WASTE INCINERATION FACILITIES

SUMMARY

Waste incinerators are identified in the Minamata Convention as one of the major industrial sources of mercury emissions. The category is listed in its Annex D.

The potential purposes of waste incineration include volume reduction, energy recovery, destruction or at least minimization of hazardous constituents, disinfection and the recovery of some residues.

To achieve best results for environmental protection as a whole, it is essential to coordinate the waste incineration process with upstream activities (e.g. waste management techniques) and downstream activities (e.g. disposal of solid residues from waste incineration).

When considering proposals to construct new waste incinerators, consideration should be given to alternatives such as activities to minimize the generation of waste, including resource recovery, reuse, recycling, and waste separation and promoting products that contribute less or no mercury to waste streams. Consideration should also be given to approaches that prevent mercury entering waste which will be incinerated.

The environmentally sound design and operation of waste incinerators requires the use of both best available techniques and best environmental practices (which are to some extent overlapping) in order to prevent or minimize the emissions of harmful substances like mercury.

Best environmental practices for waste incineration include appropriate off site procedures (such as overall waste management and consideration of environmental impacts of siting) and on site procedures which include waste inspection, proper waste handling, incinerator operation and management practices and handling of residues.

Best available techniques for waste incineration include appropriate selection of site; waste input and control; techniques for combustion, flue gas, solid residue and effluent treatment. For small medical waste incinerators, application of best available techniques is often difficult, given the high costs associated with building, operating, maintaining and monitoring such facilities.

Releases of mercury from municipal solid waste incinerators designed and operated according to best available techniques and best environmental practices occur mainly via fly ash, bottom ash and filter cake from wastewater treatment. Therefore, it is of major importance to provide for a safe sink of these waste types, for example, by pre-treatment and final disposal in dedicated landfills, which are designed and operated according to best available techniques.

With a suitable combination of primary and secondary measures, mercury emission levels in air emissions not higher than 1-10 µg /m^3 (at 11 per cent O_2) are associated with best available techniques. It is further noted that under normal operating conditions emissions lower than this level can be achieved with a well-designed waste incineration plant.

Comment [D[1]: Government of Prince Edward Island: with this in mind and given that the described facilities are small, operated intermittently, and would be difficult and costly to retrofit, they haven't been considered as candidates for mercury emissions reductions.

Comment [D[2]: Government of Prince Edward Island: A municipal solid waste incinerator (energy from waste plant), coupled to a district heating system, is located in Charlottetown. It is equipped with an all-dry scrubber that circulates the combustion gases, hydrated lime and powdered activated carbon in a venturi reactor. A pulse jet fabric filter captures particulate matter.

Comment [D[3]: Government of Prince Edward Island: Although the EFW facility has been operating since the early 1980s and is not of the most modern design, regular stack testing has shown that mercury emissions average 10 µg/m3 at 11% O2. This is consistent with the statement in this paragraph.

So, the BAT/BEP strategies described in the body of the document are comprehensive, realistic, and useful, and are shown to deliver the expected results in our experience.

Comment [dl4]: For batch waste incinerators, some of the BAT/BEP presented may apply, particularly the more general practices. This document seems to focus mainly on continuous systems. More specific information for batch systems should be included.

Comment [dl5]: This could cause some confusion that these are target emission limit values. Please add a footnote to clarify that emission limit values (ELVs) mentioned in the guidelines are meant as an indication of emission performance that can be achieved using BAT, and are not requirements or targets.

Table of Content

1 Introduction

This section addresses only the dedicated incineration of wastes and not other situations where waste is thermally treated, for example, co-incineration processes such as cement kilns and large combustion plants, which are dealt with in the sections relating to those processes.

Open burning (the burning of any type of waste in the open air or in open dumps, and in incineration devices that do not allow for complete combustion) is considered 'bad environmental practice' and should be discouraged as it can lead to emissions of toxic substances into the environment. Open burning is not covered further in this guidance.

Mercury is volatized in the incineration process and, therefore, specific action should be taken both before, during and after incineration to reduce these emissions. The only relevant primary technique for preventing emissions of mercury into the air before incinerating are those that prevent or control, if possible, the inclusion of mercury in waste.

For existing incinerators, Parties shall implement one or more of the measures listed in paragraph 5 of Article 8 of the Convention. The Party may apply the same measures to all relevant existing sources, or may adopt different measures in respect of different source categories. The objective for the measures applied by a Party shall be to achieve reasonable progress in reducing emissions over time. This can include the use of best available techniques and best environmental practices, a multi-pollutant control strategy that would deliver co-benefits for control emissions or other possible measures, with the objective being to achieve reasonable progress in reducing emissions over time.

However, for new incinerators where construction or substantial modification starts at least one year after the date of entry into force for the Party, Parties shall be required to use best available techniques and best environmental practice to control and, where feasible, reduce emissions.

2 PROCESSES USED IN WASTE INCINERATION FACILITIES, INCLUDING CONSIDERATION OF INPUT MATERIALS AND BEHAVIOUR OF MERCURY IN THE PROCESS

2.1 General Description Of Wastes That Could Result In Emissions Of Mercury Or Mercury Compounds When Incinerated

Comment [D[6]: David Lean, Lean Environmental: Waste incineration also has high emissions but few people realize what it is in the waste that releases mercury. One source is sewage sludge that is commonly incinerated. Without incineration this high level of mercury (5 to15 ug Hg per gram dry weight (which is equivalent of course to mg/kg as used in the report) is otherwise released in one form or another.

2.1.1 Waste Hierarchy

The hierarchy captures the progression of a material or product through successive stages of waste management, and represents the latter part of the life-cycle for each product. The primary aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste. The proper application of the waste hierarchy can have several benefits. It can help prevent emissions of mercury from waste materials that may contain mercury or are contaminated with mercury, reduce greenhouse gas production, reduce other air pollutants, save energy, conserves resources, create jobs and stimulate the development of green technologies. The waste hierarchy is divided into the following stages:

Prevention: The prevention of waste is the most vital point in the waste hierarchy. Prevention or reduction minimizes the generation of waste products in the first place. Prevention usually results in the least environmental and economic life cycle costs because it does not require collecting or processing of materials. Prevention also typically produces significant benefits in terms of production efficiencies and the use of resources. It involves using less material in design and manufacture, trying to keep products for longer, and using less hazardous materials.

Reuse: The reuse of waste is the next most desirable option. It is any operation where products or materials that are not waste are used again for the same purpose for which they were intended. Reusing waste often requires collection but relatively little or no processing. It involves checking, cleaning, repairing, and/or refurbishing, entire items or spare parts. Care should, however, be taken with reuse of wastes containing or contaminated with hazardous substances such as mercury.

Comment [s7]: This is often referred to as “direct reuse”, as reuse may require repair or refurbishment of an end-of-life product.

Recycle: Recycling of waste is the next step in priority. It is any activity that includes the collection of used, reused, or unused items that would otherwise be considered waste. Recycling involves sorting and processing the recyclable products into raw material and then remanufacturing the recycled raw materials into new products.

Recovery: The recovery of waste is further separated into categories: the recovery of materials and the recovery of energy. Whichever of these two choices is better for the environment and human health is the preferred option. The recovery of materials is most often preferred and includes activities such as recycling and composting. These management activities generally require a collection system and a method of material processing and conversion into a new product. Recovery of energy, such as incineration, is usually the less preferred option. The conversion of non-recyclable waste materials into usable heat, electricity, or fuel is done through a variety of processes, including anaerobic digestion, gasification, and pyrolysis.

Comment [dl8]: These definitions will need to be re-visited after the Basel Convention review of definitions is completed.

Disposal: The last resort is disposal and is only considered once all other possibilities have been explored. Disposal is any operation that involves the dumping and incineration of waste without energy recovery. Before final disposal, pre-treatment may be necessary depending on the nature of the waste. Landfilling is the most common form of final waste disposal and the final disposal option.

2.1.2 Introduction to different types of waste with regard to mercury emissions from waste incinerator facilities

2.1.2.1 Municipal Waste

Municipal Solid Waste (MSW), more commonly known as trash or garbage, consists of everyday items that are used and then thrown away, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, batteries and others. These come from households, schools, hospitals, and businesses. The municipal solid waste industry can be divided into four components namely: recycling, composting, landfilling, and waste-to-energy via incineration. The primary steps are generation, collection, sorting and separation, transfer, and disposal. A number of municipal wastes contain hazardous substances as well as organic chemicals such as pesticides. Traditional medicine, cosmetics and other items may also contain hazardous substances.

In order to ensure that hazardous substances such as mercury that may be present in municipal solid waste do not contaminate the environment, the generation and handling of such waste should be managed in a manner which establishes priorities based on sustainability. To be sustainable, waste management cannot be solved only with technical end-of-pipe solutions; instead an integrated approach is necessary. This approach may be described as a hierarchical approach, as set out in section 2.1.1.

The sources of mercury in municipal solid waste may include the following: household batteries, electric lighting, paint residues, thermometers, thermostats, pigments, dental uses, special paper coating, mercury light switches, film pack batteries and others. Typical mercury concentrations in municipal solid waste range from 0.15 to 2 mg/kg (Muenhor et al. 2009).

2.1.2.2 Hazardous Waste

Hazardous waste is a waste that has the potential to adversely affect human health and the environment, and therefore must be managed in an environmentally sound manner. Hazardous wastes can be liquids, solids, gases, or sludges. They can be discarded in commercial products, such as cleaning fluids or pesticides, or the by-products of manufacturing processes. The Basel Convention can provide further guidance and information on wastes considered hazardous, and the scope of mercury waste covered under that convention.

Comment [D[9]: Government of Manitoba: this paragraph needs some references to sources of mercury in hazardous wastes.

Comment [dl10]: This should be more more specific. Also the Basel Convention technical guidelines for mercury wastes should be added.

2.1.2.3 Waste from electrical and electronic equipment

Electrical and electronic equipment may contain mercury along with other materials that are hazardous. Often, electrical and electronic waste is collected separately, and is not usually incinerated but is the subject of recovery and recycling processes – these processes to recover materials are not the subject of this guidance. Electrical and electronic equipment may be collected together with municipal waste. Such equipment, if known to contain mercury and entering the waste stream, should be dealt with in accordance with Article 11. However, sometimes electrical and electronic equipment is incinerated along with municipal waste, and can contribute to mercury emissions.

2.1.2.4 Medical waste containing mercury or contaminated with mercury

Medical waste is generally defined as any solid waste that is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals. The World Health Organization classifies medical waste into; sharps, infectious, pathological, radioactive, pharmaceuticals and others (often sanitary waste produced at hospitals) (WHO, 2014). Specific categorizations of medical waste may vary in different countries (e.g., sharps are not classified as hazardous waste in all countries).

Hazardous medical waste has the possibility to affect humans in non-infectious ways. This type of waste includes sharps, which are generally defined as objects that can puncture or lacerate the skin, and can include needles and syringes, discarded surgical instruments such as scalpels and lancets, culture dishes and other glassware. Hazardous medical waste can also include chemicals, both medical and industrial. Some hazardous waste can also be considered infectious waste, depending on its usage and exposure to human or animal tissue prior to discard. Old pharmaceuticals are sometimes hazardous, and may contain mercury.

Mercury is used in a variety of ways specific to the medical sector and these include:

Mercury in measuring devices

Mercury is contained in many common medical measuring devices such as sphygmomanometers (blood pressure devices), thermometers (specifically body temperature thermometers but also others) and a number of gastro-intestinal devices, such as cantor tubes, esophageal dilators (bougie tubes), feeding tubes and Miller Abbott tubes. As in other types of instruments, mercury has traditionally been used in these devices because of its unique physical properties, including the ability to provide highly precise measurements.

Mercury in some types of traditional medicines

Some traditional medicines may contain mercury, although a number of regulatory authorities have introduced controls.

Mercury in dental amalgams

Dental amalgam, sometimes referred to as “silver filling,” is a silver-colored material used to fill (restore) teeth that have cavities. Dental amalgam is made of two nearly equal parts: liquid mercury and a powder containing silver, tin, copper, zinc and other metals. Amalgam has been one of the most commonly used tooth fillings. If the dental amalgam is incinerated, mercury may be emitted to the air from the incinerator stacks.

Mercury compounds in certain preservatives, fixatives and reagents used in hospital

Some mercury compounds are used as preservatives in medicines and other products including vaccines.

2.1.2.5 Sewage Sludge

Sewage sludge is a direct by-product of the treatment of domestic sewage at a wastewater treatment facility. Dental amalgam can contribute to the mercury load of sewage sludge if the amalgam waste is put into the wastewater stream, rather than being separated out. Due to the physical-chemical processes involved in the treatment, the sewage sludge tends to concentrate heavy metals such as mercury, cadmium, lead and others and poorly biodegradable trace organic compounds as well as potentially pathogenic organisms (viruses, bacteria etc.) present in waste waters. Typical level of mercury in sewage sludge range between 0.6-56 mg/kg dry sludge (Hisau; Lo, 1998). However, concentrations ranging from 1-4 mg/ kg dry matter have also been reported (Werther; Saenger 2000).

2.1.2.6 Scrap Wood

Scrap wood is generated at residential and commercial wood frame construction sites, and may include such items as window frames painted with mercury-containing paint. Demolition operations usually generate wood waste which, as a result of its non-uniform nature, compounded by commingling with other materials is not as reusable. If not contaminated with hazardous substances such as mercury (e.g. window frames painted with mercury-containing paint) the wood can still be reused, e.g. for wood panels. Contaminated wood should be burned in an incineration plant.

