

**BEST AVAILABLE TECHNIQUES GUIDANCE DOCUMENT ON
WASTE INCINERATOR**

FOREWORD

Best Available Techniques Economically Achievable (BAT) document had been prepared as a guidance notes for the nine (9) major industries in Malaysia and to support the implementation of the new Environmental Quality (Clean Air) Regulations 20xx. These documents were prepared based on the latest state-of-the-art technologies, internationally accepted limit values but had been adjusted and tailored to local requirements.

BAT is defined as the effective methods in preventing pollution and, where generally that is not practicable, to reduce emissions from industrial activities and their impact on the environment. This definition implies that BAT not only covers the technology used but also the way in which the installation is operated, to ensure a high level of environmental protection. Implementations of BAT in any specific industrial sectors are under economically and technically viable condition.

It is hope that the technical contents of these documents will prove beneficial to the industries in their endeavour to comply with the environmental regulations and standards through more cost-efficient means. In the identification of BAT, emphasis is placed on pollution prevention techniques rather than end-of-pipe treatment. These documents will be reviewed and updated from time to time.

These documents have been prepared in consultations with the University of Malaya Consultancy Unit (UPUM), Malaysia German Technical Cooperation (GTZ) and the relevant industries/stakeholders. The Department of Environment wishes to record appreciation to representatives of the relevant industrial sectors, government agencies and individuals for their invaluable input.

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LIST OF ABBREVIATIONS

BAT	-	Best Available Techniques
BREF	-	Best Available Technique Reference Document
CAR	-	Clean Air Regulation
Cd	-	Cadmium
CO	-	Carbon Monoxide
DOE	-	Department of Environment
DRE	-	Destruction and Removal Efficiency
ESP	-	Electrostatic Precipitators
FGT	-	Flue-Gas Treatment
HCl	-	Hydrogen Chloride
HF	-	Hydrogen Flouride
ICRT	-	Inducting Couple radio Frequency Plasma
IPPC	-	Integrated Pollution Prevention Control
kg/h	-	kilogram per hour
mg/Nm ³	-	milligram per cubic metre at standard temperature (273K) and pressure (1atm)
MSW	-	Municipal Solid Waste
N ₂ O	-	Nitrous Oxide
NMVOCs	-	Non Methane Volatile Organic Compounds
NO _x	-	Nitrogen Oxide
ODS	-	Ozone Depleting Substances
SCR	-	Selective Catalytic reduction
SO _x	-	Sulphur Oxide
TOC	-	Total Organic Compound
VOCs	-	Volatile Organic Compounds

1.0 PREFACE

1.1 Status of This Document

This document forms a part of a series presenting the guidance notes for selected industries in Malaysia (list given at the end of this preface) to apply best available techniques economically achievable (BAT), associated monitoring and developments in them. This series is published by the Department of Environment (DOE) in accordance to the Environmental Quality (Clean Air) Regulations 2014 (CAR 2014).

1.2 Definition of BAT

In order for the user of this document to understand the legal context of this document, the interpretation on the definition of BAT is taken from Regulation 2 – Interpretation of CAR 2014 and described as below:

“Best Available Techniques Economically Achievable” means the effective methods in preventing pollution and, where that is not practicable, generally to reduce emissions in the air from the industrial activities and their impact on the environment as a whole. In this regard:

“Techniques” includes both the technology used and the way in which the facility is designed, built, maintained, operated and decommissioned;

“Available Techniques” means those techniques that are accessible to the occupier and that are developed on a scale that allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages; and

“Best” means effective in achieving a high general level of protection of the environment as a whole;

On the basis of this assessment, techniques, and as far as possible emission and consumption levels associated with the use of BAT, are presented in this document that are considered to be appropriate to the sector as a whole and

in many cases reflect current performance of some installations within the sector. Where emission or consumption levels “associated with best available techniques” are presented, this is to be understood to mean those levels representing the environmental performance that could be expected as a result of the application, of the techniques described, taking into account the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such.

In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross media considerations, they are not considered to be appropriate as BAT for the sector as a whole. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of “levels associated with BAT” described above is to be distinguished from the term “achievable level” used elsewhere in this document. Where a level is described as “achievable” using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

The actual cost of applying a technique will depend strongly on the specific situation such as taxes, fees, and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific economic viability of techniques drawn from observations on existing installations.

The purpose of CAR 2014 is to achieve prevention and control of pollution arising from activities listed in its First Schedule and Second Schedule. More specifically, it provides for a notification system for certain categories of industrial installations to conduct an integrated and comprehensive view of the pollution and consumption potential of their installation. The overall aim is to ensure a high level of protection of the environment as a whole based on appropriate preventative measures through the application of BAT.

1.3 Objective of This Document

The 'emission minimization principle' as cited in CAR 2014 requires that the goal of emission abatement is to achieve minimum emissions as a result of applying current BAT. Hence this guideline document is meant to provide the reference information for the permitting authorities to take into account when determining permit conditions. This document should serve as valuable input to achieve better environmental performance.

1.4 Information Sources

The information is mainly based on the European IPPC BREF document where the assessment was achieved through an iterative process involving the following steps:

- identification of the key environmental issues for the sector
- examination of the techniques most relevant to address those key issues;
- identification of the best environmental performance levels, on the basis of the available data world-wide;
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in Implementation of these techniques;

- selection of the BAT and the associate emission and/or consumption levels for this sector

1.5 How to Use This Document

It is intended that the general BAT in this document could be used to judge the current performance of an existing installation or to judge a proposal for a new installation and thereby assist in the determination of appropriate BAT based conditions for that installation. It is foreseen that new installations could be designed to perform at or even better than the general BAT levels presented here. It is also considered that many existing installations could reasonably be expected, over time, to move towards the general "BAT" levels or perform better. This reference document does not set legally binding standards, but they are meant to give information for the guidance of industry, the relevant government bodies and the public on achievable emission and consumption levels when using specified techniques.

The structure of the guideline document is as follows:

An overview of each particular sector in the Malaysian context is firstly covered briefly followed by process description, process optimization, sources of pollution, emission control options, recommended practices and emission values and finally emission monitoring and reporting. More often than not, trade-off judgements between different types of environmental impacts and specific site condition are the influencing factors.

Another important point to note is that BAT change over time and this guidance document needs to be reviewed and updated as appropriate.

2.0 OVERVIEW OF WASTE INCINERATION IN MALAYSIA

Malaysia produced about 17,000 tonnes of municipal solid waste (MSW) per day. This is estimated to increase to more than 30,000 tonnes in the year 2020. Only small fraction of this waste is incinerated. MSW incinerators with 5 to 20 ton/day capacity are available at islands of Pangkor, Labuan, Langkawi and Tioman.

Currently there are also five regional clinical waste incinerators with capacity of 200 to 500 kg/hr and seven small on-site medical waste incinerators; five 20 kg/hr and two 50 kg/hr. Compared to the amount of medical waste generated, the need for more clinical waste incinerators are ever increasing. As for Schedule Waste, the incineration plant in Bukit Nenas, Negeri Sembilan is the only off-site incinerator in the country and it handles majority of waste in this category. Department of Environment also issues licenses for on-site incineration of hazardous waste and more incineration plants may be approved in the future. In summary, the country is progressing economically, socially and technologically and one can expect the waste generation to increase and possibility of new incineration plants coming into operation are a reality.

