BASEL CONVENTION TECHNICAL GUIDELINES ON INCINERATION ON LAND

Basel Convention on the Control of Transboundary Movements on Hazardous Wastes and Their Disposal

No. 4

UNEP

Basel Convention
Technical Guidelines on Incineration on land

Basel Convention series/SBC No. 02/04
First Published in 1997 and
reprinted in November 2002

Sales No. E.02.III.D.204

ISBN : 92-1-158604-6

ISSN : 1020-8364

Printed in chlorine-free cyclus paper

This Publication is available from:

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International Environment House
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BASEL CONVENTION
ON THE CONTROL OF TRANSBOUNDARY MOVEMENTS OF
HAZARDOUS WASTES AND THEIR DISPOSAL

UNEP

SECRETARIAT

TECHNICAL GUIDELINES ON INCINERATION ON LAND D(10)

Revised Version
These Technical Guidelines were prepared by the
Technical Working Group of the Basel Convention and
adopted by the third meeting of the Conference of the Parties
to the Basel Convention in September 1995, Geneva

Foreword

These technical guidelines are principally meant to provide guidance to countries who are building their capacity to manage waste in an environmentally sound and efficient way and in their development of detailed procedures or waste management plan or strategy. They should not be used in isolation by the competent authorities for consenting to or rejecting a transboundary movement of hazardous waste, as they are not sufficiently comprehensive for environmentally sound management of hazardous waste and other waste as defined by the Basel Convention. These technical guidelines concern waste generated nationally and disposed of at the national level as well as waste imported as a result of a transboundary movement, or arising from the treatment of imported wastes.

It is necessary to consider this document in conjunction with the Document on Guidance in developing national and/or regional strategies for the environmentally sound management of hazardous wastes (SBC Publication - Basel Convention Highlights No. 96/001 - December 1995) adopted by the second meeting of the Conference of the Parties. In particular, special attention should be given to the national/domestic legal framework and the responsibilities of the competent authorities.

These guidelines are meant to assist countries in their efforts to ensure, as far as practicable, the environmentally sound management of the wastes subject to the Basel Convention within the national territory and are not intended to promote transboundary movements of such wastes.

CONTENTS

PREAMBLE

1. These technical guidelines on Incineration on Land are not intended to be used as a guide to treatment and disposal technologies. While these technical guidelines may contain valuable information with regard to thermal processes control and management procedures, they do not provide for a selection of preferred environmentally sound or recommendable technological options or methods.

2. These guidelines must not be regarded as providing a "once-and-for-all" indication of appropriate action. They provide a review of available options with an assessment of their scope. They require regular update in line with developing circumstances.

3. As a consequence of this, they should not be regarded as prescriptive or a clear recommendation to use the options presented in all cases. The draft technical guidelines provide background information for guidance in the decision making process.

4. These technical guidelines refer to both industrial and hazardous wastes. According to its origin, waste is classified as municipal waste, agricultural waste or industrial waste. According to its characteristics, waste is classified as hazardous or non-hazardous waste. It is obvious that a number of industrial wastes will be defined as hazardous wastes by the Basel Convention (see Annex I to the Convention) if they exhibit one or more of the hazardous characteristics identified in Annex III to the Convention. These guidelines focus on the disposal of hazardous wastes.

I. INTRODUCTION

5. Incineration is a high temperature, thermal treatment process in which hazardous wastes are converted into gases and essentially incombustible solid residue. A high level of technical competence is required in designing, operating and monitoring an incineration facility. It is an integrated activity involving a number of process operations (feed reception, control and preparation - actual combustion stage - treatment of combustion products, waste gases and residues). The options available within these process operations can be combined in various ways to meet the technical needs of a wide range of circumstances. Thermal treatments are of three main kinds:

- incineration;
- pyrolysis;
- other thermal processes (i.e. thermal oxidation).

Thermal oxidation or process is by far the most used method for the treatment of hazardous wastes and is the subject matter of these draft technical guidelines.

6. Incineration has been used, particularly in Europe and the U.S.A., to treat hazardous wastes for many years. Incineration's main advantage is that it permanently destroys many of the hazardous characteristics of the waste. This process is accompanied by a substantial reduction in the weight and volume of industrial wastes being incinerated. For municipal wastes there is typically a weight reduction of up to 2/3 and volume reduction of up to 90%. Increasingly, incinerators also are being designed or modified to recover the energy potential in hazardous wastes. The more commonly employed combustion systems are described in Section III. Figure I on page 4 provides a general overview of incineration subsystems; it should be noted that not every

process referred to in the table is suitable for hazardous wastes. Hazardous waste incinerators have the potential to destroy hazardous pollutants such as PCBs, PCDDs or PCDFs. However, it should be noted that unless high technology emission control equipment is used and properly managed, hazardous waste incinerators could act as a significant source of such substances to the environment.

7. The two kinds of incinerator most commonly experienced are those burning municipal and industrial wastes. The former, because of the nature of the material being handled, work on the mass burn principle. The waste collected from households is normally stored in large bunkers, which provide a buffer on what is usually a tidal flow situation in respect of material reception. Material is usually removed from these bunkers by grab cranes, which are used to select and mix it. Operators become very skilled at doing this. After contraries (bulky objects, massive non-combustible material etc.) have been removed, it is then fed via feed hoppers into the incinerator. These are more usually of the inclined moving grate type where the mass moves down the grate under the effect of gravity and mechanically imported, often reciprocating, motion which is designed to turn the material over to expose new surface for combustion. They typically operate at $850^{o}C$ and by the nature of the operation, require well-directed overbed secondary air to ensure efficient combustion of the waste. The exhaust gases, after being put through a boiler to recover energy, are usually passed after conditioning with water to an electrostatic precipitator to remove suspended particulates that usually carry absorbed and adsorbed residual organic matter. In some cases, dry lime injection is practised prior to the electrostatic precipitator to neutralise acid components and sometimes wet gas scrubbing is used after the electrostatic precipitator to reduce acidic or other emissions to lower levels of contaminants. Rotary kilns have and are sometimes used for the incineration of municipal waste but they are much less common than the moving hearth type.

8. Industrial incinerator types range from the relatively uncomplicated and inexpensive cyclonic units - which can be used in series and/or in parallel to increase residence time and/or through put; because of their inability to handle significant amounts of solid residues they tend to be used for gases, liquids and sludges which are principally organic - to the rotary kiln type with afterburner chamber. These have great flexibility in terms of the physical form and nature of the wastes they can handle. They can readily handle liquid and solid wastes (even in drums) but are expensive to build and operate. Industrial incinerators if properly designed and equipped are capable of handling hazardous wastes. Industrial waste incinerators operate at higher temperatures than municipal waste units- $850^{o}C$-$1300^{o}C$.

9. Other types of incinerators are represented by fixed hearths, used for sludges, pastes and material in drums, multiple hearths, used mainly for sludges and fluid beds, which are used for sludges and acid tars.

