

# Lecture 8

## Incineration and Energy Recovery

### STRUCTURE

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  - 8.1.2 Incineration objectives**
- 8.2 Planning an Incineration Facility**
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### OVERVIEW

In Unit 7, we discussed the recovery of energy through composting and biogasification. Yet another means of energy recovery is thermal treatment of solid wastes, which is also regarded as pre-treatment of waste prior to final disposal. Thermal treatment includes both the burning of mixed MSW (municipal solid waste) in incinerators and the burning of selected parts of the waste stream as fuel. In this Unit (i.e., Unit 8), we will deal with incineration and energy recovery. We will begin the Unit with an introduction to the process and objectives of incineration. Then, we will take up the issues that are to be considered while planning an incineration facility. We will, subsequently, discuss

various incineration technologies such as mass burning system, refuse derived fuel (RDF) system, modular incineration and fluidised bed incineration. Then, we will explain energy generation, i.e., generation of steam and electricity, and cogeneration of steam and electricity. Emission of air pollutants being a major concern of incineration facilities, and we will also discuss the various gaseous pollutants and their control measures (equipment). Finally, we will discuss the environmental impacts of incineration on land, water and aesthetics.

## **LEARNING OBJECTIVES**

After completing this Unit, you should be able to:

- discuss incineration processes;
- list the objectives of incineration;
- plan an incineration facility;
- explain various incineration technologies;
- identify emissions from incinerators and their control;
- estimate the energy generation potential of wastes;
- assess the environmental impacts of incineration.

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### **8.1 INCINERATION: AN INTRODUCTION**

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Incineration is a chemical reaction in which carbon, hydrogen and other elements in the waste mix with oxygen in the combustion zone and generates heat. The air requirements for combustion of solid wastes are considerable. For example, approximately 5000 kg of air is required for each tonne of solid wastes burned. Usually, excess air is supplied to the incinerator to ensure complete mixing and combustion and to regulate operating temperature and control emissions. Excess air requirements, however, differ with moisture content of waste, heating values and the type of combustion technology employed. The principal gas products of

combustion are carbon dioxide, carbon monoxide, water, oxygen and oxides of nitrogen.

Many incinerators are designed to operate in the combustion zone of 900°C – 1100°C. This temperature is selected to ensure good combustion, complete elimination of odours and protection of the walls of the incinerator. Incinerator systems are designed to maximise waste burn out and heat output, while minimising emissions by balancing the oxygen (air) and the three “Ts”, i.e., time, temperature and turbulence. Complete incineration of solid wastes produces virtually an inert residue, which constitutes about 10% of the initial weight and perhaps a larger reduction in volume. The residue is generally landfilled.

The incineration facility along with combustion of waste emits air pollutants (i.e., fine particulate and toxic gases), which are an environmental concern, and, therefore, their control is necessary. Other concerns relating to incineration include the disposal of the liquid wastes from floor drainage, quench water, scrubber effluents and the problem of ash disposal in landfills because of heavy metal residues. By optimising the combustion process, we can control the emission of combustible, carbon-containing pollutants (EPA 1989 and 1995). Oxides of nitrogen and sulphur, and other gaseous pollutants are not considered a problem because of their relatively smaller concentration.

Having introduced you to incineration, we will touch upon the combustion of various elements of waste materials and the objectives of incineration in Subsections 8.1.1 and 8.1.2, respectively.

### **8.1.1 Combustion of waste material**

Table 8.1 shows the major elements that constitute solid wastes and the end products of combustion:

**Table 8.1  
Major Elements of Solid Wastes**

Elements	Combustion Process	End Products (Gases)
Carbon (C)		Carbon dioxide (CO <sub>2</sub> )
Hydrogen (H)		Water (H <sub>2</sub> O)
Oxygen (O)		
Nitrogen (N)		Nitrogen (N <sub>2</sub> )
Sulphur (S)		Sulphur dioxide (SO <sub>2</sub> ), other gaseous compounds and ash

Table 8.2 gives the information about several components of solid waste mixtures on the basis of proportion:

**Table 8.2  
Ultimate Analysis of Combustible Component**

Percent by Weight (dry basis)						
Component	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Food waste	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	6.0
Plastic	60.0	7.2	22.8	--	--	10.0
Textile	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	--	2.0	--	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Garden trimmings	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.
Dirt, ash, brick, etc.	26.3	3.0	2.0	0.5	0.2	68.0

Source: Tchobanoglous et al (1977, 1993)

In case energy values in KJ/kg or BTU/lb are not available, we can calculate them approximately from the data in Table 8.2 above and the Dulong formula given below:

$$\text{Energy value (BTU/lb)} = 145.4 C + 620 (H - 1/8 O) + 41S$$

**Equation 8.1**

where C, H, O, and S are in percent by weight (dry basis) and can be converted to KJ/kg by: **BTU/lb x 2.326 = KJ/kg**

### 8.1.2 Incineration objectives

The purpose of incineration is to combust solid wastes to reduce their volume to about one-tenth, without producing offensive gases and ashes (Phelps, et al., 1995). That is to say, incineration of solid wastes aims at the following (McDougall, et al., 2001):

- **Volume reduction:** Depending on its composition, incineration reduces the volume of solid wastes to be disposed of by an average of 90%. The weight of the solid wastes to be dealt with is reduced by 70 – 75%. This has both environmental and economic advantages since there is less demand for final disposal to landfill, as well as reduced costs and environmental burdens due to transport, if a distant landfill is used.
- **Stabilisation of waste:** Incinerator output (i.e., ash) is considerably more inert than incinerator input (i.e., solid wastes), mainly due to the oxidation of the organic components of the waste stream. This leads to a reduction of landfill management problems (since the organic fraction is responsible for landfill gas production) and the organic compounds present in landfill leachate.
- **Recovery of energy from waste (EFW):** This represents a valorisation method, rather than just a pre-treatment of waste prior to disposal. Energy recovered from burning the wastes is used to generate steam for use in on-site electricity generation or export to local factories or district heating schemes. Combined heat and power plants increase the efficiency of energy recovery by producing electricity as well as utilising the residual heat. Solid waste incineration can replace the use of fossil fuels for energy generation. As a large part of the energy content of solid wastes comes from truly renewable resources (e.g., biomass), there should be a lower overall net carbon dioxide production than that from burning fossil fuels, since carbon dioxide is absorbed in the initial growing phase of the biomass.
- **Sterilisation of waste:** This is of primary importance in the incineration of clinical or biomedical waste. Incineration of solid wastes will also ensure destruction of pathogens prior to final disposal in a landfill.