In Malaysia the main types of waste to which incineration is applied as a treatment are:

- (a) municipal wastes
- (b) hazardous wastes (schedule waste)
- (c) clinical wastes

Therefore only the incineration of above waste will be covered in this document.

3.0 BRIEF PROCESS DESCRIPTION

3.1 Thermal Treatment

Pyrolysis (non-oxidative thermal decomposition), gasification (partial oxidation) and incineration (full oxidative combustion) are three main types of thermal waste treatment commonly available. The reaction conditions for this thermal treatment are given in **Table 1**.

Table 1: Typical Reaction Conditions and Products from Pyrolysis, Gasification and Incineration Processes

Parameter	Pyrolysis	Gasification	Combustion (normally called as incineration process)
Reaction temperature (°C)	250 – 700	500 – 1600	800 – 1450
Pressure (bar)	1	1 – 45	1
Atmosphere	Inert/nitrogen	Gasification agent: O ₂ , H ₂ O	Air
Stoichiometric ratio (n)	0	<1	>1
Main products from the process			
Gas phase:	H ₂ , CO, H ₂ O, N ₂ and hydrocarbons	H ₂ , CO, CO ₂ , CH ₄ , H ₂ O and N ₂	CO ₂ , H ₂ O, O ₂ and N ₂
Solid phase:	Ash, coke	Slag, ash	Ash, slag
Liquid phase:	Pyrolysis oil and water	NA	NA

Pyrolysis and gasification plants follow a similar basic structure to waste incineration installations, but differ significantly in detail. In this BAT document, only incineration will be covered

3.2 Purpose of Incineration and Basic Theory

Incineration is used as a treatment for a very wide range of wastes. The objective of waste incineration is to reduce its volume and hazardous characteristics while capturing or destroying potentially harmful substances that may be released during incineration. Incineration processes which

produce hot flue gases can provide a means for recovery of the energy. Depending on the type of waste it is also possible to recover material such as mineral and/or chemical.

3.3 Stages of Incineration Process

Incineration is a general term used to describe three main stages that occurs at various temperatures in an incinerator as following:

a. Drying and Degassing

Volatile content is evolved (e.g. hydrocarbons and water) at temperatures in between 100 and 300 °C. This process does not require oxygen and only dependent on the supplied heat.

b. Pyrolysis and Gasification (within an incineration process)

Pyrolysis is the further decomposition of organic substances in the absence of oxygen at approximately 400 to 700°C. Gasification of the carbonaceous residues is the reaction of the residues with water vapor and CO₂ at temperatures between 700 and 1000°C. Thus, solid organic matter is transferred to the gaseous phase. In addition to the temperature, water, steam and oxygen support this reaction.

c. Oxidation (within an incineration process)

The combustible gases created in the previous stages are oxidized between 800 and 1450°C. These individual stages generally overlap, meaning that special and temporal separation of these stages during waste incineration may only be possible to a limited extent.

3.4 Key Environmental Issues in Incineration Plants

The main environmental issues that arise directly from incineration installations are as following:

- Overall process emissions to air and water (including odor)
- Overall process residue and by-product production
- Process noise and vibration
- Energy consumption and production
- Raw material consumption
- Fugitive emissions
- Reduction of the storage/handling/processing risks of hazardous wastes.

Among the environmental issues mentioned above, emissions to air remain an important issue for incineration plants. Significant advances in technologies for the cleaning of flue-gases in particular have lead to major reductions in the emissions to air.

3.5 Combustion Techniques for Various Waste Type

Different types of thermal treatments are applied to the different types of wastes. Municipal waste can be incinerated in several combustion systems such as traveling grate, rotary kilns and fluidized beds. For Incineration of hazardous and clinical waste, rotary kilns are most commonly used. Table 2 summarizes the current successful application of thermal treatment techniques to the main waste types at dedicated installations. Descriptions of some of the common techniques used incineration are as following:

3.5.1 Grate Incinerators

Grate incinerators are widely applied for the incineration of mixed municipal wastes. It can also be used for sewage sludge and certain clinical wastes.

Figure 1 below shows a schematic diagram of a grate incinerator.