2.2 Incineration Process

2.2.1 Introduction to general incineration technique

Incineration is used as a treatment for a very wide range of wastes. Incineration itself is commonly only one part of a complex waste treatment system that altogether provides for the overall management of the broad range of wastes that arise in society. The objective of waste incineration is to treat wastes so as to reduce their volume and hazard, whilst capturing (and thus concentrating) or destroying potentially harmful substances that are, or may be, released during incineration. Incineration processes can also provide a means to enable recovery of the energy, mineral or chemical content from waste.

Comment [s11]: Some substances may be created during incineration. Although, not in the case of mercury.

Incinerators come in a variety of furnace types and sizes as well as combinations of pre- and post-combustion treatment. There is also considerable overlap among the designs of choice for municipal solid waste, hazardous waste, medical waste and sewage sludge incineration.

Incinerators are usually designed for full oxidative combustion over a general temperature range of 850–1,200 °C. This may include temperatures at which calcinations and melting may also occur. Gasification and pyrolysis represent alternative thermal treatments that restrict the amount of primary combustion air to convert waste into process gas, which may be used as a chemical feedstock or incinerated with energy recovery. However, compared to incineration, these systems are used less frequently and operational difficulties have been reported at some installations. Waste incinerator installations can be characterized by the following: waste delivery, storage, pre-treatment, incineration/energy recovery, flue gas cleaning, solid residue management, and wastewater treatment. The nature of the input waste will have a significant bearing on how each component is designed and operated.

Waste is generally a highly heterogeneous material, consisting essentially of organic substances, minerals, metals and water. During incineration, flue gases are created that will contain the majority of the available fuel energy as heat. In fully oxidative incineration the main constituents of the flue gas are water vapor, nitrogen, carbon dioxide and oxygen. Depending on the composition of the material incinerated, operating conditions and the flue gas cleaning system installed, acid gases (sulfur oxides, nitrogen oxides, hydrogen chloride), particulate matter (including particle-bound metals), and volatile metals, as well as a wide range volatile organic compounds are emitted. Incineration of municipal solid waste and hazardous waste has also been shown to be a major potential emitter of mercury. Emissions can be substantially high when the input from possible sources (waste containing mercury, e.g., in products, treated waste wood) is not controlled and/or removed before incineration. It should be noted that mercury is present in elemental, oxidized and particulate forms in the flue gas. Mercury present in oxidized form - predominantly as mercury (II) chloride in incinerator flue gases – is generally easier to remove than elemental mercury.

Depending on the combustion temperatures during the main stages of incineration, volatile metals and inorganic compounds (e.g. salts) are totally or partly evaporated. These substances are transferred from the input waste to both the flue gas and the fly ash it contains. A residue fly ash (dust) and heavier solid ash (bottom ash) are created. The proportions of solid residue vary greatly according to the waste type and detailed process design. Other releases are residues from flue gas treatment and polishing, filter cake from wastewater treatment, salts and releases of substances into wastewater. It is therefore of major importance to provide for a safe sink of these waste types containing mercury. (see section 3.6~~3.7~~). Figure 1 presents a simplified flow scheme of an incinerator.

Comment [dl12]: Please check the reference. Section 3.7 does not seem to address sinks for mercury waste.

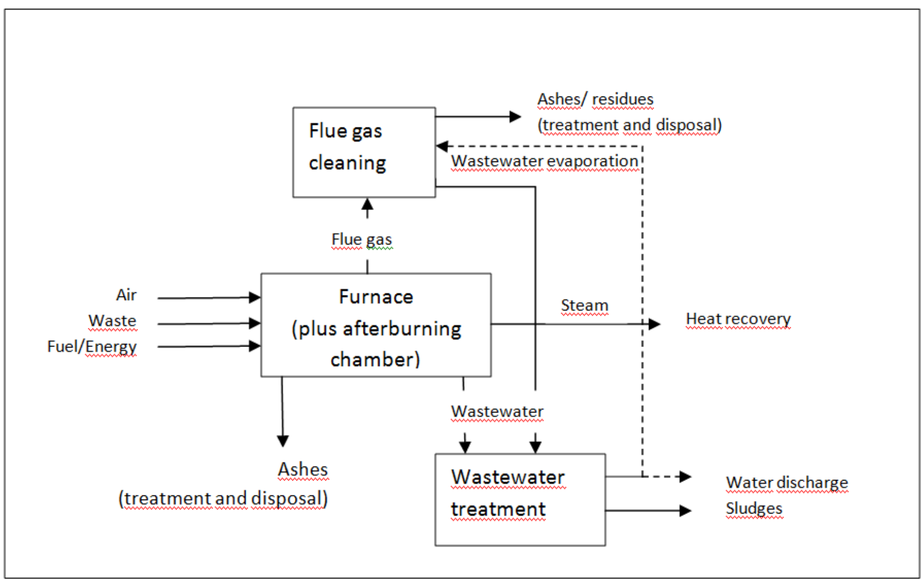

Figure 1 Simplified flow scheme of an incinerator

2.2.2 Pre-treatment of waste for incineration

Mixing of waste

Techniques used for mixing may include:

- mixing of liquid hazardous wastes to meet input requirements for the installation
- mixing of wastes in a bunker using a grab or other machine

Mixing of waste may serve the purpose of improving feeding and combustion behavior and can help to avoid high mercury concentrations in the burned waste. Mixing of hazardous waste can involve risks. Mixing of different waste types may be carried out according to a recipe. In bunkers, the mixing involves the mixing of wastes using bunker cranes in the storage bunker itself. Crane operators can identify potentially problematic loads (e.g. baled wastes, discrete items that cannot be mixed or will cause loading/feeding problems) and ensure that these are: removed, shredded or directly blended (as appropriate) with other wastes. Identifying of mercury containing waste by crane operators is difficult.

Shredding of mixed municipal wastes

Untreated mixed municipal waste can be roughly shredded by passing delivered waste through either crocodile shears, shredders, mills, rotor shears or crushers. The homogeneity of the waste is improved by shredding, resulting in more even combustion and reduction and more stable emissions from the furnace. Having a more even raw gas composition may allow closer optimization of the flue-gas cleaning process. Many wastes contain appreciable quantities of ferrous and non-ferrous metals. These can be an inherent part of the waste itself (e.g. food and drink containers in MSW) or arise from the packaging of waste in drums (e.g. hazardous wastes) or other metal containers.

Where the incoming wastes are shredded, metals can be removed before incineration to allow recycling. Metal separation can be achieved by using:

- over-band magnets for large ferrous materials e.g. shredded drums;
- drum magnets for small and heavy ferrous items such as batteries, nails, coins, etc.,
- eddy current separators for non-ferrous metals – mainly copper and aluminum used for packaging and electrical components.

Shredding of drummed and packaged hazardous wastes

The pre-treatment of liquid packaged waste and packed or bulk solid waste to produce a mixture for continuous feed to the furnace can be carried out. Suitable wastes may be treated to a pump-able state for pumped injection to the kiln or shredded for adding to the storage burner where solids and liquids separate and are then fed to the kiln separately using grabs and pumping respectively.

Pallets containing packaged liquid wastes of low to medium high viscosity are shredded to 5 to 10 cm. The shredded waste may then be screened before being transferred to tanks. Screened out plastics are passed for incineration, and ferrous metals removed using magnets for washing and recycling. In other cases, the waste is not screened, and is pumped as a mixture of liquids and shredded solids to the kiln with thinning liquids e.g. waste oils (European Commission, 2006, Waste Incineration)

Comment [dl13]: Not clear what this means

2.2.3 Description of incinerator types

2.2.3.1 Rotary kiln incinerator

For the incineration of hazardous waste which includes many types of medical waste, rotary kilns are most commonly used (Figure 2), but grate incinerators (including co-firing with other wastes) are also sometimes applied to solid wastes, and fluidized bed incinerators to some pre-treated materials. Static furnaces are also widely applied at on-site facilities at chemical plants.

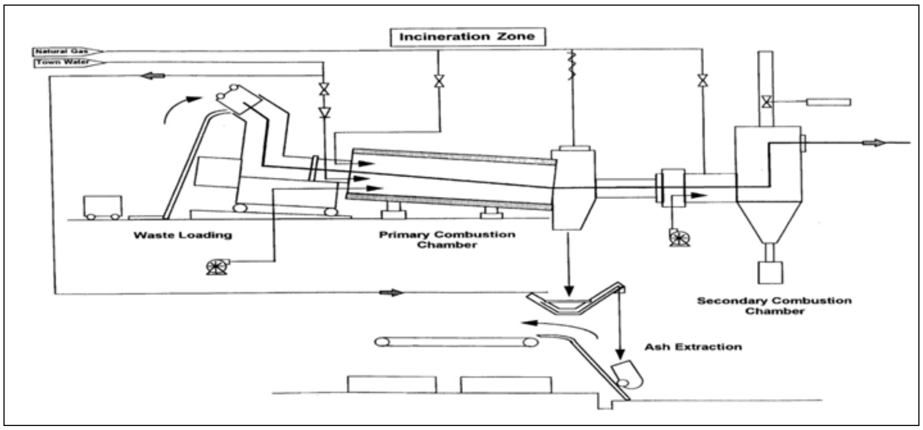

Figure 2 Schematic of a rotary kiln incineration system (www.hitemptech.com)

Due to the hazardous (and often uncertain) composition of the incoming waste streams, there is a greater emphasis on acceptance criteria, storage, handling and pre-treatment than with municipal solid waste. For low-energy-value wastes, auxiliary fuels may be required.

In a rotary kiln solid, sludge, containerized or pump-able waste is introduced at the upper end of the inclined drum. Temperatures in the kiln usually range between 850 °C (500 °C when used as a gasifier) and 1,200°C (as a high-temperature ash melting kiln). The slow rotation of the drum allows a residence time of 30 to 90 minutes. The secondary combustion chamber following the kiln allows the oxidation of the combustion gases. Liquid wastes or auxiliary fuels may be injected here along with secondary air to maintain a minimum residence time of 2 seconds and temperatures in the range of 850 °C – 1,100 °C, effectively breaking down most remaining organic compounds. Requirements for combustion conditions may be prescribed as is the case in the EU-Directive 2010/75/EU on the Incineration of Waste. Rotary kilns and afterburning chambers are in most cases constructed as adiabatic, ceramic-lined combustion chambers. After the combustion, chamber flue gases pass a void zone until a temperature of about 700 °C is reached. Subsequently heating bundles such as evaporators, superheaters and feed water preheaters are arranged. The waste heat boiler and energy supply system is comparable to that of grate firing systems. Incinerator capacities: 0.5 to 3 tons per hour (for health-care waste incineration).

2.2.3.2 Liquid Injection Incinerators

Liquid injection incinerators, like rotary kiln incinerators, are commonly used for hazardous waste incineration. Liquid injection incinerators can be used to dispose of virtually any combustible liquid or liquid-like waste (e.g., liquids, slurries, and sludges). Typical liquid injection incinerator systems, which are possibly the simplest type of combustion device, include a waste burner system, an auxiliary fuel system, an air supply system, a combustion chamber, and an air pollution control system. A typical liquid injection incinerator is shown in Figure 3~~Figure ~~3. Liquid wastes are fed and atomized into the combustion chamber through the waste burner nozzles. These nozzles atomize the waste and mix it with combustion air. Atomization is usually achieved either by mechanical methods such as a rotary cup or pressure atomization systems, or by twin-fluid nozzles which use high-pressure air or steam. With a relatively large surface area, the atomized particles vaporize quickly, forming a highly combustible mix of waste fumes and combustion air. Typical combustion chamber residence time and temperature ranges are 0.5 to 2 seconds and 700 °C to 1,600 °C, respectively, in order to ensure complete liquid waste combustion. Liquid waste feed rates can be over 2,000 l/hr. If the energy content of the waste is not high enough to maintain adequate ignition and incineration temperatures, a supplemental fuel such as fuel oil or natural gas is provided. In some cases, wastes with high solids are filtered prior to incineration to avoid nozzle plugging (US EPA 2005).

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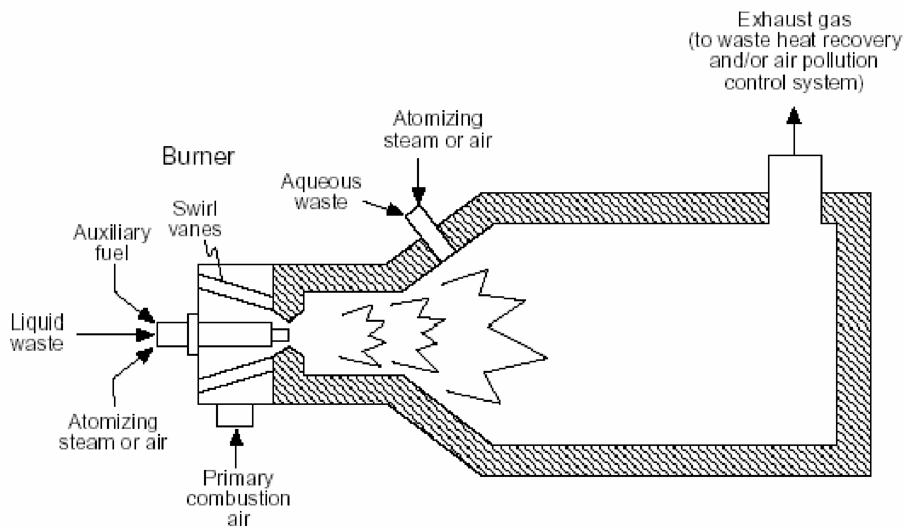

Figure 3 Typical liquid injection incinerator

2.2.3.3 Grate incinerator

There are different types of grate incinerators namely, moving and fixed grates.