Now, we discuss the planning aspects pertaining to siting and sizing an incineration facility.

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## **8.2 PLANNING AN INCINERATION FACILITY**

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Incineration of solid wastes is becoming an increasingly important aspect of solid waste management, as communities look for alternatives to rapidly filling landfills (or disappearing landfill sites). Modern incineration facilities are no longer simple garbage burners. Instead, they are designed to produce steam and electricity and can be used as a complement to source reduction, recycling and composting programmes. However, strategic long-term planning is essential for developing a successful incineration facility. In other words, it is important to develop an understanding of a variety of issues in the planning process, including the following:

- (i) **Facility ownership and operation:** One of the first planning decisions that local officials make is about the entity that will actually own the facility and oversee its operation. This decision is based largely on the amount of financial risk the community is willing to assume and the time and resources available. Some of the procurement options, in this context, are:
  - **Full service approach:** In this system, the community specifies only the process type and the performance required, and hires a (single) firm to design, construct and operate the plant.
  - **Merchant plants:** In this type of system, in which waste is accepted on weight basis, a private firm designs, constructs, owns and operates the facility.
  - **Turnkey approach:** In this system, a single company designs and builds the plant, according to the communities' specifications, and the community or a different contractor owns and operates the plant.

- (ii) **Energy market:** Waste incineration facilities differ from most government services in that they generate a product as well as energy, which are sold for revenue. Steam and electricity are the energy products at incineration facilities, depending on the particular design.
- (iii) **Marketing steam:** The primary end uses of steam from waste incineration facilities are industrial and institutional heating and cooling systems. Marketing of steam products involves identifying these industries and institutions within the region. Industrial and institutional steam users include textile, paper and pulp, food processing, leather, chemical producers, hospitals, etc. Planning must include proper backup to guarantee a consistent supply and steam demand variation (often caused by changing seasons).
- (iv) **Marketing electricity:** Incineration facilities generating electricity are referred to as *co-generators* as they provide electricity in addition to that generated by the local electric utility. Besides the plant that uses the electricity generated for its operation, customers for electricity include nearby industries and public, and private utilities. It must be equipped to give a consistent supply and must compete with other co-generators in selling energy.
- (v) **Facility siting:** Siting the incineration facility is one of the most important tasks to be undertaken and a variety of social and technical hurdles have to be negotiated. The important aspects in this context are the following:
  - **Effect on residents:** Residents will be concerned with the health effects associated with incinerator plant, decreased property value and increased traffic (e.g., due to truck movement).
  - **Environmental impact:** Incineration has the potential to create a variety of environmental concerns like air, water and noise pollution and ash disposal.



- **Development plans:** It is important to evaluate future land use plans at the possible site.
  - **Proximity to waste source:** Transportation cost is one of the most significant expenditures in waste management system.
  - **Proximity to energy market:** The energy products will have to be delivered to buyers. The location of power line must be considered.
  - **Logistic concerns:** Area zoning and access route must be considered.
  - **Residual ash disposal:** Access to a secure landfill is necessary.
- (vi) **Facility sizing:** Proper plant sizing results from careful evaluation of a wide variety of criteria such as:
- **Waste supply:** This is the most fundamental sizing factor and measures are usually taken to guarantee a waste supply for the facility. Waste flow control ordinances are often used to ascertain the quantity of waste. When properly planned, waste flow control can benefit both incineration facility and alternative waste management programme, by diverting the relevant portions of the waste stream (e.g., recyclables to the recycling programme and combustibles to incineration facility).
  - **Alternative waste management programme:** In addition to waste flow control agreements, future source reduction, recycling and composting programmes are directly related to facility design. When sizing the incineration facility, it is important, therefore, to account for the type and amount of materials that will be diverted from the facility.
  - **Waste stream characteristics:** Good combustion depends on the accuracy of waste stream data. Planning of incineration facility requires waste stream assessment to develop an accurate picture of the quantity and composition of the waste stream. From a technical standpoint, the waste stream data will be used to ascertain the heating value of the waste, which helps in plant operation.

- **Planning for facility disruption:** Accounting for downtime is an important facility planning criteria. Most incineration facilities are designed to operate continuously (i.e., 24 hours a day), but both scheduled (e.g., maintenance) and unscheduled (e.g., equipment failure) downtime situations are likely to occur. Storage space must be available for the waste that continues to arrive during downtime. If these capabilities are not built into the system, provisions must be made to send waste to a landfill or an alternative facility.
- **Facility financing:** Depending upon the procurement approach selected, incineration facility will require extensive financing agreements.
- **Time frame:** The time required to plan, develop and construct a facility will vary, but at least 5 to 8 years are required to bring a new facility from the early planning stages to in-service.

Long-term planning within the local government is the key for successful facility design and operation. By understanding all issues and dedicated workforce, waste combustion can become a positive component of waste management system (EPA 1989 and 1995).



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## **8.3 INCINERATION TECHNOLOGIES**

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The four incineration technologies covered in this Section are mass burning system, refuse derived fuel system, modular incineration and fluidised bed incineration. The two most widely used and technically proven incineration technologies are mass-burning incineration and modular incineration. Fluidised-bed incineration has been employed to a lesser extent, although its use has been expanding and experience with this relatively new technology has increased. Refuse-derived fuel production and incineration has also been used, with limited success. Some facilities have been used in conjunction with pyrolysis, gasification and other related processes that convert solid waste to gaseous, liquid, or solid fuel through thermal processing (UNEP 1996). In Subsections 8.3.1 to 8.3.4, we will discuss the four incineration technologies.