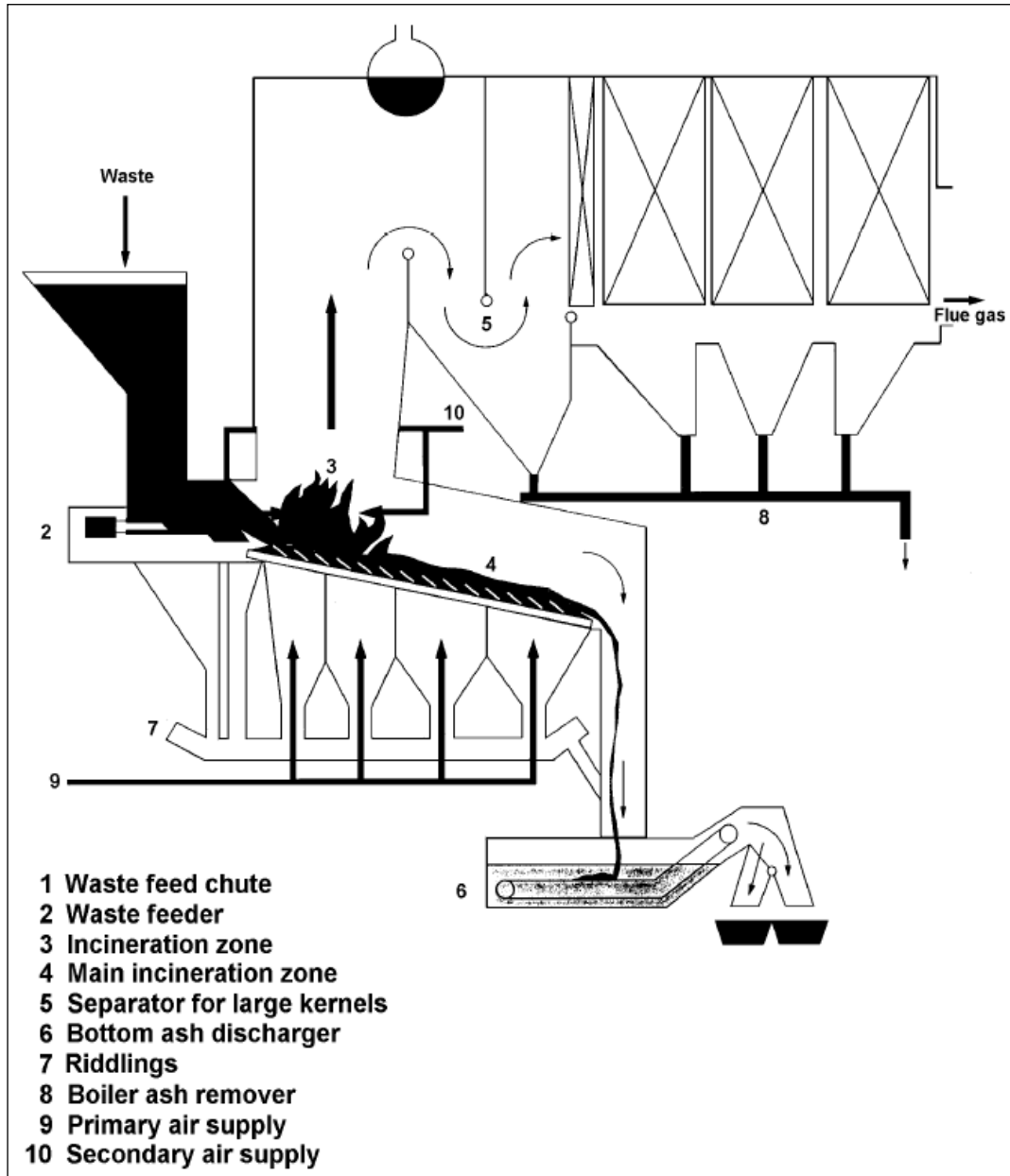


Figure 1: Grate Furnace and Heat Recovery Stages for a Municipal Waste Incineration Plant

Table 2: Summary of the Current Successful Application of Thermal Treatment Techniques to the Main Waste Types at Dedicated Installations

Technique	Untreated Municipal waste	Pretreated MSW and RDF	Hazardous waste	Clinical waste
Grate –reciprocating	Widely applied	Applied	Not normally applied	Applied
Grate –traveling	Applied	Applied	Rarely applied	Applied
Grate –rocking	Applied	Applied	Rarely applied	Applied
Grate –roller	Applied	Applied	Rarely applied	Applied
Grate –water cooled	Applied	Applied	Rarely applied	Applied
Grate plus rotary kiln	Applied	Not normally applied	Rarely applied	Applied
Rotary kiln	Not normally applied	Applied	Widely applied	Widely applied
Rotary kiln –water cooled	Not normally applied	Applied	Widely applied	Widely applied
Static hearth	Not normally applied	Not normally applied	Applied	Widely applied
Static furnace	Not normally applied	Not normally applied	Widely applied	Applied
Fluidised bed – bubbling	Rarely applied	Widely applied	Not normally applied	Not normally applied
Fluidised bed – circulating	Rarely applied	Widely applied	Not normally applied	Not normally applied
Fluidised bed – rotating	Applied	Applied	Not normally applied	Applied
Pyrolysis	Rarely applied	Rarely applied	Rarely applied	Rarely applied
Gasification	Applied	Rarely applied	Rarely applied	Rarely applied

3.5.2 Rotary Kilns

Rotary kilns are very robust and almost any waste, regardless of type and composition, can be incinerated. Rotary kilns are very widely applied for the incineration of hazardous wastes. The technology is also commonly used for clinical wastes but less so for municipal wastes. Operating temperatures of rotary kilns used for wastes range from around 500 °C (as a gasifier) to 1450 °C. When used for conventional oxidative combustion, the temperature is generally above 850 °C. Temperatures around 1200 °C are typical when incinerating hazardous wastes. A schematic drawing of a rotary kiln incineration system is shown in **Figure 2**.

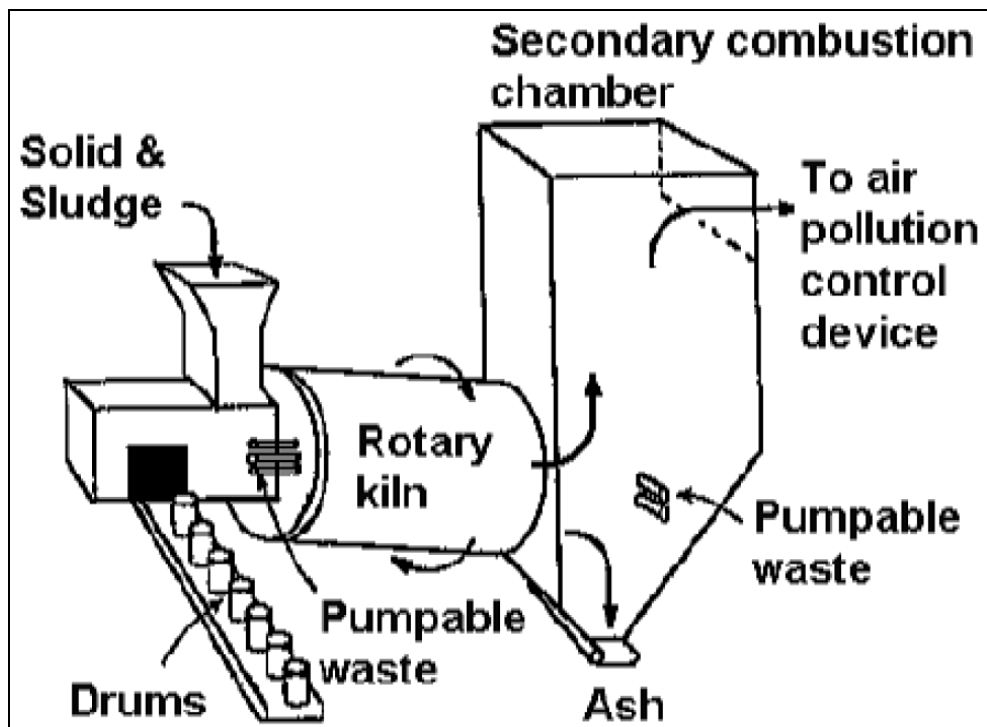


Figure 2: Schematic of a Rotary Kiln Incineration System

The rotary kiln consists of a cylindrical vessel slightly inclined on its horizontal axis. The vessel is usually located on rollers, allowing the kiln to rotate or oscillate around its axis (reciprocating motion). The waste is conveyed through the kiln by gravity as it rotates. Solid waste, liquid waste, gaseous waste, and sludges can be incinerated in rotary kilns. In order to increase the destruction of toxic compounds, a post-combustion chamber is usually added.

Additional firing using liquid waste or additional fuel may be carried out to maintain the temperatures required to ensure the destruction of the waste being incinerated.

3.5.3 Fluidised Beds

Fluidised bed incinerators are widely applied to the incineration of finely divided wastes. It has been used for decades, mainly for the combustion of homogeneous fuels. Among these are coal, raw lignite, sewage sludge, and biomass (e.g. wood). A schematic drawing of a fluidised bed incinerator is shown in **Figure 3**.