Moving grate incinerators

The typical incineration plant for municipal solid waste is a moving grate incinerator. In a moving grate, the waste moves through the combustion chamber. The moving of the waste allows a more efficient and complete combustion. The units can be designed in a variety of capacities. One example is a single moving grate boiler which can handle up to 35 metric tons of waste per hour, and can operate 8,000 hours per year with only one scheduled stop for inspection and maintenance of about one month's duration. The waste is introduced by a waste crane through the "throat" at one end of the grate, from where it moves down over the descending grate to the ash pit in the other end. Here, the ash is removed through a water lock. Part of the combustion air (primary combustion air) is supplied through the grate from below. This air flow also has the purpose of cooling the grate itself. Cooling is important for the mechanical strength of the grate, and many moving grates are also water-cooled internally. Secondary combustion air is supplied into the boiler at high speed through nozzles over the grate. It facilitates complete combustion of the flue gases by introducing turbulence for better mixing and by ensuring a surplus of oxygen. In multiple/stepped hearth incinerators, the secondary combustion air is introduced in a separate chamber downstream the primary combustion chamber.

In EU countries (Directive 2000/76/EC), incineration plants must be designed to ensure that the flue gases reach a temperature of at least 850 °C for 2 seconds in order to ensure proper breakdown of toxic organic substances. In order to comply with this at all times, it is required to install backup auxiliary burners (often fuelled by oil), which are fired into the boiler in case the heating value of the waste becomes too low to reach this temperature alone. The flue gases are then cooled in the superheaters, where the heat is transferred to steam, heating the steam to typically 400 °C at a pressure of 4,000 kPa for the electricity generation in the turbine. At this point, the flue gas is at around 200 °C and is passed to the flue gas cleaning system. Often, incineration plants consist of several separate 'boiler lines' (boilers and flue gas treatment plants), so that waste can continue to be received at one boiler line while the others are undergoing maintenance, repair, or upgrading.

Fixed grate

The older and simpler kind of incinerator was a brick-lined cell with a fixed metal grate over a lower ash pit, with one opening in the top or side for loading and another opening in the side for removing incombustible solids called clinkers. Many small incinerators formerly found in apartment houses have now been replaced by waste compactors.

2.2.3.4 Fluidized bed incinerator

Fluidized bed incinerators are widely used for the incineration of finely divided wastes such as refuse-derived fuel and sewage sludge. The method has been used for decades, mainly for the combustion of homogeneous fuels. The fluidized bed incinerator is a lined combustion chamber in the form of a vertical cylinder. In the lower section, a bed of inert material (e.g. sand or ash) on a grate or distribution plate is fluidized with air. The waste for incineration is continuously fed into the fluidized sand bed from the top or side. Preheated air is introduced into the combustion chamber via openings in the bed plate, forming a fluidized bed with the sand contained in the combustion chamber. The waste is fed to the reactor via a pump, a star feeder or a screw-tube conveyor. In the fluidized bed drying, volatilization, ignition and combustion take place. The temperature in the free space above the bed (the freeboard) is generally between 850 °C and 950 °C. Above the fluidized bed material, the freeboard is designed to allow retention of the gases in a combustion zone. In the bed itself the temperature is lower, and may be around 650 °C. Because of the well-mixed nature of the reactor, fluidized bed incineration systems generally have a uniform distribution of temperatures and oxygen, which results in stable operation. For heterogeneous wastes, fluidized bed combustion requires a preparatory process step for the waste so that it conforms to size specifications. For some waste, this may be achieved by a combination of selective collection of wastes or pretreatment, such as shredding. Some types of fluidized beds (for example, the rotating fluidized bed) can receive larger particle size wastes than others. Where this is the case, the waste may only require a rough size reduction or none at all.

2.2.3.5 Modular systems

Modular systems are a general type of (municipal solid) waste incinerator used widely in the United States of America, Europe and Asia. Modular incinerators consist of two vertically mounted combustion chambers (a primary and secondary chamber). In modular configurations combustion, capacity typically ranges from 1 to 270 tons per day. There are two major types of modular systems, excess air and starved air.

The modular excess air system consists of a primary and a secondary combustion chamber, both of which operate with air levels in excess of stoichiometric requirements (i.e., 100–250 per cent excess air). In the starved (or controlled) air type of modular system, air is supplied to the primary chamber at sub-stoichiometric levels. The products of incomplete combustion entrain in the combustion gases that are formed in the primary combustion chamber and then pass into a secondary combustion chamber. Excess air is added to the secondary chamber, and combustion is completed by elevated temperatures sustained with auxiliary fuel (usually natural gas). The high, uniform temperature of the secondary chamber, combined with the turbulent mixing of the combustion gases, favors low levels of particulate matter and organic contaminants being formed and emitted.

2.2.4 Incineration of specific waste streams

2.2.4.1 Municipal waste incineration

Although in many areas landfilling of non-recycled waste remains the principal means for the disposal of municipal solid waste, incineration and the subsequent landfilling of residues has become a common practice in many developed and industrializing countries.

Municipal solid waste incineration is commonly accompanied by the recovery of some calorific energy (“waste to energy”) in the form of steam and/or the generation of electricity. Incinerators can also be designed to accommodate processed forms of municipal solid waste derived fuels, as well as co-firing with fossil fuels. Municipal waste incinerators can range in size from small package units processing single batches of only a few tons per day to very large units with continuous daily feed capacities in excess of a thousand tons.

The primary benefits of municipal solid waste incineration are the destruction of organic (including toxic) materials, the reduction in the volume of the waste and the concentration of pollutants (e.g.

heavy metals) into comparatively small quantities of ashes, thus generating safe sinks if properly disposed of. The recovered energy can be an important additional benefit.

2.2.4.1.1 Operational considerations for municipal solid waste incinerators

In many municipal solid waste incinerators, other waste fractions such as bulky waste, (e.g. from sorting plants), sewage sludge, medical waste or the high calorific fraction from waste pre-treatment (e.g. from shredder plants) are also incinerated. These wastes have to be carefully evaluated prior to incineration to ascertain whether the waste incineration plant (including flue gas treatment, wastewater and residue treatment) is designed to handle these types of waste and whether it can do so without risk of harm to human health or the environment. Some important parameters are chlorine, bromine and sulfur content, heavy metals content, calorific content (lower heat value) and burnout behavior.

High concentration of bromine may lead to formation of brominated compounds such as polybrominated Dibenzo-p-Dioxins (PBDD) and polybrominated Di-benzo flurans (PBDF) (CSTEE, 2002).

Mercury is volatized in the incineration process. Particular actions should be taken both before and after incineration to reduce these emissions. Neglecting the limits of the incineration plant will result in operational problems (e.g. the necessity of repeated shutdowns due to cleaning of the grate or heat exchangers) or in a bad environmental performance (e.g. high emissions into water, high leachability of fly ash). Figure 4 shows the typical layout of a large municipal solid waste incinerator.

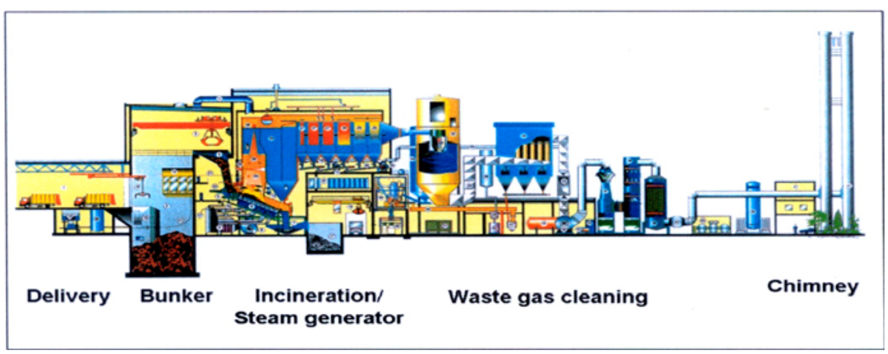

Figure 4 Typical municipal solid waste incinerator (Source: European Commission 2006)

2.2.4.1.2 Municipal solid waste incinerator designs

Municipal solid waste can be incinerated in several combustion systems including travelling grate, rotary kilns, and fluidized beds. Fluidized bed (see subsection 2.2.3.4) technology requires municipal solid waste to be of a certain particle size range – this usually requires some degree of pre-treatment and the selective collection of the waste. Combustion capacities of municipal solid waste incinerators typically range from 90 to 2,700 tons of municipal solid waste per day (modular configurations: 4 to 270 tons per day).

Other processes have been developed that are based on the decoupling of the phases that also take place in an incinerator: drying, volatilization, pyrolysis, carbonization and oxidation of the waste. Gasification using gasifying agents such as steam, air, oxides of carbon or oxygen is also applied. These processes aim to reduce flue gas volumes and associated flue gas treatment costs. Many of these developments have met technical and economic problems when scaled up to commercial, industrial sizes, and are therefore pursued no longer. Some are used on a commercial basis (e.g. in Japan) and others are being tested in demonstration plants throughout Europe, but still have only a small share of the overall treatment capacity when compared to incineration.

2.2.4.2 Hazardous waste incineration

Hazardous waste is commonly burned in rotary kilns or in grate incinerator. Other types of incinerators used for hazardous waste include fluidized beds, liquid injection units, and fixed hearth units. Before accepting a hazardous waste for treatment, merchant incinerators must assess and characterize the material. Documentation by the producer is routinely required, including the origin of the waste, its code or other designation, the identification of responsible persons and the presence of particular hazardous materials. The waste must also be properly packaged to avoid the possibility of reaction and emissions during transport.

Storage at the incinerator site will depend on the nature and physical properties of the waste. Solid hazardous waste is typically stored in bunkers constructed to prevent leakage into any environmental media and enclosed to allow the removal of bunker air to the combustion process. Liquid wastes are stored in tank farms, often under inert gas atmosphere (for example N_2), and transported to the incinerator by pipeline. Some wastes may be fed directly to the incinerator in their transport containers. Pumps, pipelines and other equipment that may come into contact with the wastes must be corrosion proof and accessible for cleaning and sampling. Pre-treatment operations may include neutralization, drainage or solidification of the waste. Shredders and mechanical mixers may also be used to process containers or to blend wastes for more efficient combustion.

Hazardous waste is also incinerated in cement kilns. This application is addressed in the cement chapter of the guidance document.

2.2.4.3 Sewage sludge Incineration

Domestic sewage sludge is disposed of in a number of ways, including application on agricultural land after pre-treatment, surface disposal (e.g. landscaping, landfilling), incineration, co-disposal with municipal solid waste and co-incineration. The incineration of sewage sludge is practiced in several countries, either alone or through co-incineration in municipal solid waste incinerators or in other combustion plants (e.g. coal-fired power plants, cement kilns). The effective disposal of sewage sludge by this process depends on a number of factors. These include whether the sewage is mixed with industrial waste streams (which can increase heavy metal loadings), location (coastal locations can result in salt water intrusion), pre-treatment (or the lack thereof), and weather (rainfall dilution) (EU IED, 2010).

The incineration of sewage sludge presents some differences from the incineration of municipal solid waste and hazardous waste. The variability of moisture content, energy value, and possible mixture with other wastes (e.g. industrial waste if sewage systems are interconnected) require special considerations in handling and pre-treatment.

Solid residues from sewage sludge incineration are mainly fly ash and bed ash (from fluidized bed incineration) and residues from flue gas treatment (see description of municipal solid waste incineration). Appropriate flue gas cleaning measures have to be combined in a suitable manner to ensure the application of best available techniques (see section 5.5 of the present guidelines).

2.2.4.4 Design and operation of sewage sludge incinerators

A typical sewage sludge incinerator may process as much as 80,000 tons of sewage sludge (35 per cent dry solids) per year. The incineration technologies of choice for sewage sludge are the multiple hearth (Figure 5) and fluidized bed furnace systems, although rotary kilns are also used in smaller applications.

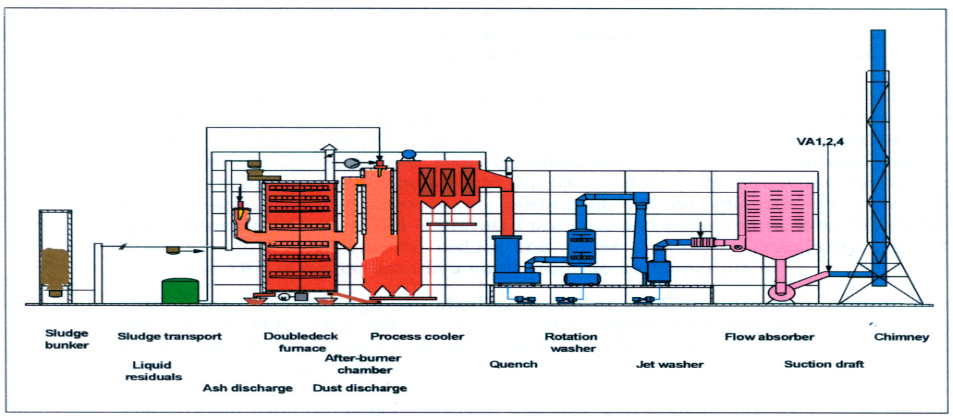

Figure 5 Example of a multiple hearth sewage sludge incinerator (European Commission, 2006)

Depending on the percentage of dry solids (dryness), an auxiliary fuel, usually heating oil or natural gas, is provided. The preferred operating temperatures are in the range of 850-950 °C with a 2-second residence time, although some fluidized bed facilities are able to operate at a temperature as low as 820 °C without deterioration in performance. Operation at or above 980 °C can cause ash to fuse (European Commission 2006).