### **8.3.1 Mass-burning system**

Mass-burning systems are the predominant form of MSW incineration. A mass-burn facility typically consists of a reciprocating grate combustion system and a refractory-lined, water-walled steam generator. Mass-burn systems generally consist of either two or three incineration units ranging in capacity from 50 to 1,000 tonnes per day. That is to say, the facility capacity ranges from about 100 – 150 to 2,000 – 3,000 tonnes per day. These facilities can accept refuse that has undergone little preprocessing other than the removal of oversized items. Although this versatility makes mass-burn facilities convenient and flexible, local programmes to separate household hazardous wastes (e.g., cleaners and pesticides) and recover certain materials (e.g., iron scrap) are necessary to help ensure environmentally viable incineration and resource conservation.

Because of the larger facility size, an incineration unit is specially designed to efficiently combust the waste to recover greater quantities of steam or electricity for revenue. To achieve this greater combustion and heat recovery efficiency, the larger field-erected incinerators are usually in-line furnaces with a grate system. The steam generator generally consists of refractory-coated water wall systems,

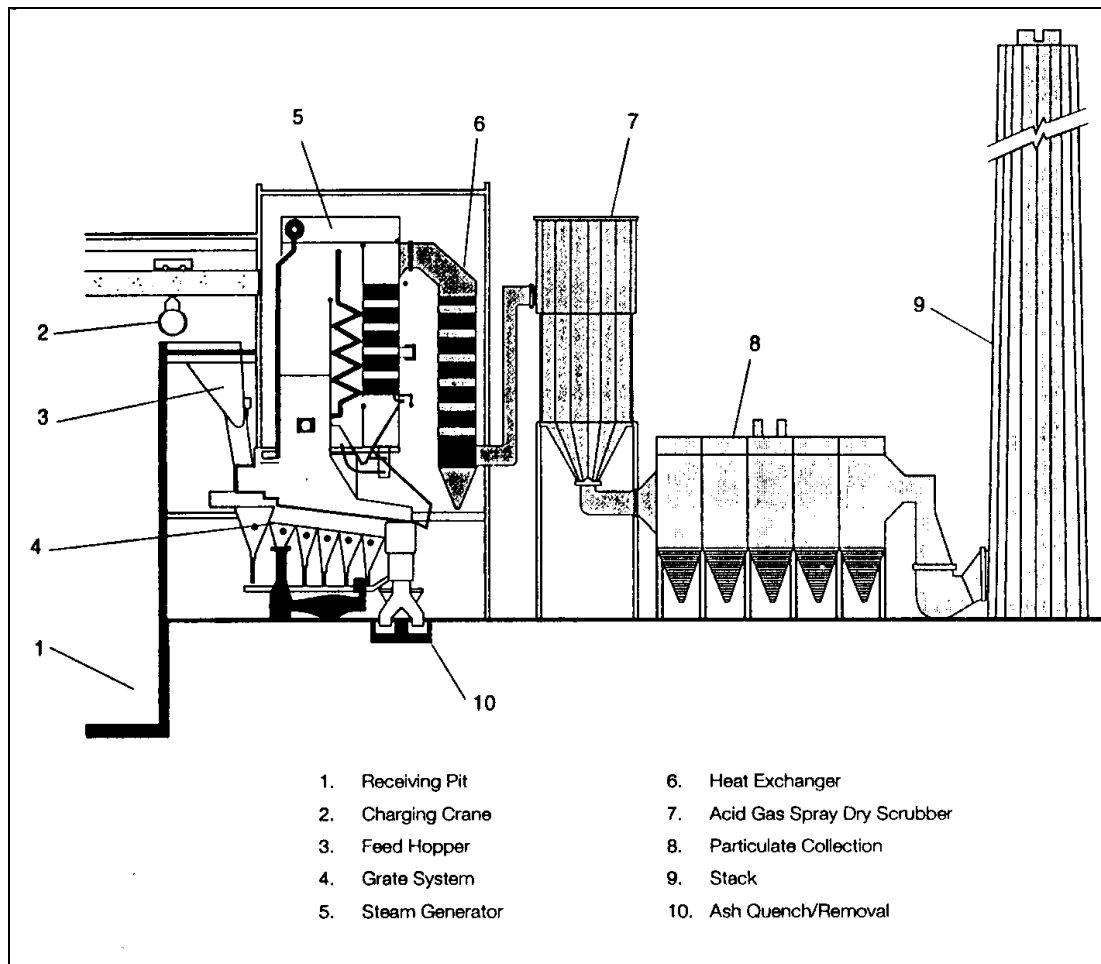
i.e., walls comprised of tubes through which water circulates to absorb the heat of combustion. In a water wall system, the boiler is an integral part of the system wall, rather than a separate unit as is in a refractory system.

Mass-burning of waste can also be achieved by the use of a rotary kiln. Rotary kilns use a turning cylinder, either refractor or water wall design, to tumble the waste through the system. The kiln is reclined, with waste entering at the high elevation end and ash and non-combustibles leaving at the lower end.

The waste intake area usually includes a tipping floor, pit, crane and sometimes conveyors. Trucks enter the tipping floor and tip their wastes either onto the floor itself, or directly into the pit. When wastes are tipped onto the floor, a front-end loader or a bulldozer is used to push them into the pit or onto a conveyor. From a feed chute, MSW is continuously fed to a grate system, which moves the waste through a combustion chamber using a tumbling motion. A travelling or reciprocating grate may follow rotary combustors to further complete combustion.

At least two combustor units are included to provide a level of redundancy and to allow waste processing at a reduced rate during periods of scheduled and unscheduled maintenance. Mass-burn facilities today generate a higher quality of steam (i.e., pressure and temperature), which is then passed through a turbine generator to produce electricity or through an extraction turbine to generate electricity as well as provide process steam for heating or other purposes. Figure 8.1 below illustrates a typical mass-burn facility:

