available;
- additional equipment and operation costs are high, as is energy consumption; the system also requires well-trained personnel.

The axis of a rotary kiln is inclined at a slight angle to the horizontal (3–5% slope). The kiln rotates 2–5 times per minute and is charged with waste at its upper end. Ashes are subsequently discharged at the bottom end. The gases produced in the kiln are heated to high temperatures to burn off gaseous organic compounds in the post-combustion chamber, and typically have a long residence time of two or more seconds.

Rotary kilns may operate continuously and are adaptable to a wide range of loading devices. Those designed to treat toxic wastes should preferably be operated by specialist waste-disposal agencies and located away from health-care facilities in industrial areas.

Small-scale incinerators

Small-scale incinerators are designed to meet an immediate need for public health protection where there is no access to more sophisticated technologies. This involves a compromise between the environmental impacts from controlled combustion and an overriding need to protect public health if the only alternative is indiscriminate dumping. These circumstances exist in many developing situations, and small-scale incineration can be a realistic response to an immediate requirement (Batterman, 2004). As far as possible, a small-scale facility should avoid burning PVC plastics and other chlorinated waste.

If small-scale incinerators are the only option available, the best practices possible should be used, to minimize operational impacts on the environment. Best practices in this context are (Batterman, 2004):

- effective waste reduction and segregation, ensuring only the smallest quantities of combustible waste types are incinerated;
- an engineered design with sufficient residence time and temperatures to minimize products of incomplete combustion;
- siting incinerators away from health-care buildings and residential areas or where food is grown;
- construction using detailed engineering plans and materials to minimize flaws that may lead to incomplete destruction of waste and premature failures of the incinerator;
- a clearly described method of operation to achieve the desired combustion conditions and emissions; for example, appropriate start-up and cool-down procedures, achievement and maintenance of a minimum temperature before waste is burned, use of appropriate loading/charging rates (both fuel and waste) to maintain appropriate temperatures, proper disposal of ash and equipment to safeguard workers;
- periodic maintenance to replace or repair defective components (including inspection, spare parts inventory and daily record keeping);



- improved training and management, possibly promoted by certification and inspection programmes for operators, the availability of an operating and maintenance manual, visible management oversight, and regular maintenance schedules.

In 2004, WHO commissioned a screening-level health risk assessment for exposure to dioxins and furans from small-scale incinerators. The study found that the expected practice with small-scale incinerators resulted in unacceptable cancer risks under medium usage (two hours per week) or higher (Batterman, 2004). The report concluded that small-scale incineration should be viewed as a transitional means of disposal for health-care waste. Single-chamber, drum and brick incinerators do not meet the BAT requirements of the Stockholm Convention guidelines (Secretariat of the Stockholm Convention, 2006).

Co-incineration

High-temperature incineration of chemical and pharmaceutical waste in industrial cement kilns or steel furnaces is practiced in some countries. Significant additional investments can be required to modify the facilities for safe handling and loading of medical wastes, and the machines are rarely equipped with filtration and clean-up equipment suitable for the pollutants generated. The Stockholm Convention guidelines list infectious medical wastes on a negative list of wastes not recommended for co-processing (Secretariat of the Stockholm Convention, 2006).

In some countries, it is permitted to incinerate health-care waste in a municipal solid waste incineration plant. The heating value of health-care waste can be higher than that of domestic refuse, and the introduction of relatively small quantities of health-care waste should not affect significantly the operation of municipal incinerators. Care must be taken with the handling and loading of the health-care wastes to avoid hazardous situations. Municipal incinerators are usually designed with an operating temperature of >850 °C.

Environmental control of incinerators

General principles

Incinerator emissions should comply with national standards and in accordance with the Stockholm Convention BAT and best environmental practices (BEP) guidance in those countries that have signed the convention. If the relevant authorities have not established such regulations, the BAT/BEP guidelines or international standards are examples of those that could be followed.

Incinerators require emission controls equipment to meet modern emission standards. It is determined that without emission controls dioxin concentrations in combustion gases were 93 to 710 times higher than the European Union legal limit (0.1 ng TEQ/m³), depending on variations in the waste composition.

Flue (exhaust) gases from incinerators contain fly ash (particulates), heavy metals, dioxins, furans, thermally resistant organic compounds, and gases such as oxides of nitrogen, sulfur, carbon and hydrogen halides. The flue gases should be treated, and this should be done in at least two different stages:

- “de-dusting” to remove most of the fly ash



- washing with alkaline substances to remove hydrogen halides and sulfur oxides.

Flue gas treatment can be performed by wet, dry or semidry treatment, or a combination of these processes. The temperature of the combustion process has to be very closely controlled to avoid generating furans and dioxins, and the temperature in the flue gases should be cooled down rapidly to prevent dioxins and furans from reforming.

