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CHAPTER 1

MEDICAL WASTE INCINERATION

1. INTRODUCTION

Of all the “permanent” waste treatment technologies, properly designed incineration systems and plasma waste destruction systems are capable of the highest overall degree of destruction and control for the broadest range of hazardous waste streams. Although both technologies are based on thermal destruction, incineration and plasma arc treatment are conceptually different. The interest of the plasma is to provide very high temperatures and energy densities, together with an ionised and reactive medium, which can increase the kinetics of some reactions. Plasmas are particularly suitable for wastes that have to be kept at high temperatures for relatively long periods to ensure destruction. Incineration relies on the decomposition and modification of substances at high temperatures, involving both pyrolysis and oxidation in excess air. This Chapter will focus on conventional medical waste incineration, although it is recognised that plasma techniques can advantageously replace conventional burners.

2. THE PRINCIPLES OF WASTE INCINERATION

Incineration is the process in which combustible materials are burned, producing combustion gases, products of incomplete combustion, and noncombustible residue and ash. Some of the basic principles relating to waste incineration are discussed in the following sections.

2.1 BASIC CHEMICAL REACTIONS

The combustible part of hospital waste consists mainly of materials containing carbon (C), oxygen (O), and hydrogen (H). These elements dictate the main combustion reactions:

$$C + O_2 \rightarrow CO_2 + \text{heat}$$

$$2H_2 + O_2 \rightarrow 2H_2O + \text{heat}$$

When combustion is complete, carbon and hydrogen combine with oxygen of the combustion air to form carbon dioxide (CO_2) and water (H_2O).

To a lesser extent, such hetero-atoms as nitrogen (N), sulphur (S), chlorine (Cl), and metals, may be present in the waste. These atoms will also participate in the chemical reactions, and a variety of compounds may form.

Chlorides, originating from chlorinated salts, solvents, and plastics, are converted almost completely to hydrochloric acid, emitted from the combustion chamber in the vapour phase. Molecular chlorine (Cl_2) forms only when the H:Cl-ratio in the combustion zone is low. If combustion is not a hundred per cent complete, a wide range of chlorinated organic compounds may form. Although these are normally emitted in low concentrations, they play an important role in air pollution and health issues.

Nitrogen and oxygen enter the system in the combustion air. These combine at high temperatures to form "thermal" nitrogen oxides (NO_x). Nitrogen oxides may also form through oxidation of nitrogen that enters the combustion chamber with the waste stream. This occurs at a much lower temperature than the "thermal' NO_x.

Sulphur compounds in the waste will be combusted to form sulphur dioxide (SO_2). In the presence of sufficient oxygen, essentially all sulphur will leave the combustion chamber as SO_2.

2.2 STOICHIOMETRY, THERMOCHEMISTRY, AND COMBUSTION

The theoretical amount of oxygen required for complete combustion is known as the stoichiometric or theoretical oxygen, and is determined by the nature and quantity of the combustible waste. Oxygen required for combustion is normally obtained from atmospheric air, blown into the combustion zone. The additional oxygen (or air) over and above the stoichiometric amount is called excess air.

The chemical and physical characteristics of medical wastes vary widely, and it is difficult to manage heat content, moisture content, and bulk density of the waste feed. The heat of combustion (or heat content) is important from an industrial point of view, and the term *calorific value* is often used to indicate the relative effectiveness of a material as a fuel. Wastes with low calorific values are difficult to incinerate, because a large quantity of energy has to be added to facilitate combustion. Typical heat values of a few types of wastes are given in Table 1.1. Scientific notation was used for the heat value, ie 19.7E+06 is the same as19 700 000 J/kg.

Table 1.1: Moisture contents and heat values of selected waste types

MAIN CONSTITUENTS	MOISTURE (WEIGHT %)	HEAT VALUE J/kg
Highly combustible waste: paper, wood, cardboard boxes, and up to 10 % treated papers, plastic, or rubber scraps	10	19.7E+06
Combustible waste, paper, cartons, rags, wood scraps, combustible floor sweepings	25	15.1E+06
Animal and vegetable wastes	70	5.8E+06
Carcasses, organs, solid organic wastes	85	2.3E+06

The overall chemical composition (ultimate analysis, mass-based) of the waste/fuel mixture can be used to calculate the mass-based stoichiometric oxygen requirements, using individual stoichiometric oxygen requirements [USEPA, 1990], reproduced here in Table 1.2.

Volumetric oxygen requirements are calculated as follows:

$$Q_O = M_O \times K$$

where: Q_O = volumetric flow of O_2 (scm/h)
M_O = mass flow of O_2 (kg/h)
K = 0.2404 scm O_2 / kg O_2 at 20 EC and 101.3 kPa.
(scm = standard cubic meters, ie volume at 0 EC and 101.3 kPa)

Total volumetric air requirements can be obtained by multiplying volumetric oxygen requirements by 5.