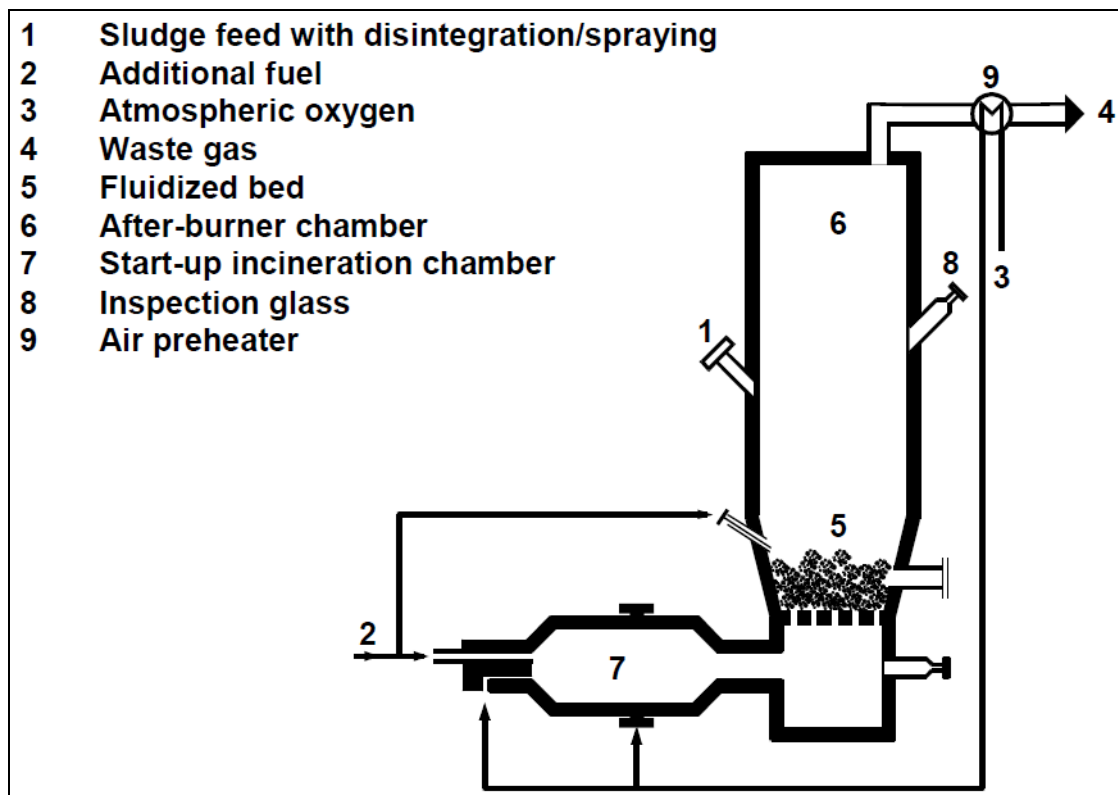


Figure 3: Schematic of a Fluidized Bed Incinerator

3.5.4 Plasma Technologies

Plasma is a mixture of electrons, ions and neutral particles (atoms and molecules). This high temperature, ionized, conductive gas can be created by the interaction of a gas with an electric or magnetic field. Plasmas are a source of reactive species, and the high temperatures promote rapid chemical reactions. Plasma processes utilize high temperatures (5000 to 15000 °C), resulting from the conversion of electrical energy to heat, to produce a plasma. They involve passing a large electric current through an inert gas stream. Under these conditions, hazardous contaminants, such as PCBs, dioxins, furans, pesticides, etc., are broken into their atomic constituents, by injection into the plasma. The process is used to treat organics, metals, PCBs (including small-scale equipment) and HCB. In many cases pretreatment of wastes may be required. The destruction efficiencies for this technology are quite high, >99.99 %. Plasma is an established commercial technology, however the process can be very complex, expensive and operator intensive. Different kinds of plasma technologies are introduced below:

(a) Argon plasma arc

The waste mixes directly with the argon plasma jet. Argon was selected as the plasma gas since it is inert and does not react with the torch components. The destruction and removal efficiency (DRE) is reported to exceed 99.9998 % for destroying ozone depleting substances (ODS) at 120 kg/h and with 150kW electrical power.

(b) Inductively coupled radio frequency plasma (ICRF)

In ICRF applications, inductively coupled plasma torches are used, and energy coupling to the plasma is accomplished through the electromagnetic field of the induction coil. The absence of electrodes allows operation with a large range of gases, including inert, reducing or oxidizing atmospheres and better reliability than plasma arc processes. The ICRF plasma process has

demonstrated a DRE exceeding 99.99 % while destroying CFC at a rate of 50 – 80 kg/h.

(c) Alternating Current (AC) plasma

The AC plasma is produced directly with 60 Hz high voltage power but in other respects is similar to the ICRF plasma. The system is electrically and mechanically simple and is thus claimed to be very reliable. The process does not require argon and can tolerate a wide variety of working gases, including air, or steam as plasma gases.

(d) CO₂ plasma arc

A high temperature plasma is generated by sending a powerful electric discharge into an inert atmospheric gas, such as argon. Once the plasma field has been formed, it is sustained with ordinary compressed air or certain atmospheric gases depending on desired process outcomes. The temperature of the plasma is well over 5000 °C at the point of generation into which the liquid or gaseous waste is directly injected. The temperature in the upper reactor is about 3500 °C and decreases through the reaction zone to a precisely controlled temperature of about 1300 °C. A special feature of the process is the use of CO₂, which is formed from the oxidation reaction, as the gas to sustain the plasma.

(e) Microwave plasma

This process feeds microwave energy at 2.45 GHz into a specially designed coaxial cavity to generate a thermal plasma under atmospheric pressure. Argon is used to initiate the plasma but otherwise the process requires no gas to sustain the plasma. The DRE for the microwave plasma process is reported to exceed 99.99 % while destroying CFC-12 at a rate of 2 kg/h. A key advantage of the process is the high destruction efficiency. The process is reported to be capable of achieving the high operating temperatures in a very short time, thus providing operating flexibility and reduced downtime.

(f) Nitrogen plasma arc

This process uses a Direct Current (DC) non-transferred plasma torch operating with water cooled electrodes and using the nitrogen as the working gas generates the thermal plasma. The process was developed in 1995 and there are commercial systems available. The process is reported to achieve a DRE of 99.99 % while destroying CFCs, HCFCs and HFCs at a feed rate of 10 kg/h. A key advantage of this technology is that the equipment is very compact in size.

3.6 Typical Type and Sizes of Incinerators in Malaysia

Table 3 below gives typical sizes and types of incinerators available in Malaysia.

Table 3: Typical Type and Sizes of Incinerators in Malaysia

Waste	Typical size	Incinerator Type
Municipal Waste	500–1000 Kg/hr	Traveling grate
Schedule waste	200 -500kg/hr 3500 kg/hr	Static Hearth Rotary kiln
Clinical waste	20 –50 kg/ hr 250- 500 kg/ hr	Static hearth Rotary kiln

4.0 PROCESS OPTIMIZATION

In incineration processes, the pollutant emitted from the stack and fugitive sources are dependent on conducting appropriate pre combustion steps and optimizing combustion process itself. Brief notes on process optimization at pre-combustion and combustion stage is as follows:

4.1 Pre Combustion Stage.

Following steps may be instituted at this stage:

- (a) General housekeeping
- (b) Quality Control of incoming waste and establishing checking, sampling and testing of incoming waste.
- (c) Apply appropriate storage techniques.
- (d) Pre treatment of incoming waste which may include mixing and shredding of bulky waste.