Stockholm Convention

The Stockholm Convention is a legally binding treaty with the goal of protecting human health and the environment from persistent organic pollutants. Under the convention, the countries party to the treaty are required to use the best available techniques for new incinerators. The Stockholm Convention's guidelines for best available techniques and best environmental practices limit the levels of dioxins and furans in air emissions to 0.1 ng I-TEQ/Nm³ at 11% O₂. Moreover, dioxins in the wastewater of treatment plants treating effluents from any gas treatment scrubber effluents should be well below 0.1 ng I-TEQ per litre. In addition, the guidelines list primary and secondary measures to achieve the performance levels for removal of dioxins and furans. The primary measures are to:

- introduce the waste into the combustion chamber only at temperatures of ≥ 850 °C;
- install auxiliary burners for start-up and shut-down operations;
- avoid regular starting and stopping of the incineration process;
- avoid combustion temperatures below 850 °C and cold regions in the flue gas;
- control oxygen input depending on the heating value and consistency of feed material;
- maintain minimum residence time of two seconds above 850 °C in the secondary chamber after the last injection of air or at 1100 °C for wastes containing more than 1% halogenated organic substances (generally the case for health-care waste) and 6% O₂ by volume;
- maintain high turbulence of exhaust gases and reduction of excess air by injection of secondary air or recirculated flue gas, preheating of the air-streams or regulated air inflow;
- conduct on-line monitoring for combustion control (temperature, oxygen content, carbon monoxide, dust), and operation and regulation of the incinerator from a central console.

The secondary measures to further reduce dioxins and furans are an appropriate combination of dust-removal equipment and other techniques, such as catalytic oxidation, gas quenching and wet or (semi) dry adsorption systems. Furthermore, fly and bottom ash, as well as wastewater, should be treated appropriately. Carbon monoxide, oxygen in the flue gas, particulate matter, hydrogen chloride, sulfur dioxide, nitrogen oxides, hydrogen fluoride, airflows and temperatures, pressure drops and pH in the flue gas should be routinely monitored according to national laws and manufacturers' guidance.

Dust removal

The design of flue gas cleaning facilities assumes normal operation of an incinerator, especially temperature and air inputs. Depending on the type of incinerator, it is likely to produce between 25 and 30 kg of dust per tonne of waste (known as fly ash). For example, an incinerator of 20 tonnes/day capacity would need to be equipped with dust removal equipment to handle at least 600 kg/day (30 kg/tonne × 20 tonnes) of dust. The most common types of dust removal equipment used at incinerator plants are:



- cyclonic scrubbers
- fabric dust removers (commonly called “baghouse filters”)
- electrostatic precipitators.

Flue gas emerges from the post-combustion chamber at about 800–1000 °C and must be cooled to 200–300 °C before entering the dust-removal equipment. This can be achieved in cooling towers, called quenching towers or baths, where the gas is cooled by water circulating in a closed system. (The water may subsequently be used for preheating waste or for other purposes.) A common method is the use of a boiler in which heat exchange takes place between the hot flue gas stream and boiler water. The hot flue gas stream is cooled, and boiler water is heated (the energy of this heated water or steam can be used for generating electricity or for other purposes). The flue gas can also be cooled by introducing fresh air, although this method is less efficient.

Removal of acids or alkalis

Three processes – wet, semi-dry and dry – are available for removing acids such as hydrofluoric acid (HF), hydrochloric acid (HCl), and sulfuric acid (H₂SO₄). In the wet process, gases are washed in a spraying tower with soda or lime solution, which also contributes to gas cooling and to the removal of very small particulates. In the semi-dry process (also known as semi-wet process), a lime suspension is injected into the gas column. Salts generated by the neutralization process have to be removed. In the dry process, lime powder is injected into the gas column, and the salts produced during the neutralization have to be removed. The wet process is the most efficient of these three options, but requires complex treatment of the resultant wastewater.

Wastewater from gas washing and quenching of ashes must undergo a chemical neutralization treatment before being discharged into a sewer. This treatment includes neutralization of acids and flocculation, and precipitation of insoluble salts.

Solid residues

Sludges from wastewater treatment and from cooling of fly ash should be considered as HZW. They may either be sent to a waste-disposal facility for hazardous chemicals, or be treated onsite by drying, followed by encapsulation. Solid ashes from health-care waste incineration (known as bottom ash) are often assumed to be less hazardous than fly ash and in the past have been reused in civil engineering works. Recently, growing debate about potential leakage of toxic substances from these ashes and possible pollution of groundwater has led some countries to require these ashes to be disposed of in landfills designed specifically for hazardous substances.



Appendix 1: Citation

- Best Available Techniques (BAT) Reference Document in the Food, Drink and Milk Industries, JOINT RESEARCH CENTRE, European IPPC Bureau, January 2017
- Best Available Techniques (BAT) Reference Document for Waste Treatment, JOINT RESEARCH CENTRE, European IPPC Bureau, December 2015
- The Used Oil Management Handbook, Guidance for Used Oil Handlers, Alabama Department of Environmental Management, August 2012
- The Used Oil Recycling Handbook, Guidance for Used Oil Handlers, Texas Commission on Environmental Quality, May 2011
- Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas, JOINT RESEARCH CENTRE, European IPPC Bureau, 2015
- Best Available Techniques (BAT) Reference Document on Surface Treatment using Organic Solvents, JOINT RESEARCH CENTRE, European IPPC Bureau, October 2017
- Best Available Techniques (BAT) Reference Document for the manufacture of Organic Fine Chemicals, European Commission, European IPPC Bureau, August 2016