II. THE INCINERATION PROCESS

10. The incineration process detoxifies hazardous wastes by destroying most of the organic compounds contained in the wastes and reduces the volume of wastes with any inert residual solids. Organic compounds (compounds composed of carbon, hydrogen, and sometimes other elements) burn over a broad range of temperatures, forming carbon dioxide, water and products of incomplete combustion, some of which may be more toxic than the original waste but there would be a much smaller quantity of such products. Wood, oil, and coal, for example, are all composed of organic compounds that effectively combust at relatively low temperatures. Some organic compounds,

including some found in certain hazardous wastes, combust less readily and must be subjected to higher temperatures before they are fully combusted. As a consequence, to ensure maximum destruction of the organic compounds in the wastes, hazardous waste incinerators must maintain extremely high temperatures (typically ranging from 850^{o}C to 1300^{o}C) and have adequate residence time. Incinerators are heat release limited and therefore are not as efficient in terms of energy recovery as steam-raising boilers.

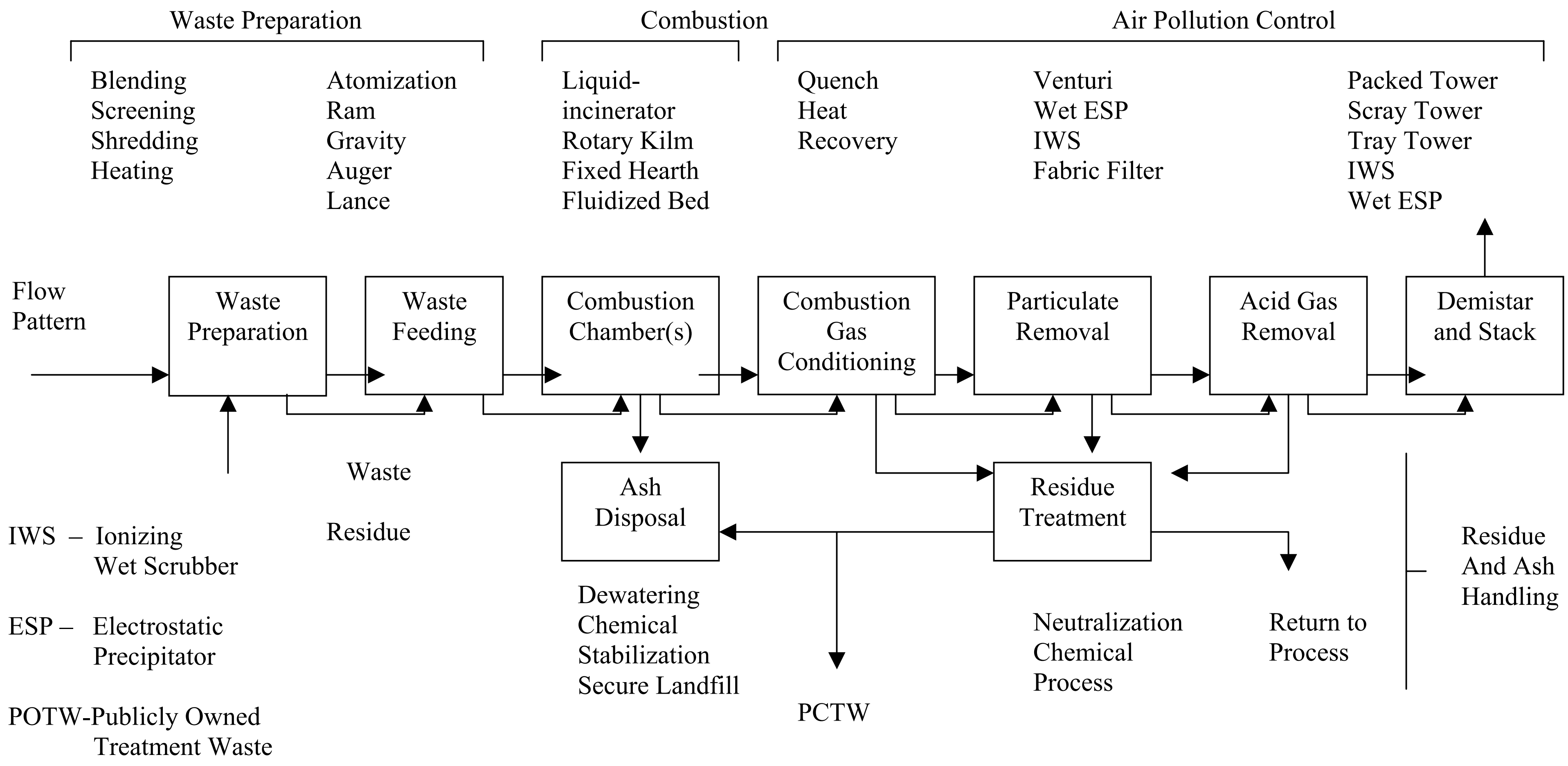
11. The physical state of the waste, i.e., liquid or solid, is an important factor influencing the mechanisms of combustion reactions. The efficiency of combustion of the waste is further governed by its physical/chemical properties, combustion air, temperature, residence time and mixing. Important chemical/physical properties of a fuel which affect its combustion characteristics are elemental composition, moisture and energy content. Constituents of the waste affect air emissions and the primary combustion and secondary control equipment required. For example, sulphur or chlorine content will influence sulphur dioxide and hydrogen chloride levels released from the combustion process which will require removal and neutralization. Likewise, chlorine in the waste may contribute to the formation of PCDDs and PCDFs, and it is noted that some metal chlorides are more volatile than oxides.

12. In the case of liquids, flow characteristics as well as size and concentration of suspended solids in the liquid are the most important physical properties that govern its combustion characteristics. The liquid must be converted to a gas before combustion occurs, and gasification must be rapid for high combustion efficiency. To enhance vaporization in the combustion chamber, the liquid is atomized into small droplets at the point of air/fuel mixing by the burners. Atomization is more efficient with low viscosity fluids than with high viscosity fuels. Suspended solids in the fuel can cause problems with plugging, erosion or build-up in the burners.

13. The size and nature of particles in suspension in the gas stream will influence the rate of combustion of solids. Systems are often designed to volatilize the solid contained in the hearth in one chamber and incinerate the resulting gases in an after-burner unit. Special treatment (e.g. shredding) is often necessary to provide as uniform a feed as possible when incinerating solids.

14. The energy content of the waste is fundamental to the design and operation of an incineration system. For efficient incineration, an adequate supply of combustion air is essential. Perfect mixing is difficult to achieve, so excess air needs to be supplied to ensure efficient combustion. Excess air causes cooling and therefore needs to be carefully controlled. One factor influencing the excess air required is determined by the degree of mixing achieved in the combustion chamber and the desired temperature and allowable flow rate of combustion gases. The operating temperature must be high enough to provide maximum combustion, but low enough to prevent damage to the combustion chamber, in particular the refractories. Heat transfer, mass transfer and reaction rates will increase with temperature. Therefore, for a given residence time and mixing regime, higher temperatures lead to more efficient combustion. The choice of temperature, residence time and turbulence for efficient destruction of a waste is presently determined through experience which includes testing as opposed to prediction.