4.2 Combustion stage

Combustion process can be optimized by following ways:

- (a) Selecting appropriate incinerator.
- (b) Pre-use of continuous rather than batch operation
- (c) Pre-treatment and blending of waste
- (d) Selection and use of suitable combustion control system
- (e) Optimization of air supply
- (f) Pre-heating of primary and secondary air
- (g) Cooling of rotary kilns
- (h) Residence time, temperature, turbulence of gases in the combustion zone and oxygen concentration.

Table 4 provide brief summary of the specifications applied.

Table 4: Combustion Specifications Applied to Incineration

Parameter	Specification	Purpose
Temperature	<ul style="list-style-type: none"> • at least 1000 °C for Municipal waste • at least 1100 °C for hazardous and clinical waste 	adequate temperatures to allow oxidation
Minimum gas residence time	<ul style="list-style-type: none"> • 2 seconds after the last injection of combustion air. 	Sufficient residence time at high enough temperature in the presence of sufficient oxygen to react and oxidized

Parameter	Specification	Purpose
Turbulence	<ul style="list-style-type: none">• Sufficient to ensure good gas mixing and combustion reaction	mixing of gas to allow reactions to proceed across the entire gas stream
Oxygen concentration (excess)	<ul style="list-style-type: none">• maximum 6 %	sufficient oxygen must be supplied to allow oxidation

5.0 SOURCE OF AIR POLLUTANT EMISSION

5.1 Carbon Monoxide

CO is produced when there is insufficient oxygen locally and/or insufficiently high temperature of combustion to carry out full oxidation to carbon dioxide. In particular, this can occur if spontaneously evaporating or rapid-burning substances are present, or when combustion gas mixing with the supplied oxygen is poor. CO is a measure of quality of combustion. If the CO emissions are very low then VOC emissions are also low. CO in the plants is often measured continuously.

5.2 Total Organic Carbon (TOC)

This parameter includes a number of gaseous organic substances, the individual detection of which is generally complex or not possible. During the incineration of organic waste, a large number of chemical reactions take place, some of which are incomplete. This leads to an extremely complex pattern of compounds in trace amounts. A complete account of every substance within the TOC parameter is not available, however incineration generally provides high destruction efficiencies for organic substances. Low TOC levels are key indicators for the quality of combustion in an incineration process.

5.3 Hydrogen Chloride, HCl

Many wastes contain chlorinated organic compounds or chlorides. In municipal waste, PVC contains 50% of the chlorides. In the incineration process, the organic component of these compounds is destroyed and the chlorine is converted to HCl. Part of the HCl may react further to metal chlorides on inorganic compounds which are also contained in the waste.

5.4 Hydrogen Fluoride, HF

The formation mechanism of HF in incineration plants corresponds to that of HCl. The main sources of HF emissions in municipal waste incineration plants are probably fluorinated plastic or fluorinated textiles and, in individual cases, the decomposition of CaF_2 during the incineration of sludge. Various kinds of fluorinated waste are treated in hazardous waste incineration plants.

5.5 Hydrogen Iodide and Iodine, Hydrogen Bromide And Bromine

Municipal waste usually contains very small quantities of bromine or iodine compounds. Bromine or iodine emissions are, therefore, of minor importance to municipal waste incineration plants. In hazardous waste incineration plants, organic and inorganic wastes containing bromine or iodine are sometimes treated. For example, bromine compounds can still be found in some electronic devices as flame protection agents. Iodine can be contained in medicines or may be used for the treatment of metal surfaces. On the whole, however, their quantity is small in relation to chlorinated compounds.

5.6 Sulphur Oxides, SO_x

If the waste contains sulphur compounds, mainly SO_2 will be created during the incineration of the waste. Under appropriate reaction conditions, SO_3 can also be created. For MSW, the proportion of SO_3 can be around 5% at the inlet to the flue gas treatment system. Common sources of sulphur in some

waste streams are: waste paper; plaster board (calcium sulphate), and sewage sludges.

5.7 Nitrogen Oxides, NO_x

Various oxides of nitrogen are emitted from incineration plants. The NO and NO₂ emitted from waste incineration plants originates from the conversion of the nitrogen contained in the waste (so-called fuel NO_x) and from the conversion of atmospheric nitrogen from the combustion air into nitrogen oxides (thermal NO_x). In municipal waste incineration plants, the proportion of thermal NO_x is usually very low due to lower temperatures in the afterburner chamber. Production of thermal NO_x generally becomes more significant at temperatures above 1000 °C.

5.8 Nitrous Oxides, N₂O

Nitrous oxide (N₂O) is not usually measured as a part of NO_x estimation. Nitrous oxide can be emitted if insufficient temperature for the combustion process is applied (e.g. less than 850 °C) and there is an insufficient oxygen concentration.

5.9 Dust

Dust emissions from waste incineration plants mainly consist of the fine ash from the incineration process that are entrained in the gas flow. Depending on the reaction balance, other elements and compounds are concentrated in this airborne dust. The separation of dust from the flue-gas using air pollution control devices removes the majority of the dust and entrained inorganic and organic substances (e.g. metal chlorides, PCDD/F, etc). Air pollution control equipment greatly reduces emissions of total particulate matter from waste incineration plants.

5.10 Mercury and Mercury Compounds

Mercury can still be found in municipal waste, notably from batteries, thermometers and dental amalgam.

5.11 Cadmium and Thallium Compounds

Common sources of cadmium in municipal waste incineration plants are electronic devices (including accumulators), batteries, some paints and cadmium-stabilized plastic. Thallium is virtually non-existent in municipal waste. Hazardous wastes may contain high concentrations of Cd and Tl compounds. Effluent treatment sludges and drummed wastes from metal plating and treatment may be significant sources.

5.12 Other Heavy Metal Compounds

This term comprises the heavy metals antimony, arsenic, lead, chromium, cobalt, copper, manganese, nickel, vanadium, tin and their respective compounds. The retention of these metals depends largely on an effective separation of dust as they are bound in dust due to the vapor pressures of their compounds, as contained in the flue-gas (mainly oxides and chlorides).

5.13 Polychlorinated Biphenyls

Low quantities of polychlorinated biphenyls (PCBs) are found in most municipal waste streams and also in some industrial wastes. PCBs are efficiently destroyed if a sufficiently high incineration temperature (above 1200 °C) and suitable processes are used. PCBs contained in the crude flue-gas of waste incineration plants can be the result of incomplete destruction.

5.14 Polyaromatic Hydrocarbons

Polyaromatic hydrocarbons are well known as products of incomplete combustion. They are significant because some of the compounds are considered to be carcinogenic.

5.15 Polychlorinated Dibenzo-Dioxins and Furans (PCDD/F)

Dioxins and furans (PCDD/F) are a group of compounds, some of which are of extreme toxic and are carcinogenic. Their production and release is not specific to waste incineration but occurs in all thermal processes under certain process conditions.

5.16 Ammonia

Ammonia emissions can arise from the overdosing or poor control of NO_x reduction reagents.

5.17 Carbon Dioxide (CO₂)

If one tonne of municipal waste is combusted, approx. 0.7 to 1.7 tonnes of CO₂ is generated.

5.18 Methane CH₄

It can be assumed that, if combustion is carried out under oxidative conditions, methane levels in the flue-gas will be almost zero and consequently not emitted to air. Methane is measured with the VOC component.