Sewage sludge is co-incinerated with municipal solid waste in both fluidized bed and mass burn (grated) incinerators. In the latter case, a ratio of 1:3 (sludge to waste) is typical, with dried sludge introduced into the incineration chamber as a dust or drained sludge applied to the grate through sprinklers. In some cases, drained or dried sludge may be mixed with municipal solid waste in the bunker or hopper before being charged to the incinerator. The feeding methods represent a significant proportion of the additional capital investment required for co-incineration.

2.2.4.4.1 **Pre-treatment of sewage sludge**

Pre-treatment, especially dewatering and drying, is particularly important in preparing sludge for incineration. Drying reduces the volume of the sludge and increases the heat energy of the product. Moisture removal to at least 35 per cent dry solids is normally required to provide the necessary heat energy for autothermal incineration. Further drying may be necessary if co-incineration with municipal solid waste is envisioned.

Some pre-treatment of sludge may occur before delivery to an incineration facility. This may include screening, anaerobic and aerobic digestion, and the addition of treatment chemicals.

Physical dewatering reduces sludge volume and increases heating value. Mechanical dewatering processes include decanters, centrifuges, belt filter and chamber filter presses. Conditioners (for example, flocking agents) are often added before dewatering to facilitate drainage. Mechanical dewatering can routinely achieve 20-35 per cent dry solids (European Commission, 2006).

Drying introduces heat to further dewater and condition the sludge. Heat for drying at the incineration facility is often provided by the incineration process itself. Drying processes can be direct (sludge contacts thermal carrier) or indirect (for example, heat supplied by steam plant). In direct drying the vapor and gas mixture must be subsequently cleaned.

Autothermal (self-sustaining) incineration of sludge requires 35 per cent dry solids. Although mechanical dewatering can reach this threshold, additional drying of sludge to as much as 80–95 per cent dry solids may be employed to increase the heat value. Co-incineration with municipal solid waste generally requires additional sludge drying.

2.2.4.5 Waste wood incineration

Wood waste containing or contaminated with mercury can be burned in grate incinerators or in fluidized bed incinerators at the same temperatures as applied for Municipal Waste Incineration.~~.~~

Another technique used is pyrolysis. Three products are usually produced: gas, pyrolysis oil and charcoal, the relative proportions of which depend very much on the pyrolysis method, the characteristics of the biomass and the reaction parameters. Fast or flash pyrolysis is used to maximize either gas or liquid products according to the temperature employed.

2.2.4.6 Behavior of ~~M~~mercury during the incineration process

This section discusses the behavior of mercury during the incineration process. As described in section 3, the ability of various controls to capture emissions is related to the speciation of mercury in the flue gas.

Due to the thermo-chemical instability of mercury compounds at temperatures above 700-800 °C, only elemental mercury exists. This means that inside the combustion chamber of a waste incinerator, mercury is present only in its elemental form. Mercury is highly volatile and, therefore, almost exclusively present in the vapor phase in the flue gas. On its way through the heat recovery section the flue gas cools down and the elemental mercury reacts depending on the presence of other flue gas components, temperature, and ash composition to oxidized mercury. The oxidized mercury compounds are generally unstable in the flue gas and under atmospheric conditions (Galbareth, Zygarlicke 1996).

Under certain conditions, elemental mercury can be oxidized. The extent of the conversion depends on the temperature, residence time, ash, unburnt carbon and the presence of gas-phase species including chlorine or SO_2. The distribution of elemental mercury and oxidized mercury in the form of mercury (II) chloride depends strongly on the amount of HCl in the flue gas. The proportion of oxidized mercury and total mercury tend to increase with increasing hydrogen chloride concentration (Nishitani et al., 1999). Due to the lower content of HCl in sewage sludge incineration plants the share of elemental mercury is significantly higher.

3 EMISSION CONTROL TECHNIQUES

The type and order of treatment processes applied to the flue gases once they leave the incineration chamber is important, both for optimal operation of the devices and for the overall cost-effectiveness of the installation. Waste incineration parameters that affect the selection of techniques include: waste type, composition, and variability; type of combustion process; flue gas flow and temperature; and the need for, and availability of, wastewater treatment. The following treatment techniques have direct or indirect impacts on preventing or reducing the emissions of mercury. Best available techniques involve applying the most suitable combination of flue gas cleaning systems. General descriptions of a number of the techniques is provided in the introductory chapter of the guidance. Information considered specific to waste incineration is presented in the following sections.

3.1 Dust (particulate matter) removal techniques

Dust removal from the flue gases is essential for all incinerator operations. Electrostatic precipitators (ESP) and fabric filters (FF) have demonstrated effectiveness as capture techniques for particulate matter in incinerator flue gases. For a description of the general principles of these techniques see the introductory chapter of this document.

To more efficiently remove mercury from flue gas, FF as well as ESP is used in combination with other techniques (see sections 3.4 – 3.5).

Pressure drop across fabric filters and flue gas temperature (if a scrubbing system is used upstream) should be monitored to ensure filter cake is in place and bags are not leaking or being wetted.

Fabric filters are subject to water damage and corrosion and gas streams must be maintained above the dew point (130-140 °C) to prevent these effects. Some filter materials are more resistant to damage.

Cross-media effects on the leaching of mercury from fly ash (EC, 2006 Waste incineration)

The fly ash generated from flue gas cleaning systems should be handled with care since it has the potential to leach mercury into land and ground water.

Cross-media effects (non-mercury related)

ESP and FF used in dust removal have high energy consumption due to electrostatic loading, high pressure drop and pulsing high pressure air cleaning respectively. The residue amount is 12-20 kg/t waste input.

Costs of installation and operation (EC, 2006 Waste incineration)

Investment costs for a two line MSWI of total capacity 200 000 t/yr are estimated as:
ESP (3 field) € 2.2 million
ESP (2 field) € 1.6 million
FF € 2.2 million (not clear if this includes an upstream flue gas cooler)
Comment: updated data will be soon available from German UBA

Co-benefits on the use of FF coupled with spray drying or semi-dry sorbent injection

For separation of other pollutants such as dust, other heavy metals and dust bonded organic compounds, fabric filters have the added advantage when coupled with dry or semi-dry sorbent injection (spray drying), of providing additional filtration and reactive surface on the filter cake.

3.2 Wet scrubbing techniques

Gaseous mercury can be captured by adsorption in a wet scrubber. In the first stage the removal efficiency of oxidized mercury as $HgCl_2$ (which is generally the main compound of mercury after waste combustion) is over 95 per cent. (EC, 2006 Waste Incineration). However, the removal rates of elemental mercury are only in the order of 0-10 per cent, mainly as a result of condensation at the scrubber operational temperature of around 60 to 70 °C.

Precipitation is another measure often used to minimize the concentration of oxidized mercury in the scrubbing water. A flocculation agent (often a sulfur compound) is added to the scrubbing water which converts the soluble mercury into an insoluble compound with reasonable efficiency, particularly in the second stage. To bind the mercury directly after the conversion into the liquid phase, another possibility is to add activated carbon to the scrubbing water (Bittig 2014). Re-emission of dissolved mercury to the flue gas can be avoiding by complexating the dissolved mercury with sequestering agents e.g. organic sulfides (Keiser et al., 2014).

Comment [dl14]: Complexing?

With the measures mentioned above, elemental mercury adsorption can be improved up to a maximum of 20-30 per cent. The overall mercury removal (both metallic and oxidized) efficiency is around 85 per cent (EC. 2006, Waste Incineration).

Cross media effects and cost of installation and operation are shown in Tables 1 and 2.

Table 1 Cross-media effects – non mercury related

Reagent consumption	2-3 kg (NaOH) or – 10 kg CaO or 5-10 kg lime stone per ton waste input
Residue amount:	10-15 l/t waste input
Water consumption:	100-500 l/t waste input
Emissions to water:	250-500 l/t waste input

(source: WT BREF 2005)

Table 2 Costs of installation and operation

FGT component	Estimated investment costs	Comments
Two stage wet scrubber	€ 5 million	Including waste water treatment
Three stage wet scrubber	€ 7 million	Including waste water treatment
External scrubber effluent evaporation plant	€ 1.5-2 million	
Spray absorber for internal effluent evaporation	€ 1.5 million	Cost estimate believed to be on the low side

(EC., 2006, Waste Incineration)

Information from a plant manufacturer from 2014

For a 200.000 t plant with 2 incineration and flue gas treatment lines: FF + 2 stage scrubber: € 16-18 million.

Co-benefits on the use of carbon impregnated materials

For the separation of acid gases, dust and dust bonded ingredients, the use of carbon-impregnated materials, activated carbon, or coke in scrubber packing materials can achieve 70 per cent reduction in PCDD/PCDF across the scrubber but this may not be reflected in overall releases (European Commission, 2006).

3.3 Activated carbon injection

The use of activated carbon to enhance the removal of mercury is described in a general way in the introductory chapter of this document. The AC technique involves the injection of activated carbon or hearth furnace coke (HOK) upstream of a bag filter (see section 3.1~~3.13.1~~) or other dedusting device. As a result, most of the mercury is then adsorbed at the filter layer. Therefore, FF are usually precoated with reagents before start-ups to ensure that a good abatement performance is already achieved when waste feeding starts.

A good mixture of the adsorbent materials with the flue gas and a sufficient contact time is important for a successful precipitation. As last step of a flue gas cleaning, as well established is a dosing of carbon based adsorbents in the flue gas before a downstream fabric filter, e.g. after a scrubber.

Consideration of the speciation mix of the flue gas is key to estimating mercury emissions control efficiency of the activated carbon. In general, the oxidized species of mercury are considered more easily controlled than the elemental form. The halogen content of the waste is important in determining the amount of oxidation taking place. High halogen content in the flue gases and, thus high percentages of oxidized mercury, may often exist in municipal waste incinerators. The removal efficiency of the injection of activated carbon in combination with a FF can be as high as is about 95 per cent.

Comment [dl15]: Awkward phrasing. Is this saying that a dosing of carbon based adsorbents in flue gas before fabric filter is a well established last step of flue cleaning?

The separate injection of AC, controlled by a continuous mercury monitoring in the raw gas, has been proven to be very effective in waste incineration. Hereby the added amount of AC can be adapted to the raw gas concentrations of mercury. In case of mercury peaks in the raw gas, highly effective AC impregnated with about 25 per cent sulfur can be injected additionally. Such an approach combines an effective mercury abatement with decreased operation costs due to a reduced use of sorbents. It should be mentioned that the investment costs of a mercury gas measuring device could be significant lower as that for a clean gas one because measurement devices tested for suitability are not necessary. (Esser-Schmittmann 2012)

Especially in cases where relative high concentrations of elemental mercury occur in the flue gas, e.g. at sewage sludge incineration plants, satisfactory reduction efficiencies can only be achieved when sulfur acid or halogen (e.g., bromine) impregnated AC is used.

Tests have shown that Hg reduction ratio increased as the flue gas temperature decreased and that the reduction efficiency is significantly higher when high concentrations of mercury in the raw gas are found (Takaoka et al. 2002)

The removal efficiency of the carbon sorbents increases if a fabric filter is used instead of an ESP, due to the longer residence time allowing more contact between the sorbent and the mercury-laden flue gas. As a result, only a third of the sorbent is needed to capture the same amount of mercury compared to an ESP (LCP BREF Draft 2013).

For a more effective removal of mercury from flue gases specially developed activated carbon impregnated with sulfuric acid, elemental sulfur or bromine is used. In this case, the removal of mercury is driven by chemisorption as well as by physisorption. Tests have shown that the mercury reduction efficiency can be increased to 99 per cent.

Cross-media effects (non-mercury related)

Carbon consumption rates of 3 kg/t of waste are typical for municipal solid waste incineration. Levels from 0.3 to 20 kg/t of hazardous waste have been reported (EC. 2006 Waste Incineration).

Costs of installation and operation

For a 200.000 t plant with 2 incineration and flue gas treatment lines: dry flue gas treatment including storage of sorbents, dosing systems, control of sorbent injection, FF and ash discharge: €5.5 – 6 million.

The costs for storage the AC are approximately € 50,000 for smaller plants (container storage) and approximately € 100,000 for bigger plants (silo storage) (data from Germany, 2014).

Comment [D[16]: Should these values not be expressed as a value per tonne of waste, or a value per year rather than a flat cost?

The operation costs depend on the kind of carbon which is used. The price of HOK is approximately € 300/t, weak sulfur acid impregnated carbon (5 per cent) costs approx. € 400/t, high sulfur impregnated carbon is approx. at € 2,000/t and bromated AC costs approximately € 1,500/t.