FIGURE 1. GENERAL OVERVIEW OF INCINERATION SUBSYSTEMS AND TYPICAL PROCESS COMPONENT OPTIONS



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15. The residence time is the length of time the waste is exposed to the temperatures required for the destruction of the waste. Residence time for effective combustion in gas-phased combustion usually takes a matter of seconds, whereas for solids in the hearth it can take up to several hours. Residence time, temperature and combustion air requirements all depend on the degree of mixing achieved in the combustion chamber, which is a function of the specific burner design, flow pattern in the combustion chamber and turbulence achieved.

16. Failures to achieve high destruction efficiency have often been linked to problems with flow patterns in the high temperature zone of the combustion chamber or other design problems which need to be further investigated and have resulted in the increased discharge of products of incomplete combustion (PICs) from the system. This problem can be minimized by using a device that has adequate turbulence in the combustion chamber.

III. COMMONLY EMPLOYED COMBUSTION SYSTEMS

17. Exhaust gas temperatures from the incineration systems are typically as high as 1100^0C. At these temperatures, most of the operating costs can be related to fuel costs. Waste heat recovery represents one method for reducing operating costs.

Combustion requirements:

- The temperature must be high enough to produce enough combustible gases (incineration temperature);
- There must be enough oxidant (air) for thorough oxidation to occur;
- The vapour and air must be efficiently mixed;
- The vapour/air mixture must be held at a high enough temperature for long enough for complete oxidation to occur (residence time).

These requirements are often referred to as the 3Ts: the Temperature must be high enough, there must be enough Turbulence in the combustion gas mixture and it must be held at these conditions for a long enough Time.

18. It is possible to specify residence time, incineration temperature and excess air requirements as design parameters for an incineration plant. But the mixing aspects of an incinerator and waste material are empirically different for each waste and each incinerator. Thus, specification of time, temperature and gas air/mixing is needed but is not necessarily satisfactory to ensure maximum destruction of the waste. A reliable test burn is desirable for each new waste material to determine the incineration characteristics. Previous experience on the incineration of similar wastes is also a source of valuable information. A combination of test burns data and previous experience is useful in ensuring the most appropriate design of incinerators. Finally, hazardous waste disposal systems can be cost effective if designed and installed having regard to the total economics included in the facility design.

19. Incinerators are designed according to the types of wastes they burn. Therefore, understanding the characteristics of different waste streams and hazardous constituents of wastes is necessary to ensure proper selection and design of the thermal process to be used. Figure 2 on page 7 describes typical incinerator processes and Figure 3 on page 8 represents a typical state-of-the-art of an industrial waste incineration unit. Modern incinerators are, in fact, a large-scale industrial process which requires careful management, high safety measures and to be operated under stringent regulation.

20. Solid and liquid residues from the incineration process often contain hazardous constituents, and should be treated with appropriate caution. These residues include slag from the furnace, fly ash and liquids from the gas cleaning plant. Liquids should be treated to remove hazardous constituents before discharge or re-use. Solids should either be recycled or disposed of. Recycling could include, for example, their incorporation into concrete. Care must be taken not to impair the quality of the concrete and to ensure that hazardous constituents are properly bound into the matrix. Disposal must be carried out in an environmentally sound manner, having proper regard to the hazards of the materials, and wherever possible reducing those hazards by pre-treatment.

Main types of incinerators

Rotary Kilns:

21. These consist of a refractory lined cylinder which rotates at a very low speed, typically 5-15 revolutions per hour, and is mounted on a slight incline so that solid materials introduced at one end will move through the kiln and be discharged at the other end. A burner is mounted at the same end of the kiln as the solid feed mechanism. The burner is fired with, for example, natural gas, oil or waste solvents.

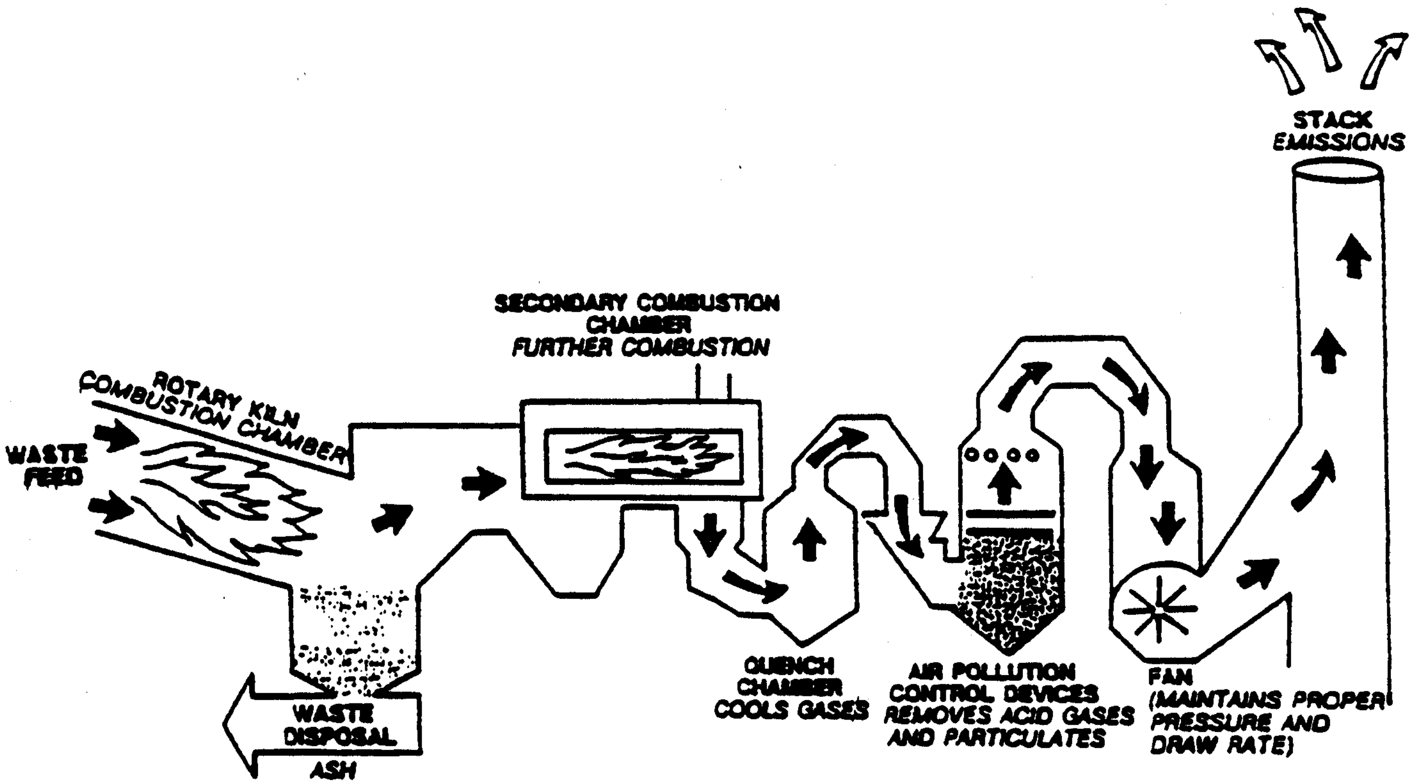
The major advantage of the rotary kiln is its ability to handle solid wastes of widely varying sizes, liquid wastes using atomizing burners centrally located at the inlet end of the kiln, high moisture content wastes and sludge-like materials, and materials which form molten slags, whilst ensuring good mixing and break up of the material.