6.0 EMISSION CONTROL OPTIONS

The key emission from incineration plants are NO_x, acid gases (HCl, HF and SO₂), dust, PCDD, PCDF and heavy metals. The options available in controlling this pollutant are given below.

6.1 Reduction of Dust Emission

The following system can be used for reducing dust emission.

- (i) Cyclones and multi cyclones
- (ii) Electrostatic precipitators (ESP's)
- (iii) Bag filters

Table 5 provides emission concentration and advantages of various dust removal systems.

Table 5: Concentration and Advantages of Various Dust Removal Systems

Dust removal systems	Emission concentrations	Advantages
Cyclone multicyclone	200 – 300 mg/m ³ 100 -150 mg/m ³ .	<ul style="list-style-type: none"> • robust, relatively simple and reliable • Appropriate only as pre-de-dusting system
Dry ESP	<25 mg/m ³	<ul style="list-style-type: none"> • Relatively low power requirements. • Ability to accommodate gas temperatures in the range of 150-350°C.
Wet ESP	<5 mg/m ³	<ul style="list-style-type: none"> • able to reach low emission concentrations
Bag filter	<5 mg/m ³	<ul style="list-style-type: none"> • the layer of residue acts as an additional filter and as an adsorption reactor

For final reduction of dust emission prior to the release from stack, bag filter can be used. Dust filters are capable of reducing dust emission up to 0.04 to 5 mg/Nm³ (24 hour average).

6.2 Reduction of Acid Gas Emission

The reduction of HCl, HF and SO₂ emission in flue gas can be reduced using following techniques.

6.2.1 Wet Scrubbing System

The emission level associated with the use of wet scrubbers are shown in **Table 6**.

Table 6: Emission Levels Associated With the Use of Wet Scrubbers

Substance(s)	Achievable emission range for 24 hour average (mg/Nm ³)
HCl	< 5
HF	< 1
SO ₂	< 20

Semi-dry scrubbing system

Reductions of emission using Semi-dry scrubbing system are shown in **Table 7**.

Table 7: Emission Levels Associated With the Use of Semi-Dry Scrubbing System

Substance(s)	Achievable emission range for 24 hour average (mg/Nm ³)
HCl	8 -10
HF	< 1
SO ₂	< 20

6.2.2 Flash Dry System

It is possible to achieve emission ranges between 1 – 6 mg/Nm³, 0.05 – 0.9 mg/Nm³ and 0 – 3 mg/Nm³ respectively for HCl, HF and SO₂ using flash dry system.

6.2.3 Addition of Alkaline Reagents To The Furnace

Addition of alkaline reagent reacts in the furnace with acid gases to reduce acid gas loads passing to flue gas treatment systems.

6.3 Reduction of Oxide of Nitrogen Emissions

Primary reasons for reducing the formation of NO_x mainly relate to management preparation of waste and thermal treatment techniques applied. Secondary techniques for reduction of NO_x are as following:

6.3.1 Selective catalytic reduction (SCR)

The catalyst material which produce the reaction consist carrier with added active substances. Reduction of emission achievable using SCR is 30 -100 mg/Nm³ and less than 5 mg/Nm³ for NO and NH₃ respectively for 24 hour average.

6.4 Reduction of PCDD/PCDF Emission

6.4.1 Presentation of Re-Formation

Minimizing dust laden gas residence time in temperature zone 450 °C -200°C reduces the risks of formation of PCDD/F and similar compounds.

6.4.2 Selective Catalyst Reduction (SCR)

SCR system used for NO_x reduction can be used of reducing PCDD/PCDF as well. Destruction efficiencies for PCDD/F of 98 to 99.9% are achievable and the emission is in the range of 0.05 – 0.002 ng TEQ /Nm³.

6.4.3 Destruction Using Catalytic Filter Bags

Destruction efficiencies of PCDD/F of above 99% is achievable.

6.4.4 Absorption By Carbon Injection

Activated carbon is injected into the gas stream where it mixes with flue-gas. Normally carbon is combined with sodium bicarbonate alkaline agent. The absorption of PCDD/F on activated carbon results in emission of PCDD/F below 0.1 ng/Nm^3 TEQ.

6.5 Reduction of Mercury Emission

The following techniques can be used for reducing mercury emissions.

- (a) Low pH wet scrubbing and addition of additive such as scrubber liquor, activated carbon and hydrogen peroxide. Overall Hg removal efficiency of 85% can be obtained through this method.
- (b) Activated carbon injection for Hg absorption. This technique involves the injection of activated carbon upstream of a bag filter. Usually 95% removal efficiency for metallic Hg can be obtained resulting in emissions to air below 0.03 mg/Nm^3 .
- (c) Use of condensing scrubbers, such as cold scrubber can condense metallic mercury. This prevents release of Hg to air.

7.0 RECOMMENDED BAT AND EMISSION VALUES

7.1 Generic BAT for All Waste Incineration

The following BAT for all waste incineration is applicable for pollution emission control and abatement :

1. Maintain the site in a generally tidy and clean state.
2. Establish and maintain quality controls over the waste input

3. Store wastes in areas that have sealed and resistant surfaces with controlled drainage and minimize waste storage times
4. Control odour (and other potential fugitive releases) from waste storage and pretreatment areas by passing the extracted air to the incinerator for combustion or passing the extracted air to the flue gas treatment equipment according to the nature of the air extracted. In addition make provision for the control of odour when the incinerator or FGT system is not available by limiting waste deliveries/storage levels and diverting waste from the plant and extracting the relevant air via an alternative odour control system.
5. Segregate, label and store wastes according to risk level of their chemical and physical characteristics.
6. Use fire detection and control systems at areas where fire hazard is possible.
7. Mix or pre-treat heterogeneous wastes in order to improve their homogeneity, combustion characteristics and burnout potential.
8. Remove ferrous and nonferrous recyclable metals from shredded wastes before the incineration stage.
9. Visually monitor waste storage and loading areas.
10. Use continuous rather than batch operation in order to avoid the need for shutdowns and start-ups.
11. Pre-heat primary and secondary air for low calorific value wastes, by using heat recovered within the installation.

12. Replace approximately 50 % of secondary combustion air with re-circulated flue-gases.
13. Use a combination of furnace design, furnace operation and waste throughput rate that provides sufficient agitation and residence time of the waste in the furnace at sufficiently high temperatures.
14. Use automatically operating auxiliary burners for start-up and shut-down and for achieving and maintaining required operational combustion temperatures
15. Use water walls in the secondary combustion zone and boiler, protected with suitable materials as required.
16. Use furnace dimensions that are large enough to provide for low gas velocities and longer gas residence times.
17. Use an overall flue-gas treatment (FGT) system that reduces emissions to air within permissible limit.
18. Criteria for selecting between wet/semi-wet/intermediate/and dry flue gas system are given in Table 8.
19. Monitor raw HCl and SO₂ levels upstream of dry, semi-wet, and intermediate FGT systems, using fast response monitors and use the signal generated to optimize FGT reagent dosing rates.
20. At all new and existing installations with a capacity above 150000 tonnes of waste per year, multiple layer SCR should be considered for combined NO_x and gaseous PCDD/F reduction
21. In situations where SCR is not used, combination SNCR and primary NO_x reduction measures could be used to achieve emissions to air within the permissible limit.