**Figure 8.1**  
**Typical Mass-Burn Facility**



### 8.3.2 Refuse derived fuel (RDF) system

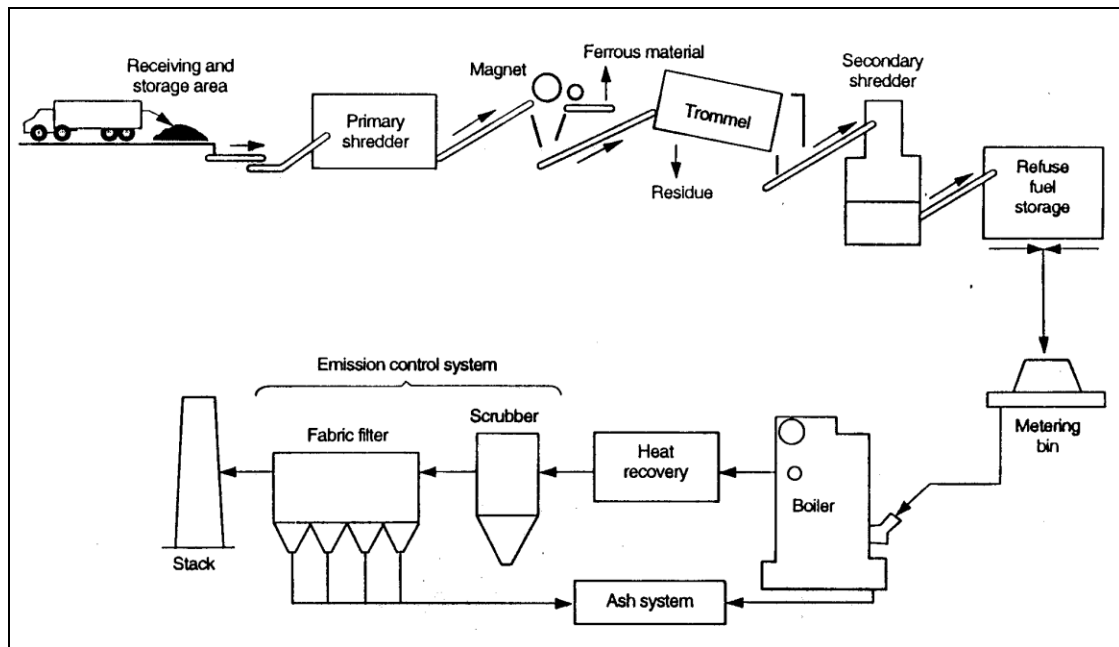
Refuse-derived fuel (RDF) refers to solid wastes in any form that is used as fuel. The term RDF, however, is commonly used to refer to solid waste that has been mechanically processed to produce a storable, transportable and more homogeneous fuel for combustion. RDF systems have two basic components: RDF production and RDF incineration.

RDF production facilities make RDF in various forms through material separation, size reduction and pelletising. Although RDF processing has the advantage of removing recyclables and contaminants from the combustion stream, on an average, capital costs per tonne for incineration units that use RDF are higher

than for other incineration options. RDF production plants like mass-burn incinerators characteristically have an indoor tipping floor. Instead of being pushed onto a pit, the waste in an RDF plant is typically fed onto a conveyor, which is either below grade or hopper fed. In some plants, the loader doing the feeding will separate corrugated and bulky items, like carpets.

Once on the conveyor, the waste travels through a number of processing stages, usually beginning with magnetic separation. The processing steps are tailored to the desired products, and typically include one or more screening stages, using trammel or vibrating screens, shredding or hammer milling of waste with additional screening steps, pelletising or baling of burnable wastes, and, depending on the local recycling markets and the design of the facility, a manual separation line. A typical RDF facility scheme is given in Figure 8.2 below:

**Figure 8.2**  
**Typical Simplified RDF Facility**



There are two primary types of systems in operation, and these are:

- (i) **Shred-and-burn systems:** Shred-and-burn systems are the simplest form of RDF production. The process system typically consists of shredding the MSW to the desired particle size that allows effective feeding to the combustor and magnetic removal of ferrous metal, with the remaining portion delivered to the combustor. There is no attempt to remove other non-combustible materials in the MSW before combustion. This, in essence, is a system with minimal processing and removal of non-combustibles.
  
- (ii) **Simplified process systems:** This is a system that removes a significant portion of the non-combustibles. A simplified process system involves processing the MSW to produce an RDF with a significant portion of the non-combustibles removed before combustion. The MSW process removes more than 85% of the ferrous metals, a significant percentage of the remaining non-combustible (i.e., glass, nonferrous metals, dirt, sand, etc.), and shreds the material to a nominal particle top size of 10 to 15 cm to allow effective firing in the combustion unit.



Depending on the type of combustor to be used, a significant degree of separation can be achieved to produce a high-quality RDF (i.e., low ash), which typically results in the loss of a higher percentage of combustibles when compared to systems that can produce a low-quality fuel (i.e., slightly higher ash content) for firing in a specially designed combustor. These types of systems recover over 95% of the combustibles in the fuel fraction.

### **8.3.3 Modular incineration**

Modular incinerator units are usually prefabricated units with relatively small capacities between 5 and 120 tonnes of solid waste per day. Typical facilities have between 1 and 4 units with a total plant capacity of about 15 to 400 tonnes per day. The majority of modular units produce steam as the sole energy product. Due to their small capacity, modular incinerators are generally used in small communities or for commercial and industrial operations.

Their prefabricated design gives modular facilities the advantage of a shorter construction time. Modular combustion systems are usually factory-assembled units consisting of a refractory-lined furnace and a waste heat boiler. Both units can be pre-assembled and shipped to the construction site, which minimises field installation time and cost. Adding modules or units, installed in parallel can increase facility capacity. For example, a 200 tonne-per-day facility may consist of 4 units, a 50-tonne-per-day consists of 2 units and a 100 tonne-per-day consists of 1 unit. The number of units may depend on the fluctuation of waste generation for the service area and the anticipated maintenance cycle of the units.

Modular incinerators employ a different process from that of mass-burn incinerators, typically involving two combustion chambers, and combustion is typically achieved in two stages.

The first stage may be operated in a condition in which there is less than the theoretical amount of air necessary for complete combustion. The controlled air

condition creates volatile gases, which are fed into the secondary chamber, mixed with additional combustion air, and under controlled conditions, completely burned. Combustion temperatures in the secondary chamber are regulated by controlling the air supply, and when necessary, through the use of an auxiliary fuel. The hot combustion gases then pass through a waste heat boiler to produce steam for electrical generation or for heating purposes. The combustion gases and products are processed through air emission control equipment to meet the required emission standards.

In general, modular incineration systems are a suitable alternative and may, for smaller-sized facilities, be more cost-effective than other incinerators. But modular incineration has become less common, partly due to concerns over the consistency and adequacy of air pollution controls.