Liquid Injection Systems:

22. The least complex of all hazardous waste incinerators are the liquid injection systems. Where liquid wastes are being burned, they are normally introduced through atomizing burners where they are intimately mixed with combustion air, elevated in temperature to about 1100"C, maintained in contact with excess air for between 1.5 and 2 seconds. Firing can be axial or tangential into one or more combustion chambers which can be arranged in series or in parallel configuration. The exhaust gases then pass through a secondary emission control system. Frequently, only a single refractory lined chamber is used for the entire combustion process with no afterburner being required. Supplementary fuel can be mixed with the waste or can be introduced through a separate orifice in the burner to maintain the required temperature for complete destruction of the waste components.

One of the key components of efficient operation of these systems is the design of the burner. However, the design of the chamber is also important because of the need to ensure a guaranteed residence time at a desired temperature. Most of the burners which have been designed especially for waste materials introduce air in a vortex section surrounding the liquid atomizing nozzle. This creates intimate mixing of the vaporized fuel and waste materials and the combustion air, yielding uniform flame temperatures and high destruction efficiencies.

FIGURE 2 TYPICAL INCINERATOR PROCESSES (ROTARY KILN)



From: "US Environmental Protection Agency - Office of Solid Waste, April 1988. Hazardous Waste Incineration: Questions and Answers."

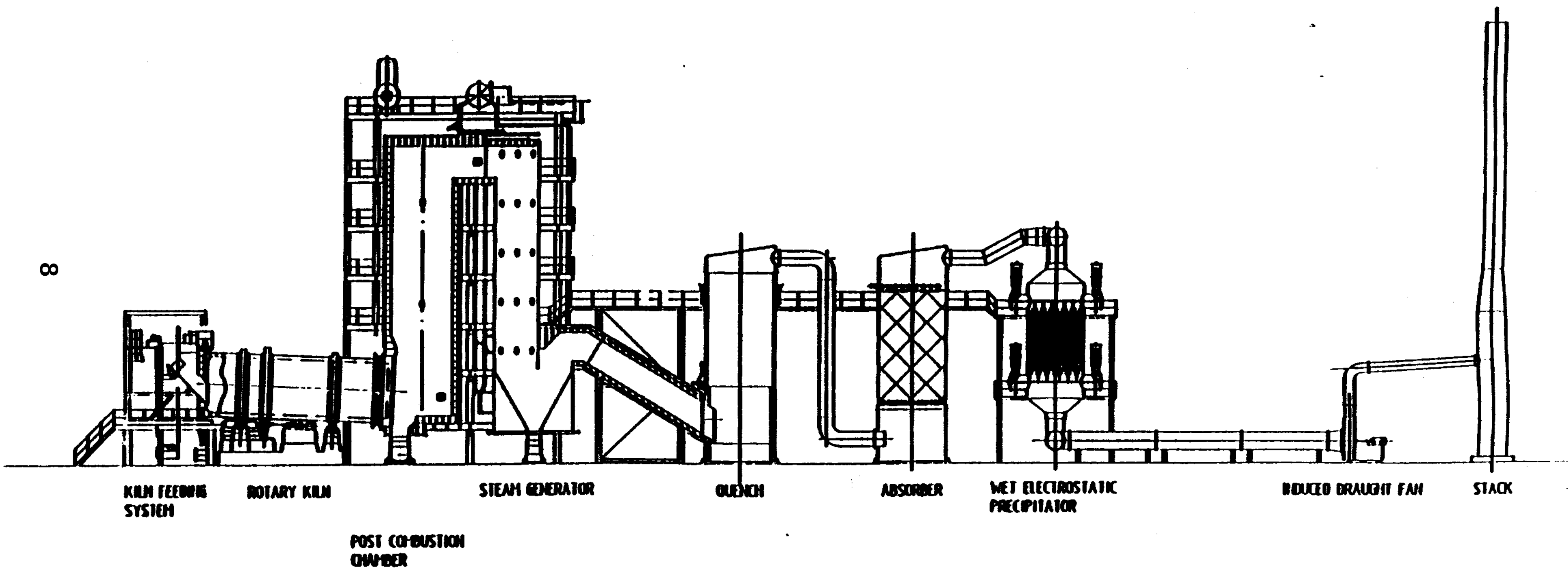


FIGURE 3

SECTIONAL ELEVATION OF INDUSTRIAL WASTE INCINERATION UNIT

Multiple Hearth Furnaces:

23. Multiple hearth furnaces are being used for the very high moisture content solid materials, or for sewage materials which must be dried before they burn completely. Combustion gases are discharged to air pollution control systems while the solids are discharged through ash hoppers at the bottom of the furnace.

Fluid Bed Combustors:

24. Advantages offered by fluid bed combustors over other hazardous waste incineration systems are: a) they have a high thermal inertia which provides for a close control over the operating temperature; b) they allow for efficient destruction at a lower temperature than required in other systems; c) they allow for the possibility of the introduction of solid absorbent materials simultaneously with the waste feed to absorb acid gases during the combustion process, rather than after the combustion process. In addition, solids residence time can be controlled by simply decreasing the feed rate and the ash removal rate while maintaining a constant temperature. This allows control over organic "burn-out", which is normally not possible with the other systems. If acid gases are expected as products of combustion, lime or limestone can also be added to the feed material and will absorb the acid gases during the combustion process. Most of the entrained solid material is then removed by a primary cyclone collector before pollution control systems remove residual particulate matter. Normally, secondary acid gas absorbers are not needed since the absorbent materials in the bed accomplish this same acid gas removal.

Primary limitations of fluid bed units are that the waste material must be of relatively uniform particle size and feed materials must not be capable of producing a molten phase in the unit. Conventional fluid bed incinerators are not normally capable of sustaining the temperature required for the efficient destruction of the more thermally stable species of hazardous wastes (i.e. PCBs).