Table 1.2: Stoichiometric oxygen requirements and combustion product yields [USEPA, 1990]

MOLECULAR WASTE COMPONENT	STOICHIOMETRIC OXYGEN REQUIREMENT	COMBUSTION PRODUCT YIELD
C	2.67 kg / kg C	3.67 kg CO_2 / kg C
H_2	8.0 kg / kg H_2	9.0 kg H_2O / kg H_2
O_2	- 1.0 kg / kg O_2	
N_2	_	1.0 kg N_2 / kg N_2
H_2O	_	1.0 kg H_2O / kg H_2O
Cl_2	- 0.23 kg / kg Cl_2	1.03 kg HCl / kg Cl_2 - 0.25 kg H_2O / kg Cl_2
F_2	- 0.42 kg / kg F_2	1.05 kg HF / kg F_2 - 0.47 kg H_2O / kg F_2
Br_2	_	1.0 kg Br_2 / kg Br_2
I_2	_	1.0 kg I_2 / kg I_2
S	1.0 kg / kg S	2.0 kg SO_2 / kg S
P	1.29 kg / kg P	2.29 P_2O_5 / kg P
Air N_2	_	3.31 kg N_2 / kg $O_{2\ (stoich)}$
Stoichiometric air requirement = 4.31 x $(O_2)_{(stoich)}$		

Maximum combustion temperature is reached at stoichiometric conditions. As the excess air is increased above the stoichiometric level, the combustion temperature is lowered because energy is required to heat the incoming excess air to the temperature in the combustion chamber. Below the stoichiometric point, the temperature decreases, because combustion is not complete. As the excess air level increases, the amount of unreacted oxygen also increases. The concentration of carbon dioxide decreases at the same time, due to dilution from the excess air. The oxygen and carbon dioxide levels are therefore good indicators for monitoring of the combustion process. The type of incinerator and waste characteristics also determine combustion parameters. For example, pathological wastes have high moisture content and low volatile and fixed carbon contents. In the case of multiple-chamber incinerators, continuous operation of an auxiliary burner is required to maintain the primary chamber temperature, which is recommended to be at a minimum of 870 °C. Combustion air can in this case be controlled at a lower level than for a typical multiple chamber incinerator. Emission guidelines of pollutants are normally expressed as concentrations at certain levels of oxygen in the stack gas, eg 7 per cent or 11 per cent.

Thermochemical calculations aim to estimate heat release and heat transfer associated with combustion. The operating temperature in an incinerator is a function of several variables. For most hospital incinerators, the operating temperature is estimated by determining the flame temperature under adiabatic or near-adiabatic conditions. The flame temperature depends strongly on the excess air requirement and the heating value of the combined waste-fuel mixture. Stoichiometric calculations and thermochemical calculations are developed independently for incinerator design and determination of operating parameters. These calculations are however interrelated. Products of combustion are a function of temperature, but the operating temperature can affect excess air requirement, which in turn affects the products of combustion significantly. Thus, an industrial application may require the simultaneous solution of several sets of stoichiometric and thermochemical equations.

2.3 THE COMBUSTION PROCESS AND AIR EMISSIONS

In an incinerator, combustion takes place in a small zone of a diffused flame. Fuel molecules from one side, and oxygen molecules from the other side, create a narrow flame region where virtually all the combustion takes place. The flame temperature is high, causing dissociation of molecules into atoms and free radicals.

Three zones can be distinguished in a diffusion flame, ie a preheat zone, a reaction zone, and a recombination zone. In the preheat zone, the fuel is broken down to smaller species which then enter the reaction zone. Reactions are mainly of the free-radical type. Kinetics are high, and true equilibrium is not attained. In the reaction zone, carbon is converted mainly to carbon monoxide and not carbon dioxide, although sufficient oxygen is present. In the post-flame zone, recombination reactions occur. Carbon monoxide is converted to carbon dioxide, and those organic radicals that did not meet an oxygen or hydroxyl radical in the reaction zone, recombine to form products of incomplete combustion. Because many different combinations are possible, a multitude of compounds can be formed.

With adequate supply and mixing of oxygen, and a sufficient residence time, the formation of products of incomplete combustion is minimised. These are commonly referred to as the “three T’s”: time, temperature, and turbulence.

- *The parameter of time*

  Residence time refers to the time that the gases remain in the combustion zone of the incinerator. It is a function of the size of the incinerator, waste feed rate, and the feed rate of combustion air. Regulatory bodies normally specify minimum residence times.

- *The parameter of temperature*

  To achieve good combustion, it is generally accepted that temperatures of 1000 EC to 1200 EC must be attained in the final combustion chamber.

- *The parameter of turbulence*

  Turbulence is required to mix the burning gases with the combustion air to obtain complete combustion. Turbulence is achieved in the incinerator by rotation, baffles, and burner location and fuel injection design.

Soot formation is a result of reduction of organic carbon in the fuel to carbon particles in the reducing section of the flame.

3. ASSESSING EFFICIENCY OF COMBUSTION

The carbon monoxide level in the flue gas is a good indication of the efficiency of combustion. Combustion efficiency is expressed as:

$$\text{Efficiency (\%)} = [\ \%\ CO_2 / (\%\ CO_2 + \%\ CO)\ ] \times 100$$

For adequate combustion, the aim is to keep CO levels below 100 ppm.

Combustion efficiency is also assessed in a destruction and removal efficiency (DRE) test. This is a standard compliance test for hazardous waste and medical waste incinerators. A substance that is difficult to incinerate, for example carbon tetrachloride, which can actually be used to extinguish a fire, is typically chosen for a DRE test. The substance is then injected together with the normal waste stream, and the stack gas analysed to quantify its release through the stack. The feed rate is adjusted to ensure detection with the sampling and analytical method at the expected level of emission.

Destruction and removal efficiency is expressed as

$$DRE = [(W_{in} - W_{out})/W_{in}] \times 100$$

where: W_{in} = feed rate of selected substance
W_{out} = emission rate of selected substance.

A DRE of better than 99.99 per cent is set as a requirement for hazardous waste incinerators. A similar specification has not been set for medical waste incinerators.

The figure of 99.99 per cent should be well understood. It does not imply that the overall combustion efficiency is 99.99 per cent, or that the stack gas will contain 1000 parts per million of unburned organic constituents. This is sometimes used incorrectly to calculate enormous releases of toxicants, based on high feed rates and only 99.99 per cent destruction. The DRE refers to a specific test, designed to assess efficiency of the system under a given set of conditions.