The usage of low sulfur acid impregnated carbon for a 300,000 t municipal waste incineration plant is estimated for 30 t/y at a plant using a police filter and 200 t/y for a plant equipped with a dry flue gas treatment system (data from Germany, 2014).

Co-benefits

Separation of volatile organic compounds in the flue gas such as dioxins can be achieved as well. It is normal for alkaline reagents to be added with the carbon, this then also allows the reduction of acid gases in the same process step as a multifunctional device.

3.4 Boiler Bromide Addition

Addition of bromide into the furnace can enhance the oxidization of mercury during boiler passage of the flue-gas, thereby promoting the transformation from the insoluble elemental gaseous mercury into its water-soluble mercury(II) bromide ($HgBr_2$) as well as adsorbable mercury species. Mercury removal can thereby be enhanced in existing downstream control devices, e.g. wet scrubbers. Another option for addition of halogens is to add bromide or other halogen compounds to the waste. (Vosteen 2006)

It should be mentioned that boiler bromide addition (BBA) alone does not reduce mercury emissions as such, in the sense of capturing elemental mercury as $HgBr_2$. BBA promotes mercury oxidation and thereby indirectly reduces mercury emissions at existing wet air pollution control (APC) systems as wet desulfurization scrubbers or dry desulfurization scrubbers; e.g. BBA improves the efficiency of activated carbon (ACI) injected at units with particulate scrubbers (ESP, FF) (LCP BREF Draft Version 2013).

In waste incineration plants, this technique is beneficial in cases where the waste contains low levels of halogens. Therefore, it is applied mainly in sewage sludge incineration plants and hazardous waste incineration plants burning waste with low halogen levels. For example, in a German waste incineration plant for hazardous waste, flue gas is monitored continuously. The monitoring takes place after the wet scrubber, but before the tail-end SCR because SCR devices retain mercury which is slowly released again. If there is a significant increase of mercury detected after the wet scrubber, bromine compounds are injected into the boiler. This results in considerable lower mercury emissions in the clean flue gas (Vosteen, 2006). This technique is not effective in case of very short mercury peaks in the flue gas because the peak has passed the flue gas treatment system before there is a possibility to react.

In general, it was reported that by applying Br/Hg mass ratios of more than~~>~~ 300 complete mercury oxidation can be achieved. Therefore, in an existing multistage scrubbing system a removal efficiency of more than 99,8 per cent was realised (VGB Power Tech2006). The same was recently demonstrated at some French hazardous waste incineration plants with mainly dry flue gas cleaning (Chaucherie et al. 2015).

The use of bromine in the process may lead to formation of polybrominated dioxins and or polyhalogenated dioxins and furans.

Cross-media effects

Mercury measurements can be very difficult in the presence of bromine in the flue gas. There is a potential for bromine-induced corrosion in the ductwork, air heater and in FGD systems. It commonly goes together with an increased bromine and mercury content in the fly ash (LCP BREF Draft Version 2013).

Costs of installation and operation

The use of ACI in conjunction with BBA may be more cost effective than the use of either ACI or BBA alone in order to achieve the same level of performance.

Comment [dl17]: Which are undesirable, and may require efforts to control emissions. It should be noted that emissions of these substances will need to be managed.

3.5 Static bed filters

Activated coke moving bed filters are used as a secondary cleaning process in the flue-gas of municipal and hazardous waste incineration plants. Using this adsorption system, it is possible to deposit substances contained in the flue gas at low concentrations with high efficiency of more than 99 per cent. Lignite coke produced in hearth furnace coke process is used in moving bed absorbers.

The flue-gases pass through a filling of grained Hearth Furnace Coke (HFC – a fine coke of 1.25 to 5 mm). The HFC's depositing effect is essentially based on adsorption and filtration mechanisms. It is thus possible to deposit almost all emission relevant flue-gas components, in particular, residual contents of hydrochloric acid, hydrofluoric acid, sulfur oxides, heavy metals (e.g. mercury), to sometimes below the detection limit.

The flue-gas is guided to the activated coke filling over a distributor bed equipped with a multitude of double funnels. The gas flows through them from the bottom to the top, while the HFC passes through the absorber from the top to the bottom. This allows an ideal distribution of the flue-gas over the whole cross-section of the absorber with optimal use of the capacity of the absorber with a minimum consumption of activated coke.

An essential feature of the moving bed system is its high efficiency with all emissions due to the large bulk of activated coke, so that variations from incineration and upstream flue-gas cleaning caused by operation will not cause disadvantageous effects.

Due to the carbon contained in the static bed filters, there is a possibility of fire outbreak. Due ~~both~~ to fire risk and to high costs, the systems are installed only in few plants. Care should be taken to avoid any fire outbreak including through the installation of a dampening system.

Cross-media effects non-mercury related (WT BREF 2005)

The non-mercury related cross-media effects include the following:

Energy Consumption	30-35 kWh/t waste input
Reagent consumption	1 kg/t waste input
Residue amount	0-1 kg/t waste input

Costs of installation and operation of coke filter

The investment cost of a coke filter for a 100,000 t/y MSWI was estimated at € 1.2 million. The investment costs for one static bed wet filter (empty) (incineration line of 50 000 t/y) is approximately € 1 million (EC, 2006, Waste Incineration)

Co-benefits

The co-benefits of using activated coke bed-moving filter include the separation of volatile organic compounds, such as dioxins, in the flue gas.

3.6 Treatment techniques for solid residues from incineration

Although this guidance is primarily concerned with air emissions, there is a need to take account of cross-media effects. On this basis, the following section provides information on managing residual waste from the incineration process, including preventing or minimizing risks of leaching or ~~distribution through~~ releases to the environment through a number of pathways.

Wastes and residues from incineration include various types of ash (e.g. bottom ash, boiler ash, fly ash) and residues from other flue gas treatment processes (such as gypsum from wet scrubbers), including liquid effluents in the case of wet scrubbing systems.

Because constituents of concern may vary considerably, maintaining the separation of residues for treatment, management and disposal is in general appropriate. The presence and concentration of mercury and its compounds in these residues (if separately treated) is a function of their presence in the incoming waste and capture during flue gas treatment. ~~Especially a~~Air pollution control residues should be treated in a way to avoid additional evaporation or ~~leaking~~ leaching of mercury and its compounds to the environment.

The release of contaminants from these dry materials into the environment may be via a number of routes, including: wind-blown dust, leaching to groundwater, plant uptake or direct ingestion by humans, domesticated animals and wildlife. Management of these materials must be done with consideration of these potential releases.

3.6.1 Bottom and boiler ash treatment techniques

Because of the differences in pollutant concentration, the mixing of bottom ash with fly ash will contaminate the former and is forbidden in many countries. Separate collection and storage of these residues may provide operators with more options for disposal. Whenever bottom ash is to be further used (e.g. as construction material), mixing with other flue gas treatment residues is generally not a best available technique. Bottom ash (or slag from fluidized bed incinerators) is disposed of in landfills in many countries but may be reused in construction and road-building material following pre-treatment. Prior to such use, however, an assessment of content and leachability should be conducted and upper levels of heavy metals, persistent organic pollutants should be determined. Pretreatment techniques include dry, wet and thermal treatment as well as screening and crushing and separation of metals.

3.6.2 Treatment of solid flue gas residues

One major flue gas treatment residue (or air pollution control residue) is fly ash. Fly ash removal from flue gas by use of dry scrubbers, cyclones or fabric filters in waste incinerators will result in dry fine solid particulate material having a range of properties and contaminants depending on the combustion source that produced it. Unlike bottom ash, air pollution control device residuals, including fly ash and scrubber sludges, contain relatively high concentrations of heavy metals, persistent organic pollutants, chlorides and sulfides. Separate removal of fly ash and residues from flue gas cleaning stages (e.g.

those for acid gas and dioxin removal) prevents mixing of low contaminated waste fractions with highly contaminated ones. Mercury distribution in waste incineration processes results in most being found in air pollution control residues (EC 2005, Song, Kim et al. 2004).

In Switzerland the treatment of fly ashes with acid waste water from the scrubber is widespread. To avoid mercury contamination of the treated ashes, the acid waste water is first cleaned by a candle-filter followed by a mercury specific ion-exchange unit. The mercury extricated wash water is used to wash out heavy metals from the fly ashes. The washing water is subsequent treated in a classic flocculation and precipitation unit. For the final cleaning of the waste water, a second ion-exchanger is used.

The cleaned fly ashes can be added to waste in the waste incineration plant to destroy the organic components in the fly ashes (Bühler et al 2015, Adam et al. 2010, *BSH 2015*).

Fly ash is disposed of in dedicated landfills in many countries. However, pre-treatment is likely to be required for this to constitute BAT (see e.g. (Song, Kim et al. 2004), depending on national landfill acceptance criteria. More detailed information on the management of waste incinerator residues containing mercury ~~management~~ can be found in the Basel Convention ESM technical guidance for mercury wastes (Basel Convention Secretariat 2015).

3.6.3 Residue reuse

Bottom and fly ashes from waste incinerators should ~~never~~ not be used as soil amendment in agricultural or similar applications if mercury concentrations exceed levels of concern. Addition to soil may result in subsequent dispersion of the ash and any contaminants. In agricultural uses, plants may take up contaminants, resulting in exposure to human or animals that consume such plants (Skinner et al, 2007). Pecking or grazing animals may directly ingest contaminants with subsequent exposure to humans when they consume the animals or animal products (e.g. milk and eggs) (deVries et al., 2007). Use of waste incineration residues for construction purposes ~~is also very problematic and cannot be considered as best environmental practice. There are examples which demonstrate that such practice can lead to serious environment contamination by~~ have potential environmental risks due to contamination of heavy metals (Pless-Mulloli, Edwards et al. 2001); Watson 2001, Petrlik and Ryder 2005; Shaheen et al., 2014), and careful evaluation of these materials should be undertaken if any re-use is anticipated.

3.6.4 Stabilization and solidification

Treatment and disposal options for solid residues from flue gas control systems include solidification or stabilization with Portland cement (or other pozzolanic materials), alone or with additives or a number of thermally based treatments, followed by appropriate disposal in conformance with national landfill acceptance criteria (based on anticipated releases from the treated residuals). The need for such treatment can be determined based on an evaluation of the release potential of these residues. More detailed information on treatment methods can be found in the Basel Convention ESM technical guidance for mercury wastes (Basel Convention Secretariat 2012).

3.6.5 Final disposal of residues

Any residues containing or contaminated with mercury should not be recycled. When disposed in a landfill, evaluation of the release potential and the appropriateness of the landfill for this type of material should be considered. More detailed information can be found in the Technical guidelines for the environmentally sound management of wastes consisting of elemental mercury and waste containing or contaminated with mercury or mercury compounds (Basel Convention, 2012).

3.7 Alternative treatment techniques for waste streams that can generate emission of mercury and mercury compounds when incinerated

This section describes some alternative treatment technologies that are currently commercially available. The goal of an alternative treatment technology would be to achieve the same degree of destruction of the organic compounds, ~~but maintain control over the~~ while controlling potential releases of residual mercury.

For municipal waste, possible alternatives to incineration are:

- Zero waste management strategies, which aim to eliminate the generation of waste through the application of a variety of measures including legislative and economic instruments (circular economic policy and recycling insurance) (Greyson, 2007; Matete and Trois, 2008; Allen, Gokaldas et al., 2012);
- Waste minimization, source separation and recycling to reduce the waste volume requiring final disposal;
- Mechanical biological treatment, which reduces waste volume by mechanical and biological means and generates residues requiring further management (Bilitewski, Oros et al. 2010); (Velis, Longhurst et al. 2009);

For medical waste, possible alternatives to incineration use are:

- Exposure of waste to saturated steam under pressure in a pressure vessel or autoclave,
- Advanced steam sterilization systems. Advanced autoclaves or advanced steam sterilization systems combine steam treatment with pre-vacuuming and various kinds of mechanical processing before, during and after steam treatment,
- Microwave treatment;
- Dry heat sterilization.

Comment [dl18]: Not clear why these methods are listed. These alternatives by themselves would not control potential mercury emissions/releases from medical waste containing or contaminated with mercury.

4 EMERGING TECHNIQUES

4.1 High Efficiency Activated Carbon Adsorber

A high efficiency activated carbon adsorber, trade-named "JFE-Gas-Clean-DX," was developed in which activated carbon is packed in an activated carbon cartridge with a fixed bed and lateral flow-type structure, thereby realizing efficient contact between the flue gas and the activated carbon.

Error! Reference source not found.~~**Error! Reference source not found.**~~~~Figure 6~~ shows a schematic illustration of the appearance of the device. Figure 7 shows a schematic diagram of the activated carbon cartridge. The device consists of an easily detached/installed activated carbon cartridge in the device housing with a compact size. High efficiency contact between the flue gas and activated carbon is realized by adopting a fixed bed and lateral flow type structure.

Comment [D[19]: Error code!