"Starved Air" Systems:

25. Any combustion system could be operated in this mode, which normally involves two stages, a starved air chamber and an oxidative after burning chamber. Such a system needs to be carefully designed for burning hazardous wastes. Some countries prohibit its use for the disposal of hazardous wastes. However, the most commonly used are the rotary kiln and fixed hearth onto which the solids are introduced via a ram feeder. The same ram feeder also pushes the ash material towards the discharge end of the hearth. Combustion air is controlled to provide for essentially no excess air. Only enough air to burn the fuel and some of the organic waste material is introduced. Such units are frequently used where there are only small mass flow rates. These systems are not normally used for waste materials which melt during the combustion process or when solid objects are being handled. The gas flows in the first step are relatively small.

Co-incineration in industrial facilities

26. Several industrial processes can provide temperatures and residence times similar to those required for hazardous waste incinerators. Examples include cement, lime, lime and aggregate kilns, industrial boilers and blast furnaces. However, the burning of hazardous waste in such facilities generates air emissions of products of incomplete combustion, including PCDDs and PCDFs, as well as volatile heavy metals. Likewise, these contaminants can be found in the products, such as cement and aggregate, of such facilities. Though there is a body of operational experience it is generally limited, but a number of trials and feasibility studies and tests have demonstrated that co-incineration in some industrial facilities with high-temperature combustion processes can provide a cost-effective and a technically acceptable alternative to the disposal of

hazardous wastes in dedicated incinerators. Where the process involves the manufacture of a product, the use of hazardous waste as a fuel can affect its quality and this can necessitate restrictions as to which types of wastes can be used. In consequence of this there is a need for careful analysis, particularly in respect to deleterious contaminants and close monitoring of such a "substitute" fuel. Great care should be taken in operating co-incineration in view of meeting both industrial production and environmental protection requirements. These industrial processes have the potential for recovering the heating value of the waste, removing chlorides, and providing a destruction and removal efficiency equivalent to hazardous waste incinerators.

27. The advantages of this approach are that:

- high capital investment in new, dedicated hazardous waste incinerators is not needed; however, some ancillary equipment is invariably required to ensure environmentally sound operations;
- existing processes can reap extra economic benefits, since the income of accepting and destroying wastes is credited against process costs;
- provides low cost fuel to energy intensive operations;
- can generate energy.

The disadvantages are that:

- the introduction of waste streams into an existing high-temperature facility has the potential to disrupt the process or degrade the product unless the waste stream is carefully studied and defined as being suitable for co-incineration. A thorough investigation and good scientific evidence is essential if plant management is to be persuaded to modify an existing, proven process;
- the lack of adequate gas cleaning equipment on many types of plants (e.g. boilers) necessitates careful selection and control of waste inputs;
- the difficulties involved in controlling the amount and quality of the wastes subject to this disposal option.

Control of Emissions

28. Although air pollution is perceived as presenting the most serious risks, this is not always the case. There is increased concern about the risk posed by the deposition and uptake of airborne pollutants on the food chain as well as inhalation of air pollutants. Waste streams from gas cleaning and ash/slag from the combustion chamber can present problems if the operation is not properly controlled. The primary method of controlling air pollution should be to use a well designed, constructed, managed, operated, monitored and maintained incinerator appropriate to the waste being burned.

29. There are a number of basic methods commonly used to reduce ground level risks of pollution.

- Site selection. It should be subject to an environmental impact assessment. The incinerator should be sited away from targets sensitive to air pollution effects. The site should lie within a topography that will permit effective and rapid atmospheric dispersion;

- Chimney height. The effluent gases should be discharged at a point sufficiently above ground level to permit dilution and dispersion of the effluent gases before the plume meets the ground;

- Appropriate technical measures must be taken to reduce the emissions of PCDDs and PCDFs from combustion gases to the lowest possible level. These include provisions for good turbulence of the combustion gas, high temperature, adequate oxygen-content, adequate residual time and the quick cooling-down of the flue gas in order to prevent *de novo* synthesis of PCDDs and PCDFs. Also, Denox-equipment normally reduces the content of PCDDs and PCDFs. If necessary, additional equipment, e.g. for the insertion of activated carbon should be installed;

- Equipment should be installed to reduce the emission of acidic combustion gases to a low level;

- Equipment should be installed to reduce the emissions of PCDDs and PCDFs from combustion gases to the lowest possible level, e.g. with the insertion of activated carbon to gas cleaning;

- Waste selection: elimination to the maximum extent possible of those elements that cannot be removed by appropriate technologies.

In addition, proper siting of the facility away from targets sensitive to air pollution effects can assist in minimizing potential impacts to humans and food sources.

30. The incineration of hazardous wastes can result in the production of harmful substances, in particular organic compounds, HCI, HF and heavy metals and particular organic compounds like halogenated dioxins and furans which are considered highly dangerous. To protect public health and the environment as much as possible against pollution resulting from the incineration of hazardous wastes, very stringent waste selection procedures and emission standards should be set and efficient abatement techniques applied. The pollutants removed from the exhaust gas by wet treatment methods should not be discharged with the waste water, but should be processed at the plant site. Any discharge of waste water from the plant has to be subjected to a permission by the authority concerned and in compliance with existing standards. It should be noted also that there is a risk of water pollution arising from the leaching of residues from incineration.

31. In the last few years, the development of reduction techniques in the field of waste incineration have progressed so rapidly that more stringent emission limit values can and have to be fixed. The establishment of such stringent emission limit values as advocated, for instance in the Proposal for the European Communities Council of Ministers Directive on the Incineration of Hazardous Waste (COM(92) 9 final-SYN UOG Brussels, 19 March 1992), implies the access and use of recently developed techniques and technologies. Given the stringent emission limit values,

correspondingly low concentrations of certain pollutants must be measured continuously by means of high quality measurement equipment and appropriate reference measurement methods for the calibration of this equipment. Stringent effluent values would also be required. In this directive are to be found emission standards as well as costs of incinerators. It should however be noted that there is considerable concern regarding the non-availability of reliable commercial systems to continuously measure some of the specified materials at the levels required within acceptable confidence intervals and, in some cases, the practicability of making meaningful measurements.

32. Proper combustion will minimize CO (carbon monoxide) levels and the emissions of organics, including toxic halogenated compounds. However, a post-combustion air pollution control system is also necessary to further reduce the emission of the trace organics, volatile heavy metals and particulate matter. The temperature profile in the gas management system will need to be taken into consideration. Such factors as dew point corrosion and the possibility of synthesis of undesirable products such as polychlorinated dioxins (PCDD) and polychlorinated furans[1] (PCDF).

33. In addition to the production of gaseous emissions which must be controlled in accordance with air pollution control regulations, incinerators also produce ashes and particulate emissions (with adhering metals and organics) which must be disposed of. Ash and other solid residue discharged from a hazardous waste incineration facility may be considered hazardous in national/domestic legislation and it would be prudent to manage them as such, unless it can be proved that they are not. In particular, landfilling of residues from incineration requires special attention because of their potential for leaching.