22. Use ammonia as NO_x reduction reagent in SNCR instead of urea.
23. For the reduction of PCDD/F use a combination of primary (combustion related) techniques to destroy PCDD/F in the waste and possible PCDD/F precursors with additional PCDD/F abatement measures.
24. For the abatement of PCDD/F, adsorption technique by injection of activated carbon into bag filtration system or using wet static coke beds shall be applied.
25. Use SCR catalytic bag filters (with additional provision made for Hg control) techniques for the destruction of gas phase PCDD/F.
26. Where wet scrubbers are used, prevent PCDD/F build up in the scrubber by adsorption on carbon impregnated materials with the subsequent re-burn of the absorbent and addition of carbon slurries to the wet scrubber with the subsequent re-burn of the spent absorbent.
27. For additional measures in reducing metallic Hg emission using wet scrubber, specific reagent is used to lowering its pH before injecting activated carbon. Static activated carbon or coke filter could be used to further reduce emission of metallic Hg.
28. For semi-wet, dry and intermediate FGT systems inject activated carbon.

7.2 Specific BAT for Municipal Waste Incineration

In addition to the generic measures given in Section 6.0 for municipal waste incineration BAT must also consider the following:

1. Store all waste, except bulk items with low pollution potential and with controlled drainage inside covered and walled buildings.
2. Mix and pre-treat the waste by first applying rough shredding in order to improve its homogeneity.
3. Maintain gas-phase combustion temperatures at a set point in the range 850 and 900°C.
4. Achieve the BAT associated emission level for all of the substances released to air, as listed in **Table 9**.

Table 8: An Assessment of the main Relevant Criteria to be Taken Into Account When Selecting the FGT Type

Criteria	Wet FGT (W)	Semi-wet FGT (SW)	Intermediate FGT (I)	Dry FGT (D)	Comments
Air emissions performance	+	0	0	-	<ul style="list-style-type: none"> in respect of HCl, HF & SO₂ wet systems generally give the lowest emission levels to air W systems are usually combined with additional dust and PCDD/F control equipment D systems may reach similar emission levels as SW & I but only with increased reagent dosing rates and associated increased residue production
Residue production	+	0	0	-	<ul style="list-style-type: none"> residue production per tonne waste is generally higher with D systems and lower with W systems
Water consumption	-	0	0	+	<ul style="list-style-type: none"> water consumption is generally higher with W systems D systems use little or no water
Effluent production	-	+	+	+	<ul style="list-style-type: none"> effluents are produced by W systems – where a suitable receptor for the salty treated effluent can be found (e.g. marine environments) this may not be a significant disadvantage
Energy consumption	-	0	0	0	<ul style="list-style-type: none"> energy consumption higher with W systems due to pump demand – and is further increased where (as is common) combined with other FGT components e.g. for dust removal
Reagent consumption	+	0	0	-	<ul style="list-style-type: none"> generally lower reagent consumption with W systems generally higher with D – but may be reduced to similar to SW & I with reagent re-circulation re-circulation is assumed to be applied with I system – without this consumption rises SW, I and D systems can benefit from use of raw gas acid monitoring.
Ability to cope with inlet variations of pollutant	+	0	0	-	<ul style="list-style-type: none"> W systems are the most capable of dealing with wide ranging and fast changing inlet concentrations of HCl, HF and SO₂. D systems generally offer less flexibility – although this may be improved with the use of raw gas acid monitoring.
Plume visibility	-	0	0	+	<ul style="list-style-type: none"> plume visibility is generally higher with wet systems (unless special measures used) dry systems generally have the lowest plume visibility
Process complexity	-	0	0	0	<ul style="list-style-type: none"> W systems themselves are quite simple but other process components are required to provide an all round FGT system, including a waste water treatment plant etc.
Costs –capital	-	0	+	0	<ul style="list-style-type: none"> additional cost of ETP for wet systems – most significant at smaller plants (<200000 t/yr)
Costs – operational	-	+	+	0	<ul style="list-style-type: none"> operational cost of ETP for wet systems – most significant at smaller plants (<200000 t/yr) higher residue disposal costs where more residues are produced, and more reagent consumed
<p>Note: + means that the use of the technique generally offers an environmental advantage in respect of the assessment criteria considered 0 means that the use of the technique generally offers no significant advantage or disadvantage in respect of the assessment criteria considered - means that the use of the technique generally offers a disadvantage in respect of the assessment criteria considered</p>					

Table 9: BAT Associated Emission Levels for Releases to Air from Municipal Waste Incinerators

Substance(s)	BAT associated emission level for releases to air in mg/Nm ³ (or as stated)			
	Value for non-continuous samples	½ hour average	24 hour average	Annual average
Total dust		1 – 15	0.5 – 2.5	1 – 2
Hydrogen chloride (HCl)		1 – 30	1 – 5	1 – 3
Hydrogen fluoride (HF)		<1	<0.5	<0.5
Sulphur dioxide (SO ₂)		1 – 50	1 – 25	1 – 10
Nitrogen monoxide (NO) and nitrogen dioxide (NO ₂), expressed as nitrogen dioxide for all installations above 150000 t/yr capacity and those below 150000 t/yr that are using SCR		40 – 220	40 – 100	40 – 100
Nitrogen monoxide (NO) and nitrogen dioxide (NO ₂) expressed as nitrogen dioxide for installations below 150000 t/yr not using SCR		30 – 220	120 – 180	120 – 180
Ammonia (NH ₃)	<10	1 – 10	<5	<5
Nitrous oxide (N ₂ O)	<15	<15	<5	1 – 2
Gaseous and vaporous organic substances, expressed as TOC		0.1 – 20	0.1 – 10	0.1 – 5
Carbon monoxide (CO)		2 – 100	5 – 30	2 – 10
Mercury and its compounds (as Hg)	<0.03	0.001 – 0.03	0.001 – 0.02	0.0002 – 0.005
Cadmium and its compounds (as Cd)	<0.003			
Arsenic and its compounds (as As)	<0.001			
Lead and its compounds (as Pb)	<0.05			
Chromium and its compounds (as Cr)	<0.002			
Cobalt and its compounds (as Co)	<0.002			
Copper and its compounds (as Cu)	<0.002			
Nickel and its compounds (as Ni)	<0.002			
Total cadmium and thallium (and their compounds expressed as the metals)	<0.03			<0.03
Σ other metals 1	<0.5			<0.05
Σ other metals 2	0.01 – 0.1			
Benz(a)pyrene				<0.001
Σ PCB				<0.005
Σ PAH				<0.01
Dioxins and furans (ng TEQ/Nm ³)	<0.05			0.002 – 0.05
Notes:				
Σ other metals 1 = sum of Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V and their compounds expressed as the metals				
Σ other metals 2 = the sum of Sb, Pb, Cr, Cu, Mn, V, Co, Ni, Se, Sn and Te and their compounds expressed as the metals				
Non-continuous measurements are averaged over a sampling period of between 30 minutes and 8 hours.				
Sampling periods are generally in the order of 4 – 8 hours for such measurements.				
Data is standardized at 11 % Oxygen, dry gas, 273K and 101.3kPa				

7.3 Specific BAT for Hazardous Waste Incineration

1. Mix and pre-treat the waste in order to improve its homogeneity and therefore combustion characteristics and burn-out by shredding drummed and packaged hazardous wastes.
2. Use feed equalization system for solid hazardous wastes.
3. Directly inject liquid and gaseous hazardous wastes.
4. Maintain gas-phase combustion temperatures at a set point in the range 850 and 1200°C, except where SCR is used.
5. Achieve the BAT associated emission level for all of the substances released to air, as listed in **Table 10**.