#### **8.3.4 Fluidised-bed incineration**

Fluidised-bed incineration of MSW is typically medium scale, with processing capacity from 50 to 150 tonnes per day. In this system, a bed of limestone or sand that can withstand high temperatures, fed by an air distribution system, replaces the grate. The heating of the bed and an increase in the air velocities cause the bed to bubble, which gives rise to the term *fluidised*. There are two types of fluidised-bed technologies, viz., bubbling bed and circulating bed. The differences are reflected in the relationship between air flow and bed material, and have implications for the type of wastes that can be burned, as well as the heat transfer to the energy recovery system.

Unlike mass-burn incinerators, fluidised-bed incinerators require front-end pre-processing, also called fuel preparation. They are generally associated with source separation because glass and metals do not fare well in these systems and also they can successfully burn wastes of widely varying moisture and heat content, so that the inclusion of paper and wood, which are both recyclable and burnable, is not a crucial factor in their operation (and thus paper can be extracted for higher-value recycling).

Fluidised-bed systems are more consistent in their operation than mass burn and can be controlled more effectively to achieve higher energy conversion efficiency, less residual ash and lower air emissions. In general, however, these systems appear to operate efficiently on smaller scales than mass-burn incinerators, which may make them attractive in some situations. For this reason, fluidised-bed technology may be a sound choice for high-recycling cities in developing countries when they first adopt incineration.

Let's see Indian Scenario in adopting incineration technology

### **Indian scenario in selection of Incineration technology**

The absence of a well planned, scientific system of waste management (including waste segregation at source) coupled with ineffective regulation leading to waste burning. The left-over waste at the dumping yards generally contains high percentage of inerts (>40%) and of putrescible organic matter (30-60%). It is common practice of adding the road sweepings to the dust bins. Papers and plastics are mostly picked up and only such fraction which is in an unrecoverable form remains in the refuse. Paper normally constitutes 3-7% of refuse while the plastic content is normally less than 1%. The calorific value on dry weight basis (High Calorific Value) varies between 800-1100 k-cal/kg. Self sustaining combustion cannot be obtained for such waste and auxiliary fuel will be required. Incineration, therefore, has not been preferred in India so far. The only incineration plant installed in the country is at Timarpur, Delhi way back in the year 1990 has been lying inoperative due to mismatch between the available waste quality and plant design. This made the government of Delhi to assure increased efforts in segregation of household MSW at source collection. However, with the growing problems of waste management in the urban areas and the increasing awareness about the ill effects of the existing waste management practices on the public health, the urgent need for improving the overall waste management system and adoption of advanced, scientific methods of waste disposal, including incineration, is imperative.

Out of most recent Waste to energy technologies adopted in India such as Biomethanation, landfill with gas recovery, gasification/pyrolysis, incineration and composting; incineration is selected as last option.



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## 8.4 ENERGY RECOVERY

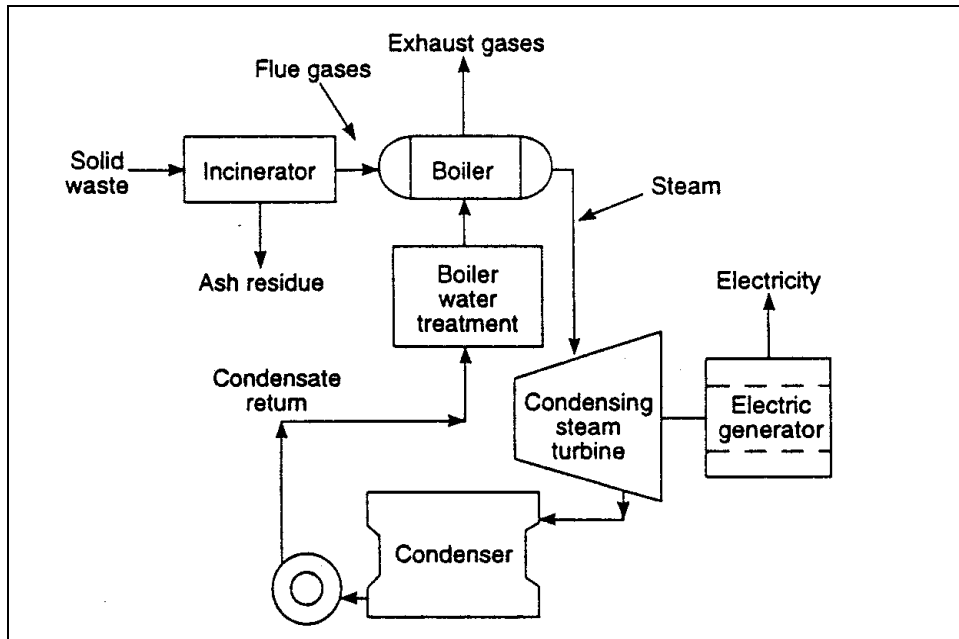
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Most of the MSW incineration currently practice energy recovery in the form of steam, which is used either to drive a turbine to generate electricity or directly for heating or cooling. In the past, it was common to simply burn MSW in incinerators to reduce its volume and weight, but energy recovery has become more prevalent (EPA 1989 and 1995).

In waste-to-energy (WTE) plants, heat from the burning waste is absorbed by water in the wall of the furnace chamber, or in separate boilers. Water when heated to the boiling point changes to steam. At this point, the steam is used either for heating or to turn turbines to generate electricity. The amount of energy recovered from waste is a function of the amount of waste combusted, energy value of the waste stream and the efficiency of the combustion process (UNEP 1996). The three basic types of waste-to-energy incineration are:

- (i) **Generation of electricity:** Electricity is the most common form of energy produced and sold from WTE facilities constructed today. By directing the steam produced from a WTE system through a turbine generator, electricity can be produced and sold. A process flow diagram of an electrical generation system is shown in Figure 8.3:

**Figure 8.3**  
**Incinerator and Electrical Generation System**



Since electric utilities can receive power 24 hours a day and are usually very stable financially, public utilities have attractive markets for power produced from WTE systems. Of the electricity produced in incineration facilities, about one-fifth is used at the facility for general operations, and the remainder is sold to public and private utilities or nearby industries. In many countries, utilities provide a stable market for electricity generated from incinerators. The availability of purchasers and rates for electricity sales will, however, vary by region.