34. Many air pollution control devices use water for gas cleaning (quenching and scrubbing), thus creating wastewaters containing the pollutants that have been removed from the gases (see note on dry and wet scrubbing of incinerator combustion gases Annex 1). Requirements for wastewater discharges placing limits on temperature, pH (a measure of the strength of an acid or alkaline) quantity of suspended solids, and pollutant levels need to be legally fixed. Any wastewater from the incinerators must be treated before being disposed of or released to a water or sewer system. Possible treatments include settling metals, precipitation and neutralization. In the first instance, the facility should be designed so as to minimize the discharge of process wastewater; where this is compatible with atmospheric emissions. Stack discharge limits have to be specified and by maintaining emission concentrations within specified limits for the selected contaminants, low emission levels for a number of other contaminants will also be achieved.

35. Adequate precautions should be taken to minimize fugitive emissions from the handling and transfer of incinerator ashes. These measures should include the damping of and the use of closed systems to handle fine dry materials and closed or covered watertight containers for the transfer of residues from the plant to the disposal site. Bottom ashes/klinkers and fly ashes produced as by-products in incineration processes can present problems in their own right. For instance, metal oxides and halides produced in the incineration process and present in these ashes can have environmentally significant water solubilities. Also the products of incomplete combustion and synthesis in the exhaust gases which have environmental impact potential can be absorbed and adsorbed onto the fly ashes. As a result of the problems caused by the presence of water soluble compounds in these ashes they are being increasingly subjected to insolubisation processes such as

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[1] Some PCDDs are poisonous. They can have the capacity to provoke cancer and reinforce the carcinogenetic properties of other chemical substances.

solidification and now some modern incinerator units have the internal facility to convert bottom ashes i.e. those coming from the combustion hearth into non-leachable glass like products. Also, where there are similar problems with the fly ashes coming from the gas cleaning system, it is proposed to subject them to an external vitrification process.

36. Noise levels in particular from fans and pumps associated with hazardous waste incineration facilities shall be controlled, limited and at least consistent with ambient levels associated with the industrial or local environment where the facilities are to be located.

37. The best management practices in terms of design, construction and maintenance are necessary to minimize both the potential for air emission particulates and trace metal migration into the environment contamination of wastewaters and the exposure of workers to materials that may endanger their health. Measures should be taken to ensure that the facility used for temporary storage and pre-processing of hazardous wastes prior to incineration be designed and managed in such a way as to avoid or minimize contamination of the environment through emission of dust, volatile substances and odours.

38. The very stringent provisions which must be satisfied in respect of the building and operating of a hazardous waste incineration plant necessitate very substantial investment costs. Additional costs should be taken into account if a treatment of the residues on site is necessary.

Problems experienced with incinerator operations

39. Heat recovery/power generation, although practised in connection with the incineration of municipal wastes can present problems. These problems can be even more serious in the case of industrial wastes becoming the energy source. This comes from the fact that apart from single stream arisings, which are frequently incinerated in dedicated onsite plants, industrial wastes of the type handled by contract incinerators tend to be heterogeneous mixtures of variable composition and properties. This tends to make them indifferent fuels and, though blending can be employed to obtain consistency in terms of energy value (CV), inorganic components frequently present can give rise to severe fouling problems in the heat exchanger systems; thus reducing energy recovery efficiency and presenting maintenance problems. In some cases by-pass systems have had to be fitted to allow for the ongoing operation of the incinerator during the necessary frequent cleaning and maintenance of the energy recovery system.

Other problems experienced with incinerator operations

40. A major issue, frequently not given sufficient consideration, is material handling. This is particularly important where solid wastes are involved as considerable problems can arise in feeding them into incinerators and in removing the solid products of combustion. Serious problems might occur with the incineration of small drums containing gaseous wastes. When incinerated in large quantities, a chain reaction may occur in the combustion chamber with the possible effect of deteriorating it. Consequently, such small drums should be fed into the incineration plant one by one. It is even preferable to open the drums beforehand. Short circuiting occurs when materials being incinerated, particularly in cyclonic units, take a shorter than intended path through the incinerator which results in a reduced residence time at the desired temperature. The fitting of baffles to such units which produces reversed flow can overcome this problem. Deterioration of refractories: this can be caused by the refractions or the cements used to locate them being attacked by aggressive materials such as molten aluminium or alkaline salts, or by the reduction in

mechanical properties resulting from phase changes in the refractory material brought about by thermal cycling. This is one of the reasons why incinerators are best operated continuously and maintained at operating temperature rather then being started up and shut down. Acid corrosion of gas cleaning systems: this results from wet acid gases being allowed to drop to temperatures below the dew point.

41. Fugitive emissions of waste chemicals may be released due to improper management during waste transfer and handling, posing threats to public health and the environment that rival those from stack emissions. Spills and accidents during incinerator operations may require extensive clean-up. Such problems are also relevant to other disposal options.

IV. SELECTION OF WASTES FOR INCINERATION

42. A well-designed hazardous waste incinerator that is properly operated will destroy all but a small fraction of the organic compounds contained in the waste. Such incinerators perform at levels extremely close to complete combustion (that is, the total destruction of all organic compounds), and new technology is being developed that will improve upon current levels of performance. Complete combustion, however, is only a theoretical concept being contrary to the laws of nature so the development of a 100 percent efficient incinerator is not possible. The combination of the most efficient combustion and gas cleaning systems can, however, reduce the release of undesirable contaminants virtually to the maximum extent possible.

43. Understanding the characteristics of different waste streams is necessary to ensure proper selection and design of the incineration system. Based on the thermal ratings, there are two basic waste classifications: high heating value waste, which is usually self-combustible and does not require supplementary fuel, and low heating value waste, which is not normally combustible without the addition of support fuel. Another method of classification is to define the waste according to its chemical make-up. The categories used are: organic, halogenated, metallic, aqueous, nitrogen-containing.

44. Incinerators can be designed to accept wastes of any physical form, including gases, liquids, solids, sludges (thick, heavy mixtures of liquids and solids), and slurries (thin mixtures of liquids and solids). Although many types of wastes can be incinerated, incineration is primarily for the treatment of wastes that contain organic compounds. However, wastes consisting principally of inorganic material but with low concentration of organic contaminants may also be beneficially subjected to incineration to destroy the organic part. Wastes with a wide range of chemical and physical characteristics are suitable for incineration. Most of these wastes are by-products of industrial manufacturing and chemical production processes or result from the clean-up of contaminated sites.

45. Incineration is one of the appropriate options if a waste stream is hazardous to man or the environment, resistant to biodegradation and persistent in the environment, volatile, has a low flash point, cannot be safely disposed of in a secured landfill or treated by any other available or proven method particularly where it contains organically bound halogens, heavy metals, nitrogen, phosphorus or sulphur.