4. TYPES OF MEDICAL WASTE INCINERATORS

The three types of incinerators used most frequently for hospital waste treatment in the USA are multiple-chamber, rotary-kiln, and controlled-air units. Many hospitals in South Africa have small incinerators, based on multiple-chamber designs.

4.1 MULTIPLE-CHAMBER INCINERATORS

Multiple-chamber incinerators consist of two or more combustion chambers. These incinerators were designed primarily for the incineration of pathological wastes. They operate at excess-air levels well above the stoichiometric level, and are commonly referred to as “excess-air” incinerators.

Traditional designs are the in-line hearth, and the retort hearth, illustrated in Figures 1.1 and 1.2. The original designs were aimed at the incineration of pathalogical (anatomical) wastes. A raised edge at the door is normally incorporated to prevent spillage of liquids during loading and firing. Because of the low calorific value of pathological waste, surface combustion of the waste is sustained with an auxiliary burner in the primary
chamber.

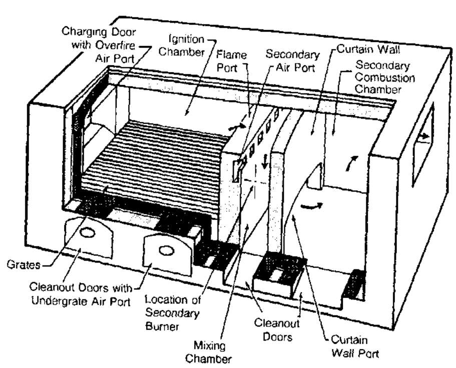

Figure 1.1: In-line multiple-chamber unit

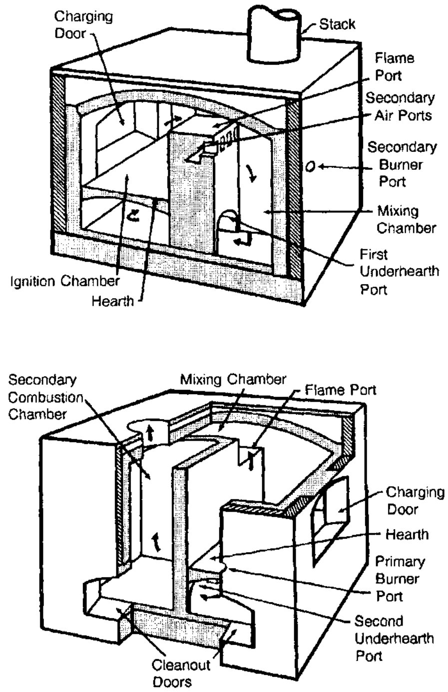

Figure 1.1: Retort-type multiple-chamber incinerator

The use of grates is not recommended for medical wastes, because liquids, sharps and other small items can fall through the grates prior to complete combustion. In the in-line design, combustion gases flow straight through the incinerator, as demonstrated by the arrows in Figure 1.1.

The retort design provides for air flows in more directions, as indicated by the arrows. At capacities lower than 350 kg/h, the retort design performs more efficiently than in-line incinerators. For higher capacities, in-line units perform better.

As the burning proceeds, the non-volatile components are combusted in the primary chamber. The combustion products and vaporised gases pass from the primary chamber through the flame port to the mixing chamber. Secondary air is added in the flame port, where a secondary burner provides additional heat to maintain adequate combustion temperatures. Combustion is completed in the secondary chamber.

Operating in the surface-combustion excess-air mode results in the entrainment of fly ash which can cause high particulate emissions. It is also difficult to control combustion air levels and combustion rates, especially where heterogeneous waste is incinerated. This may lead to insufficient control over combustion efficiency. Multiple-chamber, excess-air incinerators are better suited to incinerate pathological waste than general hospital or infectious wastes. The volatile content of pathological waste is low, and the composition is not highly variable. The incinerator can therefore operate in a relatively constant mode, with a steady, consistent combustion air input and excess air level.

It is possible to upgrade some of the older generation excess-air incinerators by adding post-combustion control equipment, and even to change the operation to sub-stoichiometric air levels in the primary chamber. In many cases, however, the cost of upgrading is excessive. Most of the older units are not able to reach temperatures above 800 EC, and it is not unusual to find installations burning and smoking at temperatures around an estimated 600 EC. Where temperatures are measured, these are measured in the flame, which do not reflect actual temperatures of combustion.

Table 1.3: Advantages and disadvantages of multiple-chamber incinerators

ADVANTAGES	DISADVANTAGES
Relatively inexpensive initial investment Physically compact	Requires very high excess air levels Unable to comply with new regulations without pollution control equipment, especially particulate emission standards Expensive to retrofit air pollution control equipment It is difficult to control combustion air levels and rate of combustion Limited to batch operation Batch operation tends to cause regular incidents of poor combustion, smoke and release of hazardous substances Ash removal is manual, leading to potential exposure to dust.

4.2 ROTARY-KILN INCINERATORS

Rotary kilns are well known in the lime processing and cement industries. The heart of the system is a refractory-lined cylindrical shell that is mounted at a slight incline, feeding the waste by rotation and gravity from the feeder through the combustion zone. Solid and drummed wastes are usually fed by a pack-and-drum system, which may be a bucket elevator for loose solids, or a conveyor system for drummed wastes. It is possible to equip the kiln with a lime or other alkaline injection system to neutralise acid gases.

Residence time is controlled by the rotational speed and the angle at which it is positioned. The residence times of liquids and volatilised combustibles are controlled by the gas velocity in the incineration system. The overall residence time can therefore be controlled effectively, to ensure complete combustion.