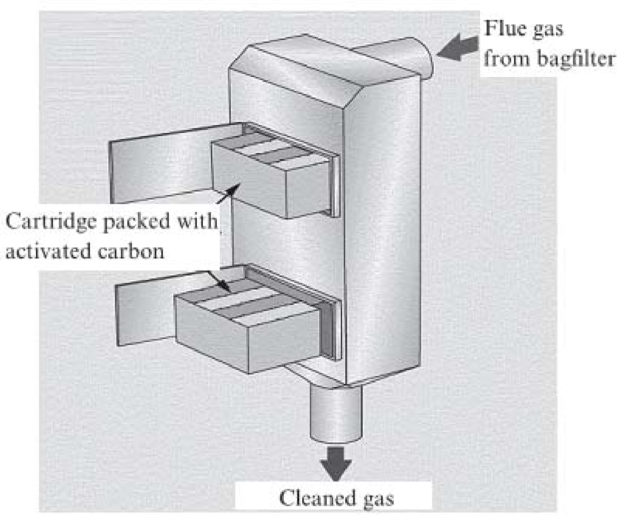

Figure 6 **Schematic illustration of activated carbon adsorber**

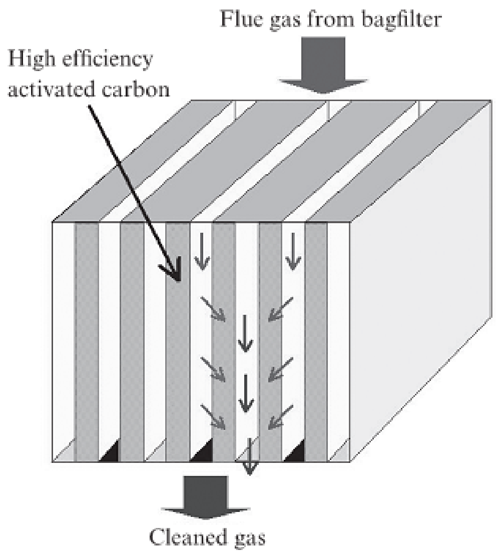

Figure 7 Cartridge packed with activated carbon

As shown in **Error! Reference source not found.**~~**Error! Reference source not found.**Figure~~ 7, flue gas is uniformly dispersed as it passes through the multiple thin packed layers of activated carbon installed in the activated carbon cartridge. As a result, contact efficiency between the activated carbon and trace harmful substances in the flue gas is high. A large decrease in activated carbon use is possible. As an additional advantage, because thin layers of activated carbon are used, pressure loss is low in comparison with the conventional moving bed-type activated carbon adsorber, which has pressure loss of approximately 2-3 kPa. Because the pressure loss is no more than 0.5 kPa per activated carbon cartridge stage, electric power consumption can be held to a low level. To prevent dust from clogging the packed bed of activated carbon, the basic method when applying this device is installation after the bag filter. For this reason, activated carbon with high ignition prevention performance should be used, enabling treatment up to a maximum service temperature of 200 °C, which is the temperature of general bag filters.

Comment [D[20]: Error code!

Comment [dl21]: It is not clear what this is trying to say. Is it trying to say that smaller amounts of activated carbon can be used by this technique compared to ACI?

Trials at a waste incineration plant have shown mercury concentrations below the detection limit of 5 µg/m^3 in the clean gas during an inlet concentration of 65 µg/m^3. The Hg concentrations under the minimum determination limit were being maintained after 6 months at the waste incineration plant.

Co-benefits

Co-benefits include the reduction of other harmful substances such as dioxins and other heavy metals.

4.2 Coconut char as an alternative to coal based activated carbon

As an alternative to AC, char from coconut fibers (CF) and from coconut pith (CP) was developed. Coconut husk is a waste from coconut processing that is widely found in the tropical region.

Trials showed that the elemental mercury adsorption capacity of char from pith is better than from CF under the conditions of the trial. The adsorption capacity for elemental mercury of CP-char (3,142 µg/g) in these trials was much higher than of coal based AC (119 µg/g). This may indicate that activated char coals from coconut pith may be a future potential source of adsorbents, which would replace the existing adsorbents, e.g. AC (Khairiraihanna et al. 2015).

Co-benefits

The use of waste such as coconut husk could provide economic benefits, as well as reduce waste disposal problems.

Comment [dl22]: This needs to be further qualified. Coconut char contaminated with mercury will still need to be properly disposed.

5 BEST AVAILABLE TECHNIQUES AND BEST ENVIRONMENTAL PRACTICES FOR WASTE INCINERATION FACILITIES

5.1 Introduction to Best Available Techniques (BAT) for Incineration of Waste

The purpose of this subsection is to assist in the identification of the best techniques applicable to the process of waste incineration. Best available techniques for waste incineration include the design, operation and maintenance of a waste incineration plant that effectively minimizes the emissions of mercury.

When considering the best available techniques for waste incineration, it is important to consider that the optimal solution for a particular type of incineration installation varies according to local conditions. The techniques provided here are not intended as a checklist indicating the best local solution, as this would require the consideration of local conditions to a degree that cannot be described in a document dealing with best available techniques in general. Hence, the simple combination of the individual elements described here as best available techniques, without consideration of local conditions, is not likely to give the optimized local solution in relation to the environment as a whole (European Commission 2006).

With a suitable combination of primary and secondary measures associated with best available techniques, mercury emission levels not higher than 10 µg/m^3 (at 11 per cent O_2) have been reported (Daschner et al., 2011). It is further noted that under normal operating conditions emissions lower than this level can be achieved with a well-designed waste incineration plant. There are many waste incinerator plants worldwide that are designed and operated according to most of the parameters defining best available techniques and that meet the associated emission levels.

There are also non-incineration techniques as described in the Basel Convention ESM technical guidance for mercury waste and *emerging technology options* (see section 444 of the present document) that may represent feasible and environmentally sound alternatives to incineration.

5.2 Pre-treatment of waste before incineration

The mixing (e.g. using bunker crane mixing) or further pre-treatment (e.g. the blending of some liquid and pasty wastes, or the shredding of some solid wastes) of heterogeneous wastes to the degree required to meet the design specifications of the receiving installation is important. Pre-treatment is most likely to be a requirement where the installation has been designed for a narrow specification, homogeneous waste.

5.3 Best available techniques for waste input and control

The following general practice for waste input and control should be considered when dealing with the best available techniques for handling waste containing or contaminated with mercury:

- Maintain the site in a generally tidy and clean state;

- Establish and maintain quality controls over the waste input, according to the types of waste that may be received at the installation. This could include:
  - Establish process input limitations and identify key risks;
  - Communicate with waste suppliers to improve incoming waste quality control;
  - Control waste feed quality on the incinerator site;
  - Check, sample and test incoming wastes;

5.4 Best available techniques for waste incineration

There is a potential trade off to be made in operating waste incinerators. To achieve the highest level destruction, the aim is complete combustion. On the other hand, mercury control techniques tend to be more efficient if there is some unburnt carbon in the flue gas stream. There therefore has to be a balance struck between these competing factors in order to achieve the best overall outcome. The following section describes first the general considerations which are likely to lead to achieving maximum combustion. There then follows a description of particular considerations for individual waste streams. The selection of a combustion technique will depend on the type of waste to be incinerated.

5.4.1 General combustion techniques

The following considerations are important for achieving optimal combustion:

- Ensure design of furnace is appropriately matched to characteristics of the waste to be processed;
- Maintain temperatures in the gas phase combustion zones in the optimal range for completing oxidation of the waste (for example, 850-950 °C in grated municipal solid waste incinerators, 1,100-1,200 °C when chlorine content of waste is high);
- Provide for sufficient residence time (e.g. at least 2 seconds) and turbulent mixing in the combustion chamber(s) to complete incineration;
- Preheat primary and secondary air to assist combustion if necessary;
- Use continuous rather than batch processing wherever possible to minimize start-up and shutdown releases;
- Establish systems to monitor critical combustion parameters such as temperature, pressure drop, levels of CO and O_2 and, where applicable, grate speed;
- Provide for control interventions to adjust waste feed, grate speed, and temperature, volume and distribution of primary and secondary air;
- Install automatic auxiliary burners to maintain optimal temperatures in the combustion chamber(s);
- Use air from bunker and storage facilities as combustion air and
- Install system that automatically stops waste feeding when combustion parameters are not appropriate.

5.4.2 Municipal solid waste incineration techniques

The following are considerations that are specific for the incineration of municipal solid waste:

- Mass burn (moving grate) incinerators are well demonstrated in the combustion of heterogeneous municipal solid waste and have a long operational history.
- Water-cooled grated incinerators have the added advantages of better combustion control and the ability to process municipal solid waste with higher heat content.
- Rotary kilns with grates can accept heterogeneous municipal solid waste but a lower throughput than the mass burn or moving grate furnaces.
- Static grated furnaces with transport systems (for example, rams) have fewer moving parts but waste may require more pre-treatment (i.e., shredding, separation).
- Modular designs with secondary combustion chambers are well demonstrated for smaller applications. Depending on size, some of these units may require batch operation.
- Fluidized bed furnaces and spreader/stoker furnaces are well demonstrated for finely divided, consistent wastes such as refuse-derived fuel.

5.4.3 Hazardous waste incineration techniques

The following are considerations that are specific for incineration of hazardous waste:

- Rotary kilns are well demonstrated for the incineration of hazardous waste and can accept liquids and pastes as well as solids (see subsections 2.2.3.12.2.3.12.2.3.1 – 2.2.3.5);
- Liquid injection incinerators are commonly used for hazardous waste incineration.
- Water-cooled kilns can be operated at higher temperatures and allow acceptance of wastes with higher energy values.
- Waste consistency (and combustion) can be improved by shredding drums and other packaged hazardous wastes.
- A feed equalization system (for example, screw conveyors that can crush and provide a constant amount of solid hazardous waste to the furnace) will help ensure a continuous, controlled feed to the kiln and maintenance of uniform combustion conditions.

5.4.4 Sewage sludge incineration techniques

The following are considerations that are specific for incineration of sewage sludge

- Fluidized bed incinerators and multiple hearth incinerators are well demonstrated for thermal treatment of sewage sludge.
- Circulating fluid bed furnaces allow greater fuel flexibility than bubbling beds, but require cyclones to conserve bed material.
- Care must be exercised with bubbling bed units to avoid clogging.
- The use of heat recovered from the process to aid sludge drying will reduce the need for auxiliary fuel.

- Supply technologies are important in the co-incineration of sewage sludge in municipal solid waste incinerators. Demonstrated techniques include: dried sludge blown in as dust; drained sludge supplied through sprinklers and distributed and mixed on the grate; and drained or dried sludge mixed with municipal solid waste and fed together (BREF on WI, European Commission 2005).

5.4.5 Medical Waste Incineration

The following are considerations that are specific for incineration of medical waste

- Where grates are used, the design of the grate should incorporate sufficient cooling of the grate such that it permits the variation of the primary air supply for the main purpose of combustion control, rather than for the cooling of the grate itself. Air-cooled grates with well distributed air cooling flow are generally suitable for wastes of net calorific value (NCV) of up to approx. 18 MJ/kg. Higher NCV wastes (e.g. above approx. 18 MJ/kg) may require water (or other liquid) cooling in order to prevent the need for excessive primary air levels to control grate temperature i.e., levels that result in a greater air supply than the optimum for combustion control.
- The use of a combustion chamber design that provides for containment, agitation and transport of the waste, for example: rotary kilns - either with or without water cooling. Water cooling for rotary kilns may be favorable in situations where:
  - the NCV of the feed waste is higher (e.g. more than 15 – 17 GJ/tonne), or
  - higher temperatures e.g. more than 1,100 °C are used (e.g. for slagging or destruction of specific wastes)
- Medical waste can be incinerated in municipal waste incinerators using the grate type of incinerator, although some special adaptations have to be made. If infectious medical ~~care~~ waste is to be burnt in a municipal waste incinerator, it has to be disinfected and sterilized beforehand or fed into the incinerator in appropriate containers by automatic loading (Eberhartinger, 2004). Previous mixing of medical waste containing or contaminated with mercury with other waste types and direct handling ~~has to~~should be avoided.

5.5 Best available techniques for flue-gas treatment

This sub-section, describes techniques that could be considered in selecting the best available techniques for flue gas treatment of waste incineration plants ~~are described~~. Unless otherwise stated, they are generally applicable for new and existing ~~sources~~facilities. The chapter also includes remarks for the upgrading of existing ~~sources~~facilities.

BAT for controlling mercury emissions from waste incineration facilities is considered to be FFs in combination with dry or wet methods for controlling volatiles. FFs have the added advantage, when coupled with semi-dry or dry sorbent injection, of providing additional filtration and reactive surface on the filter cake. ESPs in combination with wet systems can also be designed and operated to reach low mercury emissions, but in comparison to FF they have disadvantages especially when the FF is pre-coated with activated carbon to achieve a good abatement directly after the startup phase using the pre-coating for adsorption of volatile pollutants. Dry and semi dry systems have the advantage of not requiring subsequent effluent treatment. Inlet temperature to the FF in such combinations is important.

Comment [dl23]: Awkward phrasing

Temperatures above 130-140 °C are normally required to prevent condensation and corrosion of the bags.

When using a dry system, the additional injection of activated carbon (which may also be impregnated with sorbents like sulfur, bromine or others), mixed with sodium hydrogen carbonate or calcium hydroxide upstream of a fabric filter can reduce the mercury emissions by more than 95 per cent.

In the first stage of a high efficiency scrubber, the removal efficiency of oxidized mercury as mercury (II) chloride, which is generally the main compound of mercury after waste combustion, is over 95 per cent~~.~~. The overall mercury removal (both elemental and oxidized) efficiency is around 85 per cent.