- (ii) **Steam generation:** Steam is used widely in a variety of industrial applications. Steam generated in incineration facilities can also be used directly by a customer for manufacturing operations. Steam generated in an incinerator is supplied to a customer through a steam line, and a separate line sometimes returns the condensed steam. It can be used to drive machinery such as compressors, for space heating and generating electricity. Industrial plants, dairies, cheese plants, public utilities, paper mills, tanneries, breweries, public buildings and many other businesses use steam for heating and air conditioning.

When assessing potential markets for steam, it is important to consider a market's proximity to the WTE facility and the quantity of steam produced. Proximity is important because steam cannot usually be economically transported more than one or two miles. The WTE facility, therefore, should be as close as possible to the potential market. The advantages of transmitting steam over a long distance to an end user must be weighed against energy losses that will occur in transmission. Installation of a pipeline connecting the facility and the customer can also be prohibitively expensive in certain circumstances. High-temperature hot water may be an option for overcoming the transmission limitation for steam.

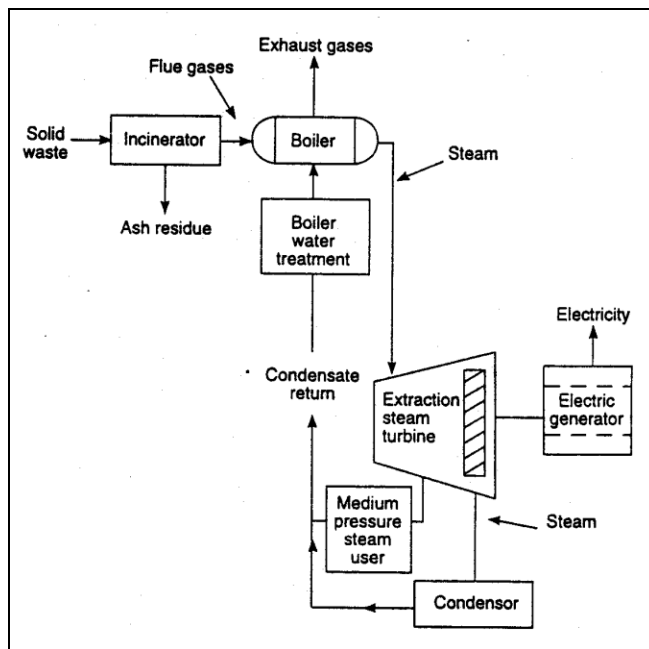
Anticipated steam quantity and quality are interrelated parameters, and must be carefully projected when assessing steam markets. The prospective user will most likely have an existing process requiring steam at a specific temperature and pressure. The quantity of steam produced from a given amount of waste will decrease, as the steam temperature and pressure increase, but the equipment using the steam will operate more efficiently. To ensure the continuing availability of high quantity and quality steam, supplementary fuels, such as natural gas, may occasionally be used, but this will result in an increase in the operating costs.

- (iii) **Co-generation:** Co-generation refers to combined production of steam and electricity and can occur in two ways. If the energy customer requires steam conditions (pressure and temperature) that are less than the incineration plant's design specifications, a turbine-generator is used to produce electricity and thus reduce steam conditions to appropriate levels for the customer. If the steam purchaser cannot accept all the steam produced by the facility, the excess can be converted to electricity. In co-generation, high-pressure steam is used first to generate electricity; the steam leaving the turbine is then used to serve the steam users. Co-generation (Figure 8.4) provides greater overall energy efficiency, even though the output of the major energy product – whether electricity or

steam – may be less than that generated by producing one type of energy alone.

Co-generation allows flexibility, so that seasonal variations in steam demand can be offset by increases in electricity production, and can provide the project a financial base by selling electricity, should the steam customer become unavailable.

**Figure 8.4**  
**Co-generation System for Producing Electricity and Steam**







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## 8.5 AIR EMISSION AND ITS CONTROL

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The operation of the combustion process plays an important role in the formation of pollutants, which are carbon monoxide,  $\text{NO}_x$  (oxides of nitrogen), hydrocarbons and other volatile organic compounds. It also produces gaseous stream containing dust, acid gases ( $\text{HCl}$ ,  $\text{SO}_x$ ,  $\text{HF}$ ), heavy metals and traces of dioxins (McDougall, et al., 2001). The majority of modern incinerators, however, produce less particulate and gaseous pollutants than their predecessors. Also, emissions from incinerators are controlled by a combination of measures that use both the pollution prevention approach and various control equipment. We will describe the main gaseous pollutants and their control measures, respectively, in Subsections 8.5.1 and 8.5.2.

### 8.5.1 Gaseous pollutants

The various gaseous pollutants formed due to incineration processes are:

- **Carbon dioxide ( $\text{CO}_2$ ):** This is one of the main products of incineration, and the other main product is water. At low concentrations,  $\text{CO}_2$  has no short-term toxic or irritating effect, as it is abundant in the atmosphere and necessary for plant life and is not generally considered a pollutant. Nevertheless, due to the high increase in global concentration of  $\text{CO}_2$ , it has been recognised as one of the gases responsible for global warming.
- **Carbon monoxide (CO):** An incomplete combustion of carbon due to the lack of oxygen forms CO. This gas is toxic, as it reacts with the haemoglobin in the blood, causing a decrease of available oxygen to the organisms. This lack of oxygen produces headache, nausea, suffocation and eventually death. Carbon monoxide in the flue gas is used to monitor the incomplete combustion of the other emissions, such as un-burnt hydrocarbons and provide information on the performance of the incinerator.
- **Sulphur oxides ( $\text{SO}_x$ ):** The emission of  $\text{SO}_x$  is a direct result of the oxidation of sulphur present in solid waste, but other conditions such as the type of

incinerator used and its operating conditions also influence its production. Approximately 90% of  $\text{SO}_x$  emissions are  $\text{SO}_2$  and 10% are  $\text{SO}_3$ . In the atmosphere, most of the  $\text{SO}_2$  is transformed into  $\text{SO}_3$ , which leads to the production of  $\text{H}_2\text{SO}_3$  (sulphurous acid) and  $\text{H}_2\text{SO}_4$  (sulphuric acid), increasing the acidity of rain. At high concentrations, it causes eye, nose and throat irritation, and other respiratory problems.