The kiln is operated under excess-air conditions. Moisture and volatiles are vaporised from the waste, and the waste is ignited. An auxiliary burner maintains the required combustion temperature if sufficient heat input is not provided from the waste. The temperature in the primary chamber varies typically between 650 and 1250 EC. Rotary kilns have mechanical waste feed systems and systems for continuous ash removal. Combustion can be controlled very effectively, maintaining high temperatures throughout the process. The waste tumbles down the incline during rotation of the kiln, providing very effective exposure of the waste to combustion air. Volatile gases pass into the secondary chamber, operated at 1100 to 1300 EC, typically. A secondary burner is used to maintain the temperature in this zone, and secondary air is added, to complete combustion of the gases.
Rotary kiln designs use high-temperature seals between the stationary ends and the rotating section. These seals are difficult to maintain, and fugitive emissions may exit

the system when seals fail. Fugitive emissions may also be generated at the feed system. Although liquid wastes are sometimes incinerated in rotary kilns, they are primarily suitable for the combustion of solid wastes. They are versatile in this regard, capable of handling slurries, sludges, bulk solids of varying sizes, and containerised wastes.

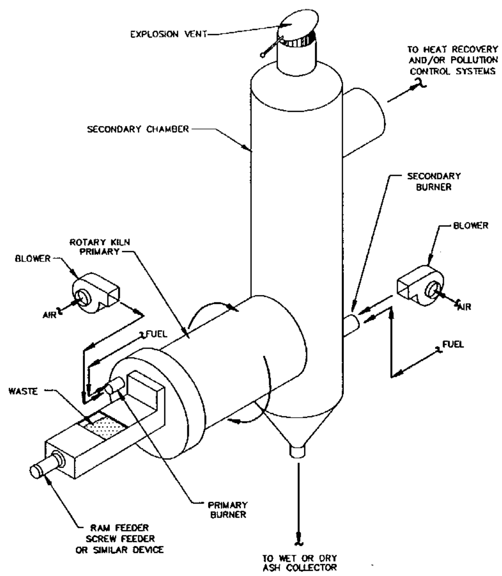

Figure 1.2: Diagram of a rotary kiln incinerator

Table 1.4: Advantages and disadvantages of rotary-kiln incinerators

ADVANTAGES	DISADVANTAGES
Can incinerate a wide variety of liquid and solid wastes Will incinerate materials passing through a melt phase Capable of receiving liquids and solids independently, or in combination Feed capability for drums and bulk containers Adaptable to a variety of feed mechanisms Characterised by high turbulence and air exposure of wastes Continuous ash removal that does not interfere with waste oxidation No moving parts inside the kiln Can be used with air pollution control devices Suitable for heat recovery Residence time can be controlled by adjusting the rotation speed of the kiln Waste can be fed directly, without preparation such as preheating or mixing Can operate at high temperatures, making them suitable for destruction of toxic compounds that are difficult to degrade thermally	High capital cost Operating care required to prevent refractory damage Airborne particles may be carried out of the kiln befor complete combustion. Spherical or cylindrical items may roll through the kiln before complete combustion May require makeup air due to leakages at seals Characterised by high particulate loading Relatively low thermal efficiency Problems in maintaining seals can cause operating difficulties and downtime.

4.3 CONTROLLED-AIR INCINERATORS

Most of the incinerators built for medical waste treatment in the USA over the past 20 years have been of the controlled-air type, also referred to as starved-air incinerators. Waste is combusted in two or more chambers. In the first chamber, waste is dried, heated, and burned at between 40 and 80 per cent of the stoichiometric air requirement. Combustion gases are mixed with air in the secondary chamber, and combusted under excess air conditions.

Temperatures in the incinerator are controlled through adjustment of the air levels. The primary chamber temperature is regulated around 850 EC, to achieve pyrolysis and trapping of metals in the ash. An advantage of low air levels in the primary chamber is that there is little entrainment of particulate matter in the gas stream. These are great advantages of this type of technology. It is however difficult to control the temperature where wastes are heterogeneous in calorific value. The secondary chamber is operated at high temperature, usually in the range 1100 to 1200 EC.

Figure 1.4 illustrates a typical controlled air incinerator manufactured by Atlas Incinerators Inc in the USA. Waste feed systems can be automated, and air control and combustion rates managed by microprocessors. Although particulates are controlled to quite low levels, it is often necessary to add a scrubbing device to remove acid gases, eg hydrochloric acid.

Figure 3: Drawing of a controlled-air incinerator

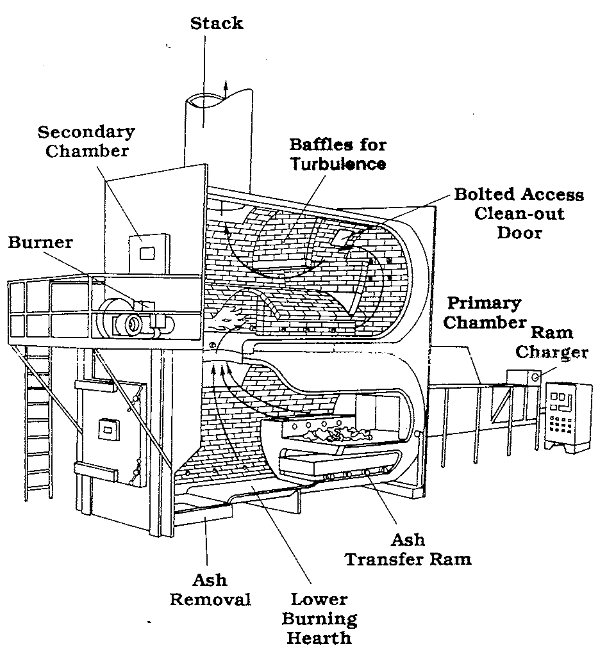

Figure 1.4: Drawing of a controlled air incinerator

Controlled-air incinerators are made in different capacities. Small batch-type units handle single loads and have throughputs in the range of 20 to 200 kg/h. Intermittent-duty units handle multiple charges per day, typically in the range 20 to 450 kg/h. The waste loading period is limited by the quantity of ash that can be accommodated in the primary chamber before shutting down for removal. Such units are operated typically for 8 to 14 hours, allowing the remainder of the 24-hour period for burndown of the ash, cooldown, ash cleanout, and preheat.