7.4 Specific BAT for Clinical Waste Incineration

1. Use automatic waste handling and loading systems.
2. Use water (or other fluid) cooling for grates.
3. Use water cooling for rotary kilns.
4. Maintain gas-phase combustion temperatures at a set point in the range 850 and 1200°C.
5. Achieve the BAT associated emission level for all of the substances released to air as listed in **Table 11**.

Table 10: BAT Associated Emission Levels for Releases to Air from Hazardous Waste Incinerators

Substance(s)	BAT associated emission level for releases to air in mg/Nm ³ (or as stated)			
	Value for non-continuous samples	½ hour average	24 hour average	Annual average
Total dust		1 – 15	0.5 – 2.5	<2
Hydrogen chloride (HCl)		1 – 30	1 – 5	<2
Hydrogen fluoride (HF)		<1	<1	<1
Sulphur dioxide (SO ₂)		0.1 – 100	0.1 – 50	0.1 – 5
Nitrogen monoxide (NO) and nitrogen dioxide (NO ₂), expressed as nitrogen dioxide for all installations above 150000 t/yr capacity and those below 150000 t/yr that are using SCR		50 – 220	50 – 100	50 – 100
Nitrogen monoxide (NO) and nitrogen dioxide (NO ₂), expressed as nitrogen dioxide for installations below 150000 t/yr not using SCR		50 – 220	120 – 180	120 – 180
Ammonia (NH ₃)	<10	1 – 10	<5	<5
Nitrous oxide (N ₂ O)	<20	<20	<10	<5
Gaseous and vaporous organic substances, expressed as TOC		0.1 – 20	0.1 – 10	<2
Carbon monoxide (CO)		10 – 100	10 – 30	<15
Mercury and its compounds (as Hg)	<0.03	<0.03	<0.02	<0.005
Cadmium and its compounds (as Cd)	<0.003			
Arsenic and its compounds (as As)	<0.001			
Lead and its compounds (as Pb)	<0.05			
Chromium and its compounds (as Cr)	<0.002			
Cobalt and its compounds (as Co)	<0.002			
Copper and its compounds (as Cu)	<0.001			
Nickel and its compounds (as Ni)	<0.002			
Total cadmium and thallium (and their compounds expressed as the metals)	<0.05		<0.05	<0.005
Σ other metals 1	<0.5		<0.5	<0.1
Σ PCB	<0.001			<0.001
Σ PAH	<0.001			<0.001
Dioxins and Furans (ng TEQ/Nm ³)	<0.05			0.002-0.05

Notes: Σ other metals 1 = sum of Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V and their compounds expressed as the metals Σ other metals 2 = the sum of Sb, Pb, Cr, Cu, Mn, V, Co, Ni, Se, Sn and Te and their compounds expressed as the metals Non-continuous measurements are averaged over a sampling period of between 30 minutes and 8 hours. Sampling periods are generally in the order of 4 – 8 hours for such measurements. Data is standardised at 11 % Oxygen, dry gas, 273K and 101.3kPa

Table 11: BAT Associated Emission Levels for Releases to Air from Clinical Waste Incinerators

Substance(s)	BAT associated emission level for releases to air in mg/Nm ³ (or as stated)			
	Value for non-continuous samples	½ hour average	24 hour average	Annual average
Total dust		1 – 15	0.5 – 2.5	<2
Hydrogen chloride (HCl)		1 – 50	1 – 5	<2
Hydrogen fluoride (HF)		<2	<1	<1
Sulphur dioxide (SO ₂)		0.1 – 100	0.1 – 50	0.1 – 5
Nitrogen monoxide (NO) and nitrogen dioxide (NO ₂) expressed as nitrogen dioxide for all installations above 150000 t/yr capacity and those below 150000 t/yr that are using SCR		50 – 220	50 – 100	50 – 100
Nitrogen monoxide (NO) and nitrogen dioxide (NO ₂) expressed as nitrogen dioxide for installations below 150000 t/yr not using SCR		50 – 220	120 – 180	120 – 180
Ammonia (NH ₃)	<10	1 – 10	<5	<5
Nitrous oxide (N ₂ O)	<20	<20	<10	<5
Gaseous and vaporous organic substances, expressed as TOC		0.1 – 20	0.1 – 10	<2
Carbon monoxide (CO)		10 – 100	10 – 30	<15
Mercury and its compounds (as Hg)	<0.03	<0.03	<0.02	<0.005
Cadmium and its compounds (as Cd)	<0.003			
Arsenic and its compounds (as As)	<0.001			
Lead and its compounds (as Pb)	<0.05			
Chromium and its compounds (as Cr)	<0.002			
Cobalt and its compounds (as Co)	<0.002			
Copper and its compounds (as Cu)	<0.001			
Nickel and its compounds (as Ni)	<0.002			
Total cadmium and thallium (and their compounds expressed as the metals)	<0.05		<0.05	<0.005
Σ other metals 1	<0.5		<0.5	<0.1
Σ PCB	<0.001			<0.001
Σ PAH	<0.001			<0.001
Dioxins and furans (ng TEQ/Nm ³)	<0.05			0.002 - 0.05

Notes: Σ other metals 1 = sum of Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V and their compounds expressed as the metals Σ other metals 2 = the sum of Sb, Pb, Cr, Cu, Mn, V, Co, Ni, Se, Sn and Te and their compounds expressed as the metals Non-continuous measurements are averaged over a sampling period of between 30 minutes and 8 hours. Sampling periods are generally in the order of 4 – 8 hours for such measurements. Data is standardized at 11 % Oxygen, dry gas, 273K and 101.3kPa

8.0 MONITORING AND REPORTING FORMAT

8.1 Monitoring Emissions

(a) The following emission compounds are to be measured on a continuous basis:

- dust
- HCl
- SO₂
- CO
- C_xH_y
- NO_x (if emission standards apply)
- HF (but not if the process ensures adequate HCl- removal).

(b) Additionally, the following process parameters need to be monitored continuously:

- Furnace temperature
- O₂
- Pressure
- Flue-gas outlet temperature
- Water vapour content (unless emission measurements are executed in dried flue-gas).

(c) Other emission compounds to be measured on a regular basis (minimum of 2 to 4 times per year) are:

- heavy metals
- PCDD/F.

REFERENCES

1. European Integrated Pollution Prevention and Control Bureau (EIPPCB), (August 2006). Best Available Techniques (BAT) Reference Document for Waste Incineration. Joint Research Centre, Institute of Prospective Technological Studies, EIPPCB