Some hazardous wastes that could be incinerated are, for instance:

- waste pharmaceutical, drugs and medicine (Y3);
- waste from the production, formulation and use of organic solvents (Y6);
- waste mineral oils unfit for their originally intended use (Y8);
- waste substances and articles containing or contaminated with PCBs, PCTs and PBBs (Y10);
- wastes tarry residues arising from refining, distillation and any pyrolytic treatment (Y11).

46. However, the environmentally sound management of hazardous wastes requires the design of a methodology concerning the selection of the appropriate treatment and disposal options for hazardous wastes. Such methodology would guide qualified and experienced waste managers in their evaluation of the potential hazards of wastes to human health and the environment and on the best available technique by which to dispose of such wastes. In this regard, incineration of hazardous waste in any incinerator should include consideration of:

- the quantity of waste to be disposed of;
- its chemical and physical nature;
- other possible disposal options;
- the total rate of feed of waste into the incinerator in question;
- the blending to ensure optimal combustion;
- the design and operating conditions of the facility;
- measures taken to prevent or mitigate air emissions and pollutant migration into the environment;
- an assessment of the impact of the waste under consideration on effluent gas quality;
- problems associated with the management of residues from incineration, e.g. ash;
- capability for monitoring as required (e.g.:effluents).

47. Certain wastes should not normally be considered for incineration unless all the other circumstances are such as to make it technically viable, e.g. air pollution control equipment of very high standards of performance are fitted. These wastes include:

- wastes containing significant concentrations of arsenic, mercury, fluorine, bromine, iodine, organosilicon compounds, lead.

Certain other wastes can pose serious combustion problems:

- explosives;
- waste in drums which cannot, for one reason or another, be opened, shredded and emptied;
- extremely, or spontaneously, flammable materials. Where possible, these should be diluted or treated at source to reduce the risks of premature ignition;
- also extremely toxic materials, hazardous wastes in particular, can pose severe restraints on the methods of handling and treatment of the materials prior to incineration.

Metals will not be destroyed by incineration. They will either be emitted in gaseous and liquid effluents or remain in ashes and clinkers from which leaching is possible. Consequently, wastes containing high concentrations of toxic metals should not be incinerated.

V. MONITORING AND OPERATING PARAMETERS

48. Continuously monitored incinerator parameters should include carbon monoxide and possibly total hydrocarbons, temperature and oxygen. The temperature shall be measured at the end of the designated residence zone. CO and O2 should be measured immediately after the secondary combustion chamber. If a waste heat boiler is installed, the CO and O2 monitors may be placed after the boiler to minimize sampling and gas conditioning problems.

49. Continuous in-stack monitoring should be provided for opacity and HCl. At present there are severe limitations on continuous measurements of low levels of HCl within the desired confidence limits. Opacity should be measured by a continuous monitor equipped with alarm setpoints determined in consultation with the appropriate authorities. When exceeding these setpoints visible and audible alarms should be activated. The HCl monitor should be similarly equipped and shall also be linked to the reagent feed system for process control. In some cases indirect monitoring for HCl may be suitable.

50. The monitoring equipment should be on line whenever the incinerator is in operation and during both start-up and shutdown. The data from the continuous emission monitors should be collected for both process control and reporting functions. The continuous monitoring system should be installed and operated to measure and record the following parameters:

- opacity;
- oxygen (O2);
- carbon monoxide (CO) and possibly total hydrocarbon;
- hydrogen chloride (HCl); and
- temperature.

Consideration should also be given to continuously monitoring carbon dioxide (CO2), nitrogen oxides (NOx) and sulphur dioxide (SO2) as well as periodic monitoring of PCDDs and PCDFs, other products of uncompleted combustion and heavy metals in stack emissions, residues of pollution control devices, and ash or slag.

All monitoring requirements shall apply also to coincineration of hazardous wastes in industrial facilities.

Hazardous waste handling

51. The overall performance of any hazardous waste incineration facility depends on the successful integration of all the material handling systems with the thermal destruction equipment. The incineration facility shall be appropriately designed to receive, segregate and store the wastes on site, allow the wastes to be adequately prepared prior to burning, and ensure proper charging of the wastes into the combustion unit. The manner in which a waste is handled at an incineration facility is determined by such factors as incinerator design, control and analysis of waste received, on-site waste storage and processing capabilities and the nature of the waste such as its physical properties, corrosivity, explosivity, heating value, etc.

52. Segregating wastes during storage is a function of the properties and classes of hazards of the wastes to be stored. Waste segregation is of particular importance when incompatible waste types are received at the incineration facility. Incompatible wastes should be segregated on the

basis of their corrosive and /or reactive properties. For example, reactive chemicals shall be stored in airtight or watertight containers; oxidizing agents shall be isolated from flammable wastes; and chemical accelerators shall not be stored with wastes that can polymerize. The mixing of incompatible wastes may produce undesirable and/or uncontrolled reactions that may cause one or more of the following conditions:

- heat generation, fire and/or explosions;
- formation of toxic fumes;
- formation of flammable gases;
- volatilization of toxic or flammable substances;
- formation of substances that have greater toxicity than the original wastes;
- formation of shock and friction sensitive compounds;
- pressurization in closed vessels;
- emission of toxic dusts, mists and particles;
- violent polymerization.

53. It may be advantageous to segregate and store compatible wastes in categories determined by the heating value of the components. This practice enables the waste to be blended so as to have the necessary calorific value in order to maximize the performance of the incinerator. Typical categories of compatible wastes based on the fuel value of the waste include:

- light hydrocarbons and non-aqueous solvents (e.g. paint thinners, aromatics);
- medium to heavy-weight hydrocarbons (e.g. crankcase oils, still bottom residues);
- dirty solvents (e.g. soluble inks, oil/solvent residues); and
- high water content aqueous wastes (e.g. sludges, low heating value liquids).

54. In the design of waste blending or processing systems, the following factors should be considered: the nature of the waste to be burned, the type of combustion system, and the pumping and piping layout for liquid waste blending and feeding. Wastes that would not benefit from combustion or do not contribute to the operation of the combustion facility should not be blended into wastes going for combustion.

55. A spill handling plan shall be developed for the incineration facility to adequately deal with spills or other discharges that may occur on site. The spill handling plan shall include at least the following information:

- monitoring and reporting procedures for all possible spills of materials;
- identification of all plant equipment and contents;
- a description of the hazards of materials that could be involved in potential spills;
- emergency shutdown procedures;
- the chain of command designation during a spill incident;
- emergency contact list with telephone numbers;
- specification of equipment available for containment and clean-up procedures; and
- options available for the ultimate disposal of materials involved in a spill.

56. Ongoing inspection of the hazardous waste incineration facility by competent persons shall be carried out to detect leakage, spills, corrosion, hot spots and malfunctions. The inspection should reveal whether gauges, recorders and monitors are functioning, if there are any signs of tampering with incinerator equipment and if repairs are required. In addition, machinery including pumps,

hoses, connections, and other equipment used to handle hazardous waste should be thoroughly inspected for leaks and signs of wear during each start-up and shut-down of operation of the equipment and at least once during every continuous eight hour period of operation of the equipment.