Figure 1.5 illustrates a small, intermittent-duty unit.

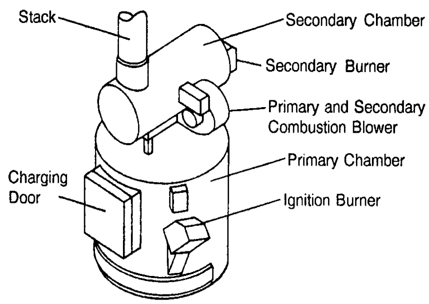

Figure 1.5: Intermittent-duty controlled-air incinerator

Table 1.5: Advantages and disadvantages of controlled-air incinerators

ADVANTAGES	DISADVANTAGES
There is a potential for by-product recovery Reduction of waste volumes without large quantities of supplementry fuel High thermal efficiency due to relatively low air requirements Uncontrolled air emissions can be low Converts carbonaceous solids to gases that are more easily combusted Limited particulate emissions Can burn waste with a minimum amount of processing Capital costs relatively low compared to performance	May have incomplete burnout of carbonaceous material in ash Cannot operate continuously for long, because of problems with clinkers or scale builtup on refractory surfaces Difficult to control operating parameters when waste stream varies If primary chamber temperature is too high because of waste characteristics, metal emissions may be high.

5. POST-COMBUSTION CONTROL OF EMISSIONS AND ASH MANAGEMENT

Despite sophisticated designs and control equipment, medical waste incinerators have the potential to cause air pollution. Pollutants of interest are toxic organic compounds (volatiles and semi-volatiles), toxic metals, sulphur oxides, nitrogen oxides, and particulate matter. Effective incinerator design, setting of standards on acceptable wastes, and good operating practices, are essential considerations in optimising the environmental performance of an incineration facility. To meet regulatory requirements, it is often necessary to add additional control equipment to prevent air pollution. Toxicants that accumulate in the control devices as particulates or in the form of liquid waste have to be managed as separate potentially-hazardous wastes. Incinerator ash is often removed manually from incinerators. After quenching under a water spray, the ash is removed to a drum or skip. Although ash from medical waste incinerators should be low in hazardous constituents, and is as a rule handled as non-hazardous waste for disposal at domestic waste landfill sites, it should be handled with caution. Ash and dust collected in control equipment may contain hazardous metals and organic products of incomplete combustion. The major concern is occupational exposure that may occur as a result of re-suspension of dust during cleaning of the equipment. The potential for environmental pollution can be assessed through chemical analysis, as is required for the characterisation of industrial wastes.

5.1 SOURCES AND FORMATION OF AIR POLLUTANTS

Pollutants released into the air from medical waste incinerators originate from the waste feed, or are formed during the combustion process. Part 2 Chapter 2 presents a discussion of the health impacts of the major substances of concern, as well as standard methods for sampling and analysis. This section refers to sources of pollutants, with the objective of discussing effective air pollution control strategies.

5.1.1 Particulates

Three factors are associated with the formation of particulates:

- Suspension of non-combustible materials: The ash content of the waste feed represents those substances that will not burn under any conditions. Emission of these particulates into the stack results from entrainment by the combustion air. This is a known problem with excess air incinerators operating at high excess air levels. The more air is added, the higher is the potential that non-combustible materials will be carried over into the flue gas.

- Products of incomplete combustion: Under conditions of inadequate combustion control, soot may form as a result of reduction of organic carbon to carbon particles.

- Non-combustible substances in the vapour state at primary combustion chamber temperatures, may condense as discrete particulates, or associate with the surfaces of other particles, when the flue gas cools down.

5.1.2 Toxic metals

Emission of metals is related to the metals content of the waste feed. Various metal objects, lead from batteries, mercury from thermometers, pigments from paints, and a diverse range of chemical and pharmaceutical wastes, are potential sources of toxic metals. These are largely converted to the oxides during combustion, and are trapped in the ash. If primary chamber combustion temperatures are too high, some of the metals may be volatilised and carried to the stack in the combustion gas stream. They will then condense on small particles in the flue gas. It is known that removal of particulates also leads to a reduction in the emission of metals. The objective should be to remove all sizes of particulates.

5.1.3 Toxic organic compounds

In principle, all organic materials should be combusted to carbon dioxide and water in an incinerator. Incomplete combustion, however, leads to direct emission of organic constituents fed in with the waste, or as new compounds that may form during the combustion process. Medical waste incinerators are known to have the potential to emit polychlorinated dioxins and furans, because of the combustion of chloride-containing plastics in the presence of organic matter. Polynuclear organic hydrocarbons are also formed as prominent products of incomplete combustion. Combustion conditions that cause high particulate emissions, generally also lead to high emissions of toxic organic compounds.

5.1.4 Acid gases

Acid gases form as a result of combination of available hydrogen with chlorides and sulphur associated with the waste. Formation of acid gases depends on the levels of the constituents in the waste, and is irrespective of the type of incinerator. Nitrogen enters the combustion chamber with the combustion air, and as a waste component. It reacts during the combustion process to form nitrogen oxides.