- **Nitrogen oxides ( $\text{NO}_x$ ):** This is predominantly formed during the incineration process. However, they oxidise to  $\text{NO}_2$  in the atmosphere.  $\text{NO}_x$  is formed from two main sources – thermal  $\text{NO}_x$  and fuel  $\text{NO}_x$ . In thermal formation, the oxygen and nitrogen react in the air. Fuel  $\text{NO}_x$  is formed during the reactions between oxygen and nitrogen in the fuel. Nitrogen oxides are important, as they participate in several processes in atmospheric chemistry. They are precursors of the formation of ozone ( $\text{O}_3$ ) and peroxy acetyl nitrate (PAN). These photochemical oxidants are responsible for smog formation and cause acid rain.
- **Particulates:** This is formed during the combustion process by several mechanisms. The turbulence in the combustion chambers may carry some ash into the exhaust flow. Other inorganic materials present in the waste volatilise at combustion temperature and later condense downstream to form particles or deposits on ash particles. The main component of fly ash is chemically inert silica; but it may also contain toxic metal and organic substances.
- **Hydrochloric acid (HCl):** Hydrochloric acid results from the high concentration of chlorine containing materials (e.g., some type of plastics like polyvinyl chloride) in solid waste. Chlorine easily dissolves in water to form HCl. Its presence in the gaseous state may increase the acidity of local rain and ground water, which can damage exposed and unprotected metal surfaces, erode buildings and may affect the mobilisation of heavy metals in soil.
- **Hydrogen fluoride (HF):** Hydrogen fluoride is more toxic and corrosive than HCl, although its presence in the emissions from solid waste incinerators occurs in much smaller quantities. It is formed due to the presence of trace amounts of fluorine in the waste.

- **Heavy metals (Hg, Cd, Pb, Zn, Cu, Ni, Cr):** Solid waste contains heavy metals and metallic compounds in the combustible and incombustible fractions. During the incineration process, metals may vaporise directly or form oxides or chlorides at high temperatures in the combustion zone. They condensate over other particles and leave the incineration process in the flue gas.
- **Dioxins and furans:** Polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) have been detected in the emissions from solid waste incinerators. Dioxins can be formed in all combustion processes, where organic carbon, oxygen and chlorine are present, although the processes by which they are formed during incineration are not completely understood. The concern over dioxins and furans has increased after a number of animal studies have shown that for some species, they are carcinogenic and highly toxic, even at very low levels of exposure.

### 8.5.2 Gas-cleaning equipment

The technologies employed to carry out the necessary flue gas cleaning include:

- **Electrostatic precipitators (ESP):** These are used for particle control. ESP use electric forces to move the particle flowing out of the gas stream on to the collector electrodes. The particles get a negative charge, when they pass through an ionised field. The electric field that forces the charged particles to the walls comes from discharged electrodes maintained at high voltage in the centre of the flow lane.

When particles are collected, they must be carefully removed to avoid their entry into the gaseous stream. This is achieved by knocking them loose from the plates and by intermittent and continuous washing with water. The removal efficiency is more than 99% with a low-pressure drop. Particle size and other physical characteristics such as gas stream temperature, flue gas volume, moisture content, gas stream composition, particle composition and particle surface characteristics affect the performance of the equipment. ESP's come in one- or two-stage designs and can have different

configurations: plate wire, flat plate and tubular. These configurations can be wet or dry, depending on the method of dust collection.

- **Fabric filters:** In fabric filtration, the gas flows through a number of filter bags placed in parallel, leaving the dust captured by the fabric. Extended operation of fabric filters requires periodic cleaning of the cloth surface. After a new fabric goes through a number of cycles of use and cleaning, it forms a residual cake of dust that becomes the filter medium, which is responsible for highly efficient filtering of small particles that characterises fabric filter. They are widely accepted for controlling particulate matter.

The type of cloth fabric limits the temperature of operation of fabric cloth: cotton is least resistant (82°C) while fabric glass is the most resistant (277°C). This temperature requirement makes the use of a cooling system necessary for the gas, before it enters the equipment, but it is also necessary that the temperature of the exhaust gas stream be maintained above the dew point because liquid particles block the pores in the fabric very quickly. The major difference between different configurations of fabric filters is the cleaning method used during operating cycles such as shaker, reverse-air and pulse-jet cleaning.

- **Scrubbers:** Scrubbers are used to control particulate matter and acid gases leaving the incinerator. Particulates and gases are removed from the gas stream mainly by absorption and adsorption. The particles are moved to the vicinity of the water droplets and collide with each other. The particles adhere to the liquid media and precipitate to the bottom of the unit containing the dust particle from the gas phase. In addition to removing entrapped particulate matter, scrubbers can also remove gases by absorption and adsorption. Any other type of particulate control equipment does not possess this capability of scrubber. It can remove particles of size 0.1 to 200µm efficiently. The various types of scrubbers can be dry, semi-dry or wet, depending on the composition of flue gas.



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## 8.6 ENVIRONMENTAL CONCERNS

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In Section 8.5, we discussed the various air pollutants emitted from an incinerator and their control equipment. Apart from air pollution, there are other environmental concerns related to incineration (EPA 1989 and 1995), some of which are touched upon below:

- (i) **Water pollution:** Wastewater in an incineration facility can be generated in various forms. These include tipping floor runoff system wash water, ash quench water and water from pollution control systems. These systems also deal with normal problems experienced by all large industrial facilities, including sanitary wastewater disposal and surface-water runoff. For most incineration facilities, wastewater can be recycled in a closed-loop system. In these systems, water from floor drains, ash dewatering, water softener recharge and other process wastewaters are collected and stored in a tank. This water is then reused for ash quenching. Sanitary waste can be directed to municipal sewer systems. In some cases, regulatory authorities may require that the waste stream be pretreated before discharge.
- (ii) **Land-retained pollution:** Land-retained pollutants originate as stack or fugitive emissions and are of increasing concern. Bioaccumulation and subsequent ingestion from food is an indirect exposure route resulting from land-retained emissions. To provide better understanding of land-retained pollutants, it may be desirable to establish baseline contaminant levels, before incineration plant construction so that changes in those levels throughout the plant's operating lifetime can be monitored.
- (iii) **Residue disposal:** An incineration facility and its emission control system produce a variety of residues such as large quantity of bottom ash, the unburned and not burnable materials discharged from the incinerator at the end of the burning cycle. The process also produces a lighter emission known as fly ash. Fly ash consists of products in particulate form, which are

either produced as a result of the chemical decomposition of burnable materials or are unburned (or partially burned) materials drawn upward by thermal air currents in the incinerator and trapped in pollution control equipment. Fly ash normally comprises only a small proportion (ranging from 10 to 20%) of the total volume of residue from an incineration facility.