As additional measure for minimizing mercury in the scrubbing water and to avoid re-emission of the soluble mercury, the precipitation of oxidized mercury with a suitable precipitating agent, e.g., sulfide, trimercaptotriazine (TMT 15) or PRAVO (a bromine containing chemical, Material Safety Data Sheet 2014) and the addition of activated carbon, can be used.

~~Especially a~~At low concentrations of halogens in the waste, bromine addition into the waste or boiler can lead to high oxidation rates of mercury to improve the mercury removal in downstream control devices, e.g. scrubbers (see also section 3.4~~3.4~~3.4). The technique is mainly used in mono-combustion plants for sewage sludge and hazardous waste incineration plants.

Effective maintenance of dust control systems is very important.

With these applications, concentration of mercury below 10 µg/m³ (yearly average) has been reported (UNECE, 2013). In general, the use of fabric filters gives the lower levels within these emission ranges. Adsorption using carbon based reagents is generally required to achieve these emission levels with many wastes. Some waste streams have very highly variable mercury concentrations and waste pre-treatment may be required in such cases to prevent peak overloading of the flue gas treatment system capacity.

For wastes with high levels of mercury, such as hazardous or medical wastes, the combination of various flue gas treatment steps can be appropriate. For example, a scrubber with oxidation ingredients and ACI before a fabric filter can be used.

The most relevant secondary emission reduction measures are outlined in Table 3. If re-burn of flue gas treatment residues is applied, then suitable measures should be taken to avoid the recirculation and accumulation of mercury in the installation.

SCR for control of nitrogen oxides also reduces mercury emissions as a co-benefit by changing it into a form that can be collected by FF or precipitated by wet scrubbers.

Pressure drop across fabric filters and flue gas temperature (if a scrubbing system is used upstream) should be monitored to ensure filter cake is in place and bags are not leaking or being wetted.

Where temporary peak mercury concentrations are to be expected, the retention and injection of sulfur-impregnated activated carbon/coke should be considered as a safety precaution

Comment [dl24]: Is this all there is for this paragraph? Perhaps a reference to another part of the document can be given here.

Comment [dl25]: Not clear what ranges this refers to, given that it states (in the preceding sentence) there being a concentration of mercury below 10 µg/m³ reported.

Table 3 Control measures and reduction efficiencies for municipal, medical and hazardous waste incineration for stack gases

Control measure	Reduction efficiency
High efficiency scrubbers with ingredients in the scrubber liquor	> 85%
Scrubber + Injection of bromine containing chemicals into the combustion chamber	> 90%
Activated Carbon injection + FF	> 95%

Reference: BREF on WI, European Commission 2005

Reduction efficiencies depend on mercury input, concentrations in the raw gas and operating conditions.

5.5.1 Upgrading and improvement of existing treatment techniques

If the exhaust gas treatment of existing plants does not meet the requirements described above, there are various options for upgrading. In systems which are equipped with an electrostatic precipitator, the electrostatic precipitator may be replaced by a fabric filter. In the flue gas stream ahead of the fabric filter, coke-based adsorbents or substances equivalent in their effects~~, have to be~~ are added to reduce mercury emissions. ~~For minimization of~~ To minimize potential fire hazards, a mixture with limestone reagents~~ is useful~~ may be used.

Comment [dl26]: Not clear what requirements this refers to.

In case of high mercury emissions at facilities that are equipped only with a scrubber, a combination of additive-injection~~,~~ with fabric filters can be installed downstream.

Both measures have the added benefit that acidic and organic pollutants can also be removed from the flue gas. However, due to increased fire hazards the addition of a static-bed filter with activated carbon or lignite coke requires additional security measures and is also relatively expensive.

Comment [dl27]: Is this because security/safety measures add to the cost of this installation? Please clarify.

5.5.2 Performance levels associated with the use of BAT

Figure 8 shows annual mean values of mercury emissions for different combined or 1-step waste gas control techniques of 51 plants used for municipal, medical, hazardous waste incineration. All plants are equipped with continuous mercury measurement. For each technique combination, the mean of all reported values is indicated (center line) together with the standard variation (orange) as well as the minimum and maximum values (grey).

The mean annual emission value is about 2.5 µg/Nm^3 (yearly average based on daily averages), similar for all combinations of control techniques installed. More than 90 per cent of the installations emit less than 10 µg/m^3. All applied combinations of techniques are appropriate for mercury reduction as proven by the small ranges of the annual emission values reported for each combination.

For reduction efficiencies see Table 3.

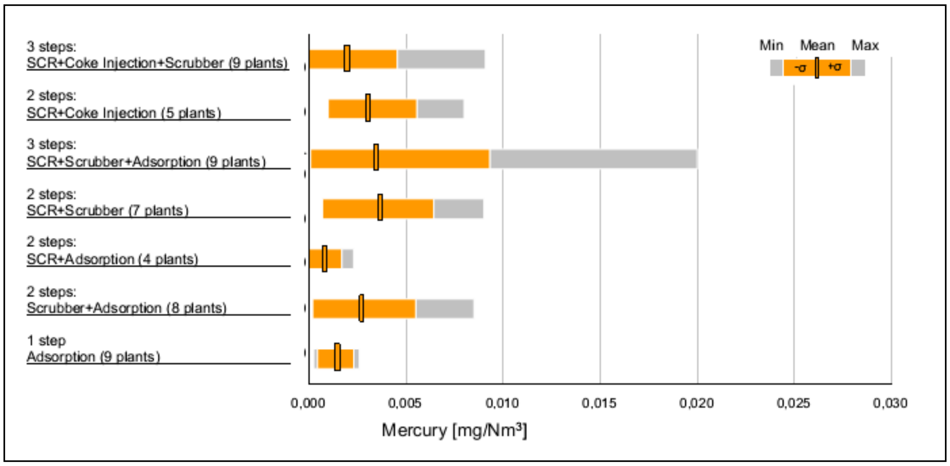

Figure 8 Comparison of waste gas control techniques for mercury reduction (number of plants in brackets) (Daschner et al., 2011)

Table 4 shows emission levels of waste incineration plants in Japan based on discontinuous measurement. For general waste incineration the levels are below 6 µg/m^3. The range at two medical waste incineration plants equipped with FF in combination with ACI is very high with an average of 7 µg/m^3.

Table 4 Emission levels of Japanese waste incineration plants for different abatement techniques.

Comment [dl28]: Not clear what this statement is trying to say. Not clear what is being compared. "Very high" compared to what? Emissions may depend on the mercury content of the waste input.

Comment [D[29]: Header should be on the same page as the table.

Classification of waste	Exhaust gas abatement technology	Number of the incineration facilities	Mercury concentration in the exhaust gas	Applied method of measurement
General waste	Bag Filter	n = 1	< 0.006 mg/m^3	Discontinuous
	Activated carbon spray and Slaked lime spray + Bag Filter	n = 2	< 0.0001 ~ < 0.001 mg/m^3 Reduction efficiency; 91%	Discontinuous
	Activated carbon spray and Slaked lime spray + Bag Filter + Catalytic reaction tower	n = 3	< 0.005 mg/m^3	Discontinuous
Medical waste	Fabric Filter + Activated carbon spray	n = 2	Hg^0; < 0.1 µg/m^3 ~ 1.6 µg/m^3, average; 0.04 µg/m^3 Hg^{2+}; 0.2 µg/m^3 ~ 200 µg/m^3, average; 6.4 µg/m^3	Discontinuous

The mercury concentration was normalized by 12 per cent oxygen based on the Japanese standard.

Trials at a Japanese stoker fired WI plant for municipal waste equipped with a spray tower and following $Ca(OH)_2$ and ACI injection before a FF showed emission levels in a range between 0.4 and 11.3 µg/m^3. (Takaoka 2002)

Comment [dl30]: Does WI stand for waste incineration? A list of acronyms and full names would be helpful.

5.6 Introduction to Best Environmental Practices (BEP)

Best Environmental Practices (BEP) as defined in the Minamata Convention means the application of the most appropriate combination of environmental control measures and strategies. The following graduated range of measures should be considered in applying BEP:

- A regulatory infrastructure with sufficient capacity to permit installations, control and monitor mercury emissions regularly;
- the provision of information and education to the public, users and decision makers about the environmental consequences of choice of particular activities and choice of products, and ultimate disposal;
- the development and application of codes of good environmental practice which covers all aspect of the activity in the product's life;
- the application of labels informing users of environmental risks related to a product, its use and ultimate disposal;
- saving resources, including energy;
- making collection and disposal systems available to the public;
- avoiding the use of hazardous substances or products that contain hazardous substances and the generation of hazardous waste;
- recycling, recovery and re-use;
- the application of economic instruments to activities, products or groups of products;
- establishing a system of licensing, involving a range of restrictions or a ban,

Comment [dl31]: What kinds of restrictions or bans?

- evaluation of mercury life cycle as important perspective for ESM of mercury wastes in order to reduce mercury input into the waste incineration process (see Technical guidelines Basel Convention)
- Creating and maintaining public goodwill towards a waste incineration project is critical to the success of the venture. Effective practices for improving public awareness and involvement include: placing advance notices in newspapers; distributing information to area households; soliciting comment on design and operational options; providing information displays in public spaces; maintaining pollutant release and transfer registers; and holding frequent public meetings and discussion forums. Authorities and proposers of incineration projects should engage with all stakeholders including the public interest groups. Consultations with the public must be transparent, meaningful and sincere if they are to be effective.

5.6.1 Waste management practices

The approaches outlined below, must be taken into account as part of overall waste prevention and control strategies for mercury containing or contaminated waste.

5.6.1.1 Waste minimization

Reducing the overall mass of wastes that have to be disposed of by any means serves to reduce both the releases and residues from incinerators.

In many industrialized countries, health care institutions have begun to phase-out mercury uses and phase-in effective alternative products or devices that avoid the use of mercury. A co-benefit of mercury-free alternatives is to a reducetion of the generation of mercury containing waste. Many health care institutions have also instituted housekeeping and management practices to better control mercury releases from sources still present in their facilities. Such policies and practices substantially decrease emissions and releases of mercury to the environment.

5.6.1.2 Source separation and recycling

The only relevant primary technique for preventing emissions of mercury into the air before incinerating are those that control or prevent, if possible, the inclusion of mercury in waste. The control or prevention of the inclusion of mercury in waste inputs serves to reduce overall mercury emissions from incineration. Therefore, measures to exclude mercury from waste inputs are of special importance. This could be separate collection systems or proper classification of waste at all stages before incineration, as well as separation of waste at the facilities as a primary technique.

The separate collection of waste streams, some of which could potentially be contaminated with high amounts of mercury, and the diversion of mercury-containing waste to proper management facilities can lead to a significant reduction of the mercury content in the waste, which can, thereafter, be burnt

~~in a waste incineration plant~~ going to incineration. ~~This includes~~There could be separate collection for the following wastes:

- ~~Separate collection of~~ mercury containing batteries;
- ~~Separate collection of~~ mercury containing lamps;
- ~~Separate collection of those~~ electrical devices (switches and others) that contain mercury;
- ~~Separate collection of~~ potentially contaminated waste from households and municipal institutions (old paint and varnish, insecticides, solvents, used laboratory chemicals from schools etc.).

5.6.1.3 Waste inspection and characterization before incineration

The following general practice for waste input and control should be considered when dealing with the best available techniques for handling waste containing or contaminated with mercury. When establishing and maintaining quality controls over the waste input, according to the types of waste that may be received at the installation, it is of importance to establish process input limitations and identify key risks, as well as ~~to~~ communicate with waste suppliers to improve incoming waste quality control.

A thorough knowledge of the characteristics and attributes of the incoming waste is essential. The characteristics of a particular waste stream may vary significantly from country to country and region to region. If certain wastes or waste constituents are considered inappropriate for incineration, such as waste included in Article 11 of the Convention, procedures should be in place for detecting and separating these materials in the waste stream or residues prior to incineration, unless the waste is intended for thermal treatment to recover mercury as described in the ~~final~~ Basel Convention Technical Guidance for ESM of mercury waste. ~~Checking~~Inspection, sampling and analyses should be routinely performed. This is particularly true for hazardous wastes. Manifests and audit trails ~~are important to~~ should be maintained and ~~they should be~~ kept updated. Table 5 illustrates some of the inspection techniques applicable to the different types of waste.

Table 5 Examples of inspection techniques (EC 2006)

Waste type	Techniques	Comments
Mixed municipal wastes	Visual inspection in bunker Spot checking of individual deliveries by separate offloading Weighing the waste as delivered Periodic sampling and analysis for key properties or substances	Industrial and commercial loads may have elevated risks
Pretreated municipal wastes and refuse-derived fuels	Visual inspection Periodic sampling and analysis for key properties or substances	
Hazardous wastes	Visual inspection Sampling/analysis of all bulk tankers Random checking of drummed loads Unpacking and checking of packaged loads	Extensive and effective procedures are particularly important for this sector. Plants receiving

Waste type	Techniques	Comments
	Assessment of combustion parameters Blending tests on liquid wastes prior to storage Control of flashpoint for wastes in the bunker Screening of waste input for elemental composition, for example by EDXRF[a]	monostreams may be able to adopt more simplified procedures
Sewage sludges	Periodic sampling and analysis for key properties and substances Process control to adapt to sludge variation	

[a] EDXRF: energy dispersive X-ray fluorescence (spectrometer).