5.2 CONTROL STRATEGIES

Air pollution from medical waste incinerators may be caused by three primary factors:

- Problems as a result of waste composition, eg high levels of chlorinated plastics may lead to the formation of dioxins and high levels of hydrochloric acid.

- Problems associated with poor incinerator design and inadequate combustion may lead to the release of hazardous air pollutants.

- Non-conformance in operation as a result of poor management and maintenance practices.

The first step in preventing air pollution is to address these three factors. The critical problem with medical waste in this regard lies in its heterogeneity, and the difficulties associated with waste separation at the source. It is not feasible to eliminate the constituents that form acid gases. The incinerator cannot destroy these critical constituents in the combustion process, and formation of hydrochloric acid, for example, is in direct proportion with the presence of chlorides in the waste feed, irrespective of the type of incinerator.

Modern installations make it possible to manage combustion efficiency of organic constituents, but the varying nature of the waste can make it difficult to control primary chamber temperatures and emission of metals. Emission of particulates remains a problem in many cases, especially since it is recognised that where incinerator design and combustion conditions favour high particulate loads in the flue gas, these are also associated with high releases of toxic metals and organic compounds.

Where incinerators cannot meet emission guidelines because of limitations in design, or because of waste characteristics, additional control equipment may be required to manage air emissions down to acceptable levels.

An incinerator should not be operated without a formal quality assurance system, which should provide, among others, for operator training, maintenance programmes, and monitoring.

5.3 AIR POLLUTION CONTROL EQUIPMENT

Post-combustion air pollution control equipment has to be assessed not only on the efficiency of removal of the substances of concern, but also on the potential environmental impacts that such processes may have. For example, a wet scrubber may remove acid gases quite efficiently, but the scrubber solution has to be regenerated and/or disposed of, potentially transferring the air pollution issue to a soil or water pollution issue. It is possible to use more than one type of control device in tandem for certain applications.

5.3.1 Centrifugal separators

Centrifugal separators, also referred to as cyclones, are widely used to remove solid and liquid (aerosol) matter from gas streams. In a cyclone, the gas stream with entrained particles is forced into a constrained vortex in the cylindrical section of the unit. Because of their inertia and momentum, the particles tend to move outward across the gas stream lines in a tangential rather than a rotary direction. In a simplistic description, the particles eventually reach the wall of the cyclone and are carried down to the dust outlet by gravity and the downward movement of the outer vortex. Clean gas leaves the center of the inner vortex to the outlet of the module. A number of cyclones are often arranged in large modules to achieve high separation efficiency. Figure 1.6 illustrates a typical centrifugal separator. Different types of cyclones are available, designed to handle different requirements in terms of gas flows, particulate loads, and particle sizes.

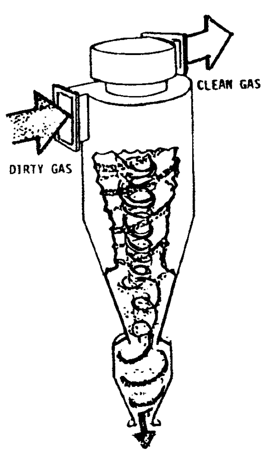

Figure 1.6: A centrifugal dust separator

5.3.2 Wet scrubbers

Wet scrubbing describes the process of cleaning of a gas stream through intimate contact with a liquid. Wet scrubbers are constructed in many designs, but the venturi, spray tower, and packed-bed concepts are the most common types used with hospital waste incinerators.

Venturi scrubbers are used primarily for particulate control. Conceptually, they capture particulates in an upstream spray of large liquid droplets produced through aspiration of liquid in the scrubber. Formation of droplets is achieved by atomisation of the liquid through small orifices of spray nozzles under high pressure An alternative design uses a venturi throat which serves to increase linear velocity and turbulence under high pressure to such an extent that droplets form.

The performance of these scrubbers is dependent on the size distribution of the particulate matter. For particles larger than 1 to 2 Φm, removal is quite effective, and they are used mostly on multiple-chamber incinerators which emit significant quantities of large particles.

For smaller particles, as occur normally in emissions of controlled-air incinerators, venturi scrubbers are not effective. A typical spray venturi is illustrated in Figure 1.7.

Scrubbing of gaseous pollutants refers to their absorption in a liquid. It is a mass transfer reaction, driven by concentration differences. Absorption depends on the solubility of the pollutant in the liquid, and also on the kinetics of diffusion in the gas and liquid phases. To enhance gas diffusion, and therefore absorption, optimisation of the area of interfacial contact, good mixing, and sufficient contact time, are critical parameters.

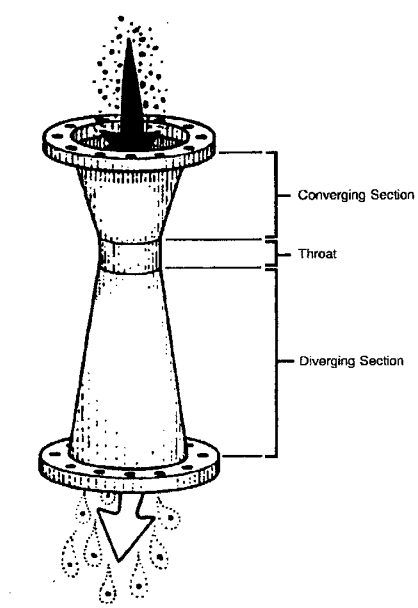

Figure 1.7: A typical spray venturi

5.3.3 Gravity spray towers

The most common low-energy wet scrubbers in the industry are gravity released spray towers. They operate on the principle that liquid droplets are released through spray nozzles to fall through rising exhaust gases and are drained at the bottom of the chamber.