VI. TESTING PARAMETERS

57. Test burns should always be carried out as part of the commissioning process and this is particularly important when hazardous wastes are to be burnt. The major objective of a test burn is to generate quantitative data that will be representative of the actual planned incineration operations. This data includes combustion air and supplemental fuel requirements, combustion temperatures, flue-gas volumes and constituents and contaminant emission rates. This information should demonstrate that the proposed incineration facility can meet the requirements and successfully destroy the designated waste and should define operating limits for temperatures, feed rates, firing conditions and other parameters.

58. Waste feed analysis should be conducted in accordance with recognized sampling and analytical methods to provide as a minimum:

- heating value (CV);
- total hydrocarbons;
- primary fuel feed rate;
- density;
- exhaust gas velocity;
- carbon monoxide;
- percentage oxygen;
- heavy metals;
- chlorine contents;
- PCDDs and PCDFs.

It is presumed that the last two items refer to the exhaust gas.

VII. SITE SELECTION PARAMETERS

59. Site selection should be considered a phased decision process that examines each potential location on the basis of protecting human life, health and property from contaminants as well as protecting the natural environment.

60. In many cases, an incineration system represents only one component of an integrated hazardous waste management facility designed to provide complete treatment and/or disposal options for waste materials. Therefore, the site that is ultimately selected for the location of a hazardous waste management facility should reflect the requirement of each individual component unit. In general, factors that should be considered in any site selection process for an integrated hazardous waste management facility may be grouped into the main headings of site suitability and public acceptance.

61. Once suitable candidate sites have been identified, a detailed assessment shall be done to determine the environmental, technical and economical feasibility of establishing the proposed facility at a particular site. At this stage, issues that shall be considered include:

- site hydrology (surface water);
- geology of the site;
- hydrogeology of the site;
- presence of sensitive habitat;
- urbanization of surrounding areas;
- socio-economic aspects (including impacts of transportation);
- streams in and around the site, stream flow rates, and public use of stream water;
- location of markets for any recovered materials and proximity of potential energy users;
- availability and cost of land;
- cost of site development;
- ambient air quality conditions, dispersion characteristics and wind direction;
- economic viability (including transport costs).

62. An environmental impact assessment should be made prior to final decisions on the siting of the plant. Land use factors should also be addressed (i.e. population density and proximity to facility; transportation network;future land-use planned for the area). The social acceptability of the facility is key to the site-selection process together with the environmental suitability, the technical and economic feasibility and land use compatibility. Public acceptance represents a basic element in the site-election process. Public participation should be encouraged in the overall process, in particular at the early planning stages of a proposed facility. Public participation should be actively solicited during the entire process, beginning with needs assessment and site selection.

VIII. ELEMENTS TO BE CONSIDERED FOR ENVIRONMENTALLY SOUND MANAGEMENT

63. Environmentally sound management involves the use of appropriate state-of-the-art facilities operated under quality assured management regimes.

64. The assessment of the disposal option to be selected as to whether it is environmentally sound is an essential task for the waste management professional or the decision maker. Although the best option is to avoid the generation of hazardous wastes, other potentially environmentally sound options for closed loop recycling[2] for recovery or re-use should be considered.

65. Also, the granting or rejecting of an authorization for the operation of a treatment and disposal facility should be based on the following criteria:

- Site selection;
- Design standards for facilities;
- Training of operators of the facility;
- Environmental assessment;
- Operation/discharge standards;

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[2] Closed loop recycling means that the unwanted by-product (waste) at a process is - after some treatment in an integral process - put directly back into the process from which it came.

- Monitoring and control;
- Emergency and contingency plans;
- Records and record-keeping;
- Decommission;
- Treatment of slag and dust from the incineration plant.

66. In addition, when considering the treatment and disposal option, the associated financial parameters should be identified and assessed. These could include for instance:

- Disposal costs (operating and recovered costs[3]);
- Transportation costs;
- Storage costs;
- Remedial costs;
- Plant decommissioning costs;
- Insurance/surety costs;
- Training costs;
- Capital payback period;
- Landfill construction and operation for disposal of residues from incineration;
- Wastewater treatment system.

IX. TECHNICAL COOPERATION

67. As for any large scale industrial process, technical cooperation should cover a broad range of inter-related activities. Scientific and technological means should be made available to countries who are in the process of developing their waste management infrastructure, including incineration of hazardous wastes. In this regard, developing and improving existing proven technologies which are environmentally sound should be encouraged. The transfer of appropriate and environmentally sound technologies should form part of a technical assistance programme together with human resource development, through training, in particular and capacity-building. The purpose is to establish sufficient capacity and capabilities to treat and safely dispose of waste and hazardous waste, to manage efficiently activities concerning incineration or activities related to it and perform efficient anti-pollution controls over the entire incineration process (collection, transport, pre-treatment, recovery, treatment, disposal).

68. Experience has shown that when parties with little experience are seeking to select an incinerator it is essential for an objective assessment of the detailed requirements to be made, preferably by an independent expert. This is to ensure the not uncommon practice of an integrated unit capable of handling a very broad spectrum of wastes of vastly different physical and chemical properties being recommended by those with vested interests on the grounds of the flexibility it offers when a much simpler and less expensive unit would be more appropriate. Such integrated units are very expensive and have high base load requirements for cost effective operation and in such instances their expensive capabilities are grossly under utilised, 30,000 to 50,000 tpa unit

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[3] Operating costs:
i.e. utility costs, depreciating capital cost, interest and maintenance costs, labour costs.

Recovered costs:
i.e. steam generation, HCl recovery, alternate disposal costs.

costing $50m to more than $100m. Where the waste contains little material which will form a solid residue a simple cyclonic (modular) unit can often be employed. Also where there are small separable component streams which produce significant solid residues these can be dealt with in small appropriate units like rotary kilns, the exhaust gases from which can be fed into a common gas cleaning unit serving both systems.

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The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal was adopted in 1989 and entered into force in 1992. Presently, there are more than 150 Parties to the Basel Convention. Its objective is to protect human health and the environment from the adverse effects caused by the generation, management and transboundary movements of hazardous wastes.

The fundamental aims of the Basel Convention are the reduction of the transboundary movements of hazardous wastes, the prevention and minimization of their generation, the environmentally sound management of such wastes and the active promotion of the transfer and use of cleaner technologies.

In December 1999, the Parties to the Basel Convention adopted the Basel Protocol on Liability and Compensation for Damage resulting from the Transboundary Movements of Hazardous Wastes and Their Disposal.

www.basel.int

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Sales No. E.02.III.D.204
ISBN 92-1-158604-6
ISSN 1020-8364

UNEP