Constituents in both ash and scrubber product vary, depending on the materials burned. In systems burning a homogeneous fuel such as coal, oil, or tires, the level of pollutants in residues may be relatively constant. Systems burning a more heterogeneous mixture, such as municipal, industrial, or medical waste may experience wide swings in the chemical composition of residues. The major constituents of concern in municipal waste combustion ash are heavy metals, particularly lead, cadmium and mercury. These metals may impact human health and the environment; if improperly handled, stored, transported, disposed of or reused.

- (iv) **Noise pollution:** Truck traffic is the greatest source of noise pollution in incineration plant operations. Well-maintained and responsibly operated trucks will help minimise this problem. Local ordinances may restrict truck traffic to certain hours of the day and to specified truck corridors. Under these conditions, noise pollution should not be a significant factor. Noise resulting from plant operations and air handling fans associated with the combustion and emission control equipment is also a potential problem. Noise levels are likely to be the highest in front of waste tipping floor doors, ash floor doors and the vicinity of air emission stacks. Walls, fences, trees and landscaped earthen barriers can serve to reduce noise levels.
- (v) **Aesthetic impact:** Proper site landscaping and building design can help minimise or prevent negative aesthetic impacts. Such impacts are much less problematic, if the facility is sited in an industrial area and not adjacent to residential or commercial districts. Local zoning ordinances may ensure that aesthetic impacts are minimised. Keeping the process building at negative pressure can prevent undesirable odours from escaping outside of



the building. Also, the use of internal air for combustion in the plant processes will destroy most odours.

Some facilities may emit visible steam or vapour plumes. Smoke, resulting from improper conditions in the combustion chamber, can also be problematic. Air emission stacks and cooling towers may also be unappealing anomalies in the skyline of some areas. If external lights on buildings prove objectionable to neighbours, perimeter lights (on stands) directed towards the plant may be preferable.

## **SUMMARY**

Incineration is a chemical reaction by which carbon, hydrogen and other elements in the waste combine with oxygen in the combustible air and generate heat. In this Unit, we discussed the objectives and issues to be considered while planning an incineration facility. In this context, we discussed the various incineration processes and technologies such as mass burn, refuse derive fuel, modular incineration and fluidised bed incineration. We said that the product of incineration is heat that can be utilised for the generation of steam and electricity. We also pointed out that the amount of energy recovered is a function of the amount of waste combusted, the energy value of the waste stream and the efficiency of the combustion process. We then discussed energy generation. We also discussed the various air pollutants emitted out of an incineration facility and the equipment used for their control namely scrubbers, electrostatic precipitators and fabric filters. Finally, we listed some of the impacts of incinerators on the environment.

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# Lecture 8

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## Model Answers to Learning Activities

### LEARNING ACTIVITY 8.1

Incineration is the controlled high temperature oxidation of primarily organic compounds to produce carbon dioxide and water. Incineration of municipal solid waste can reduce its volume by more than 90%. Incineration reduces financial expenses that are necessary to carry waste to the landfill site. Due to the reduction in haul distance, fuel cost is reduced. The thermal conversion products that can be derived from solid wastes include heat and gas, which can be recovered. The low level heat remaining in the gases after heat recovery can also be used to preheat the combustion air, boiler makeup water or solid waste fuel. Overall incineration increases the efficiency of solid waste management by producing less waste and reducing cost.

### LEARNING ACTIVITY 8.2

Strategic long-term planning is necessary for developing a successful incineration facility. This includes:

- Facility ownership and operation (full service approach, merchant plants and turnkey approach).
- Energy market (marketing steam and marketing electricity).
- Facility siting (effect on residents, environmental impact, development plans, proximity to waste source, proximity to energy market, logistic concern and residual ash disposal).
- Facility sizing (waste supply, alternative waste management programme, waste stream characteristics, planning for facility disruption, facility financing and time frame).

### **LEARNING ACTIVITY 8.3**

Mass-burning system has several advantages. Apart from being the widely technically proven incineration technology, a mass-burn facility can accept refuse that has undergone little preprocessing other than the removal of oversized items. This provides advantages such as convenience and flexibility. Due to the large facility size, the incineration unit can be used to recover greater quantities of steam and electricity. The steam generated is of higher quality, which is then passed through a turbine to produce electricity or through an extraction turbine to generate electricity as well as provide process steam for heating purposes. One of the disadvantages of mass-burn facility is that a local programme is needed to separate household hazardous wastes and recover certain materials (e.g., iron scrap) so as to help ensure environmentally viable incineration and resource conservation. Other disadvantages include increased cost of construction and land space.

### **LEARNING ACTIVITY 8.4**

The three basic types of waste-to-energy (WTE) incineration involve the generation of electricity, steam or the cogeneration of both electricity and steam. Electricity is the most common form of energy produced and sold from WTE facilities. By directing the steam produced from a WTE system through turbine generator, electricity can be produced and sold. The second method uses steam generated from incineration facilities directly by a customer for manufacturing operations. This steam can be used to drive machinery such as compressors, for space heating and generating electricity. Cogeneration involves the combined production of steam and electricity. In cogeneration, high-pressure steam is used first to generate electricity; the steam leaving the turbine is used to serve the steam users.

### **LEARNING ACTIVITY 8.5**

Electrostatic precipitators (ESP) are used for particle control. ESP uses electric forces to move the particle flowing out of the gas stream on to the collector

electrodes. The particles get a negative charge, when they pass through an ionised field. The electric field forces the charged particles to the walls. The particles that are collected are removed by knocking them loose from the plates and by intermittent and continuous washing with water. The removal efficiency is 99%.