The major disadvantage of spray towers is their relatively low scrubbing efficiency for particulates in the range up to 5 Φm. They are therefore not suitable for removal of particulates from medical waste incinerator emissions. These systems are also not very effective for absorption of gaseous pollutants. Since very fine droplets are necessary for good contact, spray nozzles operated with high pressure drops are required.

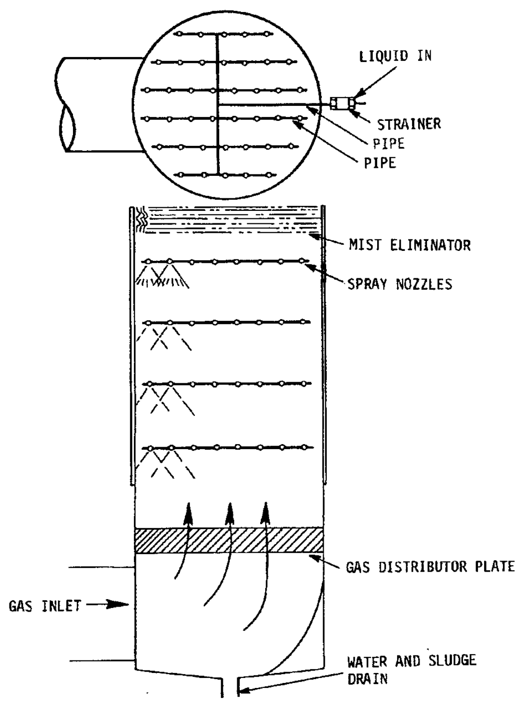

Figure 1.8: A typical gravity spray

5.3.4 Packed-bed scrubber

Packed-bed scrubbers are used primarily for reduction of acid gas releases. Scrubber liquid is circulated in countercurrent mode through the scrubber. The large liquid-to-gas surface ratio promotes diffusion and absorption. The effectiveness of absorption depends on the gas velocity distribution through the packed bed, the surface contact area, the volume and uniform distribution of the scrubber liquid, and the liquid characteristics. Sodium hydroxide and sodium carbonate, are frequently used as scrubber media. Gas velocity through the scrubber is relatively low, and these units are therefore not suitable for removal of particulates.

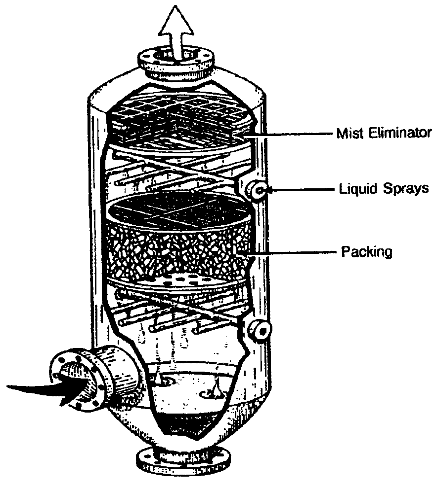

Figure 1.9: Counter current packed bed absorber

5.3.4 Fabric filters

Although fabric filters provide one of the oldest, most efficient methods for the removal of particulates from gas streams, few medical waste incinerators use fabric filtration (also known as baghouses). A fabric filter is capable of removing particulates as small as 0.5 Φm, as well as a large proportion of those down to 0.01 Φm. The filter medium is essentially a woven or felted fabric through which dust-laden gases are circulated. In addition to the filter action of the fabric, the cake of dust that forms after some use, also acts as a sieving mechanism. Collection of particles is by direct interception, or impaction. Interception is a function of the geometry of the fabric filter and particle sizes, whereas impaction occurs where particles have too much inertia to follow the gas stream lines around the filter.

Baghouses are normally classified according to the type of cleaning mechanism used to remove the dust from the bags. The types of units are:

Mechanical shakers   Reverse air cleaning   Pulse jet cleaning

In the USA, only pulse jet baghouses are used in medical waste incineration systems. Figure 1.10 illustrates a pulse jet fabric filter installation.

In pulse jet cleaning, a momentary burst of compressed air is introduced in the discharge nozzle of the filter bag, causing a shock wave to travel down the baghouse. This inflates the bags in the opposite direction, causing the cake to crack and shatter. The dust can then be collected and disposed of.

The operating temperature of the baghouse is a critical parameter for medical waste incineration systems. Because the combustion air contains hydrochloric acid, the temperature in the baghouse should be maintained above the dewpoint of HCl. The boiling point of HCl is 110 EC. The baghouse temperature should not be allowed to fall below 150 EC. Otherwise, serious corrosion and damage to the filter may result.

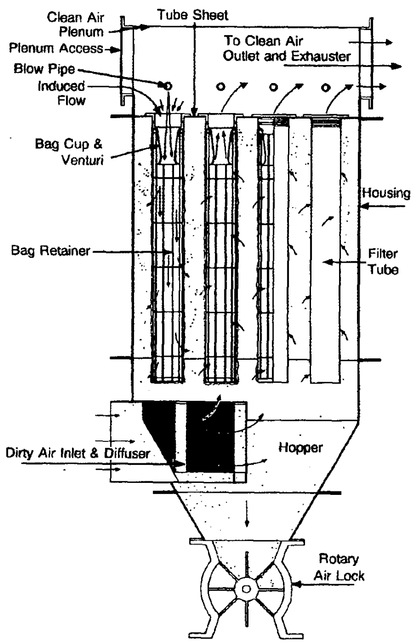

Figure 1.10: Diagram of a pulse jet baghouse

5.3.5 Dry scrubbers

Dry scrubbers use absorption for the removal of acid gases. The success of fabric filters in removing particulates from gas streams, has encouraged the use of a combination of dry scrubbing and fabric filter systems. Dry scrubbers offer potential advantages over their wet counterparts, because they are relatively simple in design, and the ultimate waste is a dry solid, rather than a wet sludge.