5.6.1.4 Removal of non-combustibles at the incinerator

The removal of both ferrous and non-ferrous metals on site is a common practice at municipal solid waste incinerators, and helps to prevent these wastes~~, potentially containing~~ which may contain mercury as an impurity, ~~to~~ from entering waste incineration.

5.6.1.5 Proper handling, storage

Proper handling, particularly of hazardous waste, is essential. Appropriate sorting and segregation should be undertaken to enable safe processing (Table 6).

Storage areas must be properly sealed with controlled drainage and weatherproofing. Fire detection and control systems for these areas should also be considered along with adequate capacity to retain contaminated fire water onsite. Storage and handling areas should be designed to prevent contamination of environmental media and to facilitate clean-up in the event of spills or leakage. Odors and release of volatile persistent organic pollutants to environmental media can be minimized by using bunker air for the combustion process.

Table 6 Examples of segregation techniques (EC 2005)

Waste type	Segregation techniques
Mixed municipal wastes	Segregation is not routinely applied unless various distinct waste streams are received, when these can be mixed in the bunker Bulky items requiring pre-treatment can be segregated Emergency segregation areas for rejected waste
Pretreated municipal wastes and refuse-derived fuels	Segregation not routinely applied Emergency segregation areas for rejected waste

Waste type	Segregation techniques
Hazardous wastes	Extensive procedures required to separate chemically incompatible materials (examples given as follows): Water from phosphides Water from isocyanates Water from alkaline materials Cyanide from acids Flammable materials from oxidizing agents Maintain separation of pre-segregated ~~packed delivered~~ wastes
Sewage sludges	Wastes generally well mixed before delivery to plant Some industrial streams may be separately delivered and require segregation for blending

Comment [dl32]: Awkward phrasing.

Comment [dl33]: Not clear what this is trying to say. Please clarify.

5.6.1.6 Minimizing storage times

Although having a constant supply of waste is important for continuous operation and stable firing conditions in large municipal solid waste incinerators, ~~stored wastes are unlikely to improve with age~~ the accumulation and storage of a given waste for a long period of time is undesirable. Minimizing the storage period of waste will help prevent putrefaction and unwanted reactions, and the deterioration of containers and labelling. Managing deliveries and communicating with suppliers will help ensure that reasonable storage times (e.g. four to seven days for municipal solid waste) are not exceeded.

5.6.1.7 Establishing quality requirements for waste-fed facilities

Comment [dl34]: To remove repetition with sub-section 5.6.1.9, can sub-section 5.6.1.7 be combined with 5.6.1.9?

Operators must be able to accurately predict the heating value and other attributes of the waste being combusted in order to ensure that ~~the design parameters of the incinerator are being met~~ it is appropriate for use as inputs for which the incinerator was designed to handle. This can be done using the results from a feed monitoring program of key contaminants and parameters; if the waste is variable, more frequent sampling and analysis will be needed.

5.6.1.8 Waste loading

For facilities that accept heterogeneous municipal solid waste, proper mixing and loading of the feed hopper is critical. Loading crane operators must have ~~both~~ the experience and the appropriate vantage point to be able to select the appropriate mix of waste types to keep the incinerator performing at peak efficiency.

The approach to best environmental practices for incinerating wastes containing or contaminated with mercury are captured under the following:

- Waste prevention before incineration;
- Incinerator operating and management practices;
- Post incineration operating and management practices.

Comment [dl35]: Not clear why this is here.

5.6.1.9 Incinerator operating and management practices

Proper operation is critical to achieving design parameters. In general, the manufacturer or designer of the equipment should provide a manual that discusses operating practices including startup procedures, shutdown procedures, normal operation, troubleshooting, maintenance procedures, recommended spare parts and others. Operators must be able to accurately predict the heating value and other attributes of the waste being combusted in order to ensure that the design parameters of the incinerator are being met. This can be done using the results from a feed monitoring program of key contaminants and parameters where sampling and analysis frequencies and rigor would increase as feed variability increases. Detailed information can be found in sections 2.2.3.1 – 2.2.3.5.

Comment [dl36]: Repetitive of sub-section 5.6.1.7. To remove repetition with sub-section 5.6.1.9, can sub-section 5.6.1.7 be combined with 5.6.1.9?

5.6.1.10 Site selection of an incinerator plant

The location of an incinerator can significantly affect dispersion of the plume from the chimney, which in turn affects ambient concentrations, deposition and exposures to workers and the community. In addition to addressing the physical factors affecting dispersion, siting must also address issues of permissions/ownership, access and convenience. Best practices siting has the goal of finding a location for the incinerator that minimizes potential risks to public health and the environment (EPA 1997).

5.6.1.11 Design

Adequate plans, drawings, and quality control are necessary to construct incinerators. Dimensional drawings, tolerances, material lists are necessary. Proper design and operation of incinerators should achieve desired temperatures, residence times, and other conditions necessary to minimize emission of mercury into the environment, avoid clinker formation and slagging of the ash (in the primary chamber), avoid refractory damage ~~destruction~~, and minimize fuel consumption.

5.6.1.12 Regular facility inspections and maintenance

Routine inspections by the operator and periodic inspections by the relevant authority of the furnace and air pollution control devices should be conducted to ensure system integrity and the proper performance of the incinerator and its components. Regardless of how well equipment is designed, wear and tear during normal use and poor operation and maintenance practices will lead to the deterioration of components, a resultant decrease in ~~both~~ combustion quality, an increase in emissions, and potential risks to the operator and public.

5.6.1.13 Operator training

Regular training of personnel is essential for good operation of waste incinerators. Proper operation of incinerators is necessary to minimize emissions and other risks. Only a trained and qualified operator should operate or supervise the incineration process. The operator must be onsite while the incinerator is operating. Without proper training and management support, incinerators cannot achieve proper treatment and acceptable emissions.

6 Monitoring Techniques of Mercury

General and cross cutting aspects of testing, monitoring and reporting are discussed in the introductory chapter of this document. Specific aspects inherent to waste incineration processes will be discussed in this chapter.

6.1 Direct Methods

Direct mercury measurements can be carried out either continuously or discontinuously.

Continuous Emission Measurement (CEM)

The advantage of a continuous monitoring is that the proper function of the flue gas treatment installation can be monitored and a change in the mercury content in the waste is detected fairly quickly.

Despite various measures to control or minimize the input of mercury in waste incineration plants, significant amounts of mercury can occasionally get in via the waste bunker into the combustion and thus into the flue gas, and potentially vary the level of mercury emissions.

With the help of continuously operating mercury measuring devices such contamination can be recognized and countermeasures be quickly initiated as needed. FigureFigureFigure 9 shows the variation of mercury concentration in the clean gas of a waste incineration plant in Hamburg within one year. Especially in the months October and November distinct peaks can be seen.

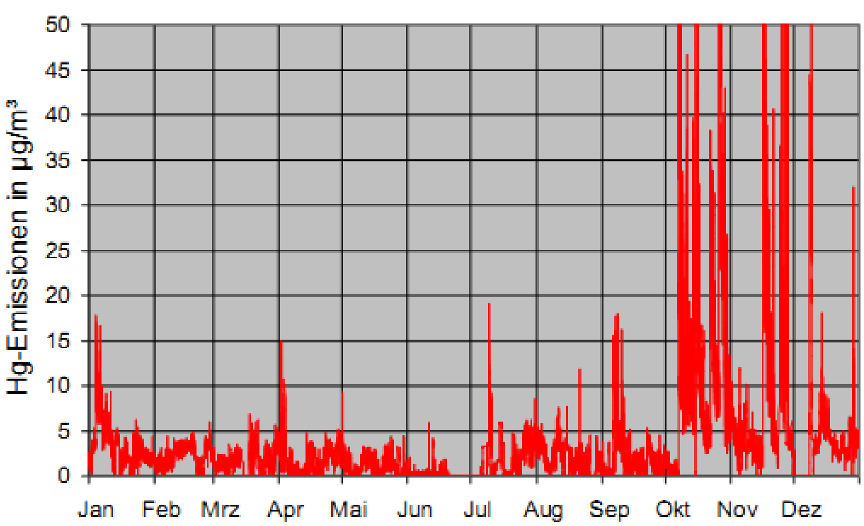

Figure 9 Mercury emission data of one line of a waste incineration plant in Hamburg in 2014

In some countries, the majority of the waste incineration plants are equipped with continuous operating devices. If elevated levels of mercury are detected in the flue gas, counter-measures can be initiated. These include, for example, the following:

- increasing the injected amount of sorbents into the flue gas stream;
- use of sulfur-pre-doped activated carbon with an increased reduction efficiency for mercury;
- adding bromine to the combustion to enhance the oxidation of mercury.

If very high level of mercury is detected in hot spots in the waste, these hot spots should be evacuated. In case of elevated mercury levels in the flue gas cleaning system, cleaning of the flue gas to remove mercury should be considered.

When multiple exceedances of emission limits are observed, measures that should be taken include information of the waste deliverer about the monitoring operations at the plant and/or input-controls or other measures. These measures are found to be effective in most cases, and as a result the amount of exceedances tend to decrease significantly.

~~To determine elevated mercury concentrations in raw gas~~ CEMs are sometimes used to sample the particulate laden gas stream before a particulate control device (see 3.3~~3.3.5.3~~)~~. That gives the possibility to react immediately~~ in order to determine elevated mercury concentrations in raw gas and take quick corrective action as needed, e.g. inject AC or halogenated compounds.

Comment [dl37]: Awkward phrasing. Basically this is saying that when emission limits are exceeded, the facility operator should check its monitoring operations/systems, input controls and other measures to determine the cause in order to make corrective action.

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Stationary source measurement (impinger)

The use of impinger methods for mercury monitoring in waste incineration plants has historically been the prominent method. Due to the complexity and cost of this method, impinger sampling is done less frequently, such as quarterly or annually only. Stationary source measurement (impinger) of a proper function of the flue gas treatment installation is only possible during short sampling periods. The detection of mercury peaks in the flue gas is commonly not possible and, therefore no counter measures can be initiated. However, impinger methods~~,~~ are not appropriate for long sampling periods and in practice, are limited to several hours.

Sorbent Trap Systems

Sorbent trap systems allow a surveillance of a proper function of the flue gas treatment installation after a sampling period. While sorbent trap systems do not provide real-time results, the data obtained can indicate the operating performance over the previous set time period. With this feedback loop approach, adjustments to the process can then be made as needed. Compared to the impinger methods, sorbent traps provide more stable mercury retention and a simpler sampling protocol. The simpler sampling protocol allows for unattended operation of the monitoring over extended periods, which is not possible with the impinger methods.

This system is not commonly used in EU because there are no legal~~ly~~ obligations. However, it is possible that it may be used in other regions of the world.

6.2 Indirect methods

Mass balances

Mass balances are extremely difficult to apply due to potential high ~~Hg~~mercury variations in waste input and great difficulties to reliably monitor ~~Hg reliably~~ mercury levels in heterogeneous waste.

Predictive emissions monitoring

Predictive emissions monitoring (parametric monitoring) ~~are~~ is not possible ~~because~~ at waste incineration plants since there is no relation between other pollutants and mercury in the flue gas. Additionally, mercury content in furnace feedstocks can change significantly over short periods, depending on the concentration of the mercury in the waste.

Emission factors

For monitoring purposes, emission factors should not be used ~~in~~ for determining mercury emissions from waste incineration plants. ~~This is~~ The use of emission factors gives estimates that may not be accurate due to the mercury content variation in waste.

Engineering estimates

Engineering estimates are not an accurate method of mercury air emission monitoring for waste incineration plants.

6.3 Most appropriate techniques for monitoring in the waste incineration sector

Both~~,~~ continuous and discontinuous monitoring are considered ~~as~~ part of BAT implementation.

Continuous measurements are suitable for various reasons, which include:

- the proper function of the flue gas treatment installation can be monitored;
- a change of the mercury content in the waste is fast detectable and
- high concentrations of mercury due to ~~illegal~~ improper input of contaminated waste can be detected.

Several countries require continuous monitoring of mercury at their waste incineration installations already. They consider techniques for continuous monitoring as BAT. The majority of countries using mercury monitoring use discontinuous monitoring, e.g. impinger sampling.

Only continuous monitoring ensures that elevated mercury levels in cleaned gas and/or raw gas are detected for effective control. In such cases, a sorbent may be used, e.g. sulfur-doped activated carbon.

In particular for hazardous waste, medical waste, mixed commercial and municipal waste as well as all other wastes~~,~~ (including illegal entries),when it cannot be guaranteed that no mercury is contained in these waste types, continuous measurement of mercury may be most effective.

Discontinuous measurement methods are also applicable. Sorbent trap systems and stationary source testing (impinger) monitoring allow a surveillance of a proper function of the flue gas treatment installation during the sampling periods. With these measurement methods, the detection of high mercury levels in the flue gas is commonly not possible and, therefore no counter measures can be initiated.

Indirect methods, e.g. mass balances, predictive emissions monitoring, emission factors and engineering estimates are not useful as measurement methods for waste incineration plants.

Comment [dl38]: Please provide explanation of why detection of high mercury levels in the flue gas is commonly not possible with discontinuous measurement methods and no counter measure can be initiated.

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