Two types of so-called dry scrubber systems are available, ie spray drying, and dry injection. In the USA, spray driers have not been installed at medical waste incineration systems, but their use has been proposed for hazardous waste incinerators.

Spray dryer

The method of operation of a spray drier is relatively simple, requiring only a spray drying module, as illustrated in Figure 1.11, and a bag filter. In the spray dryer, an alkaline slurry is injected into the incoming gas stream. Droplets are formed by a rotary atomiser or atomising nozzles, increasing the liquid-gas surface area to promote mass transfer. The thermal energy of the gas and chemical reaction evaporates the moisture from the droplets, producing a dry powdered reaction product. The flue gas does not become saturated with moisture, and troublesome moist eliminators are not required. The cleaned gas is discharged through a fabric filter, through an induced draft fan, and the stack.

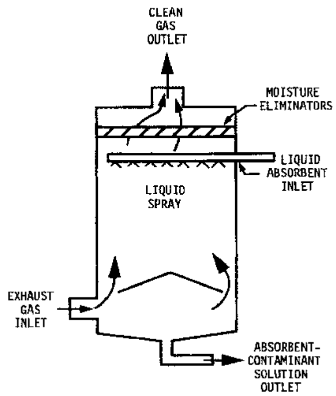

Figure 1.11: Diagram of a spray dryer

<u>Dry scrubber system</u>

This type of scrubber injects a finely divided alkaline sorbent such as calcium hydroxide or sodium carbonate into the gas stream for the absorption of acid gases. The key operating parameters for dry injection systems are the sorbent injection rate and the particle size of the sorbent. The sorbent feed rate is usually three to four times the stoichiometric requirements. The gas stream containing the entrained sorbent particles and fly ash is then ducted to a dust collecting system. Figure 1.12 illustrates a possible layout of a dry injection absorption system.

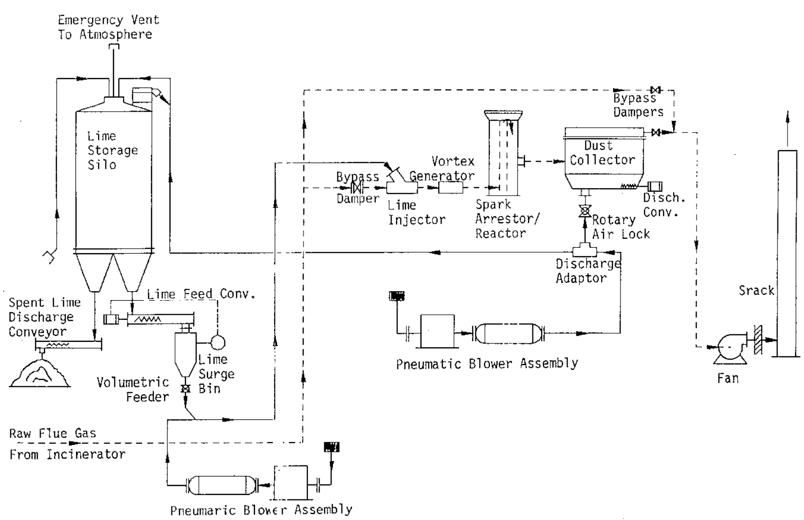

Figure 1.12: Process flow diagram of a dry injection system for the removal of acid gases

5.4 ADVANTAGES AND DISADVANTAGES OF AIR POLLUTION CONTROL EQUIPMENT

Table 1.6 summarises some of the advantages and disadvantages of air pollution control equipment. Certain equipment are more suitable for use with certain types of incinerators and waste streams than others, because of such parameters as gas flow rate, temperature, particle size and mass, and removal objectives. For example, the information shows that different devices have different capabilities for removal of particulates in certain size categories. Particulates of all sizes should be removed. This section and summary table should be regarded as a basic overview, presented with the understanding that the subject is much more complex.

Table 1.6: Advantages and disadvantages of air pollution control equipment

ADVANTAGES	DISADVANTAGES
CENTRIFUGAL SEPARATORS	
Can handle a wider range of chemical and physical conditions than most other types of dust collecting equipment. No moving parts. Low cost. Multiclone systems can be made to increase capacity.	Possibility of plugging and flow equalisation. Not effective in separating particles smaller than 5 Φm.

Table 1.6: Advantages and disadvantages of air pollution control equipment (continued)

ADVANTAGES	DISADVANTAGES
VENTURI WET SCRUBBER	
Effective for collection of particles larger than 1 to 2 Φm. Can remove gaseous pollutants through absorption.	Not suitable to remove small particles (0.1 to 0.5 Φm.) Creates liquid effluent. Relatively expensive to operate, because of requirement for high-pressure pumping equipment.
GRAVITY SPRAY TOWER	
Adequate for collection of particles larger than 10 to 25 Φm. Inexpensive and simple construction. Low energy scrubbing.	Must be larger than other scrubbers for the same exhaust stream flow rates. Droplets may agglomerate after short distances, reducing efficiency. Poor collection efficiency for small particles.
FABRIC FILTERS	
Highly efficient for removing small particles. Relatively inexpensive.	Sensitive in operation, can lead to bag blinding, bag corrosion, or bag erosion. Must operate at temperatures above 150 EC.

DRY SCRUBBER: SPRAY DRYER	
Relatively simple operation Mist eliminators not essential Reduced auxiliary power Reduced water consumption.	Difficult to achieve efficiencies better than 85 %.
DRY SCRUBBER: DRY INJECTION	
More simple to operate than spray dryers.	Limitations in efficiency, similar to spray dryers.

6. BIBLIOGRAPHY

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