

## CHAPTER 4 - AIR EMISSION CONTROL STRATEGIES

### 4.0 INTRODUCTION

Significant improvements have been made in the air emission control systems of MSW incinerators [MSWI] since the early 1980s. These improvements, prompted by concerns over air emissions, were the result of significant research efforts that identified the mechanisms responsible for the release of various pollutants. This work provides an understanding of the processes that in turn allowed formulation of design and operating guidelines to limit the release of these pollutants (Seeker et al., 1987).

The material in the gas stream leaving the heat recovery system consists of:

- gaseous products of combustion including carbon dioxide, hydrogen chloride, sulphur dioxide and oxides of nitrogen
- vapour forms of metals and organics
- solid particulate matter.

Testing programs on production installations have demonstrated that effective control of the emissions of trace metals, particulate matter and acid gases is possible with the new generation of equipment (Environment Canada, 1986; LIRPB, 1992). The environmental implications of the application of this technology, particularly with respect to changes in residues captured in the systems, need to be addressed.

Successful control of MSWI air emissions involves a combination of two processes:

- combustion control to limit conventional and trace contaminant emissions;
- post-combustion control to reduce the amount of material leaving the stack.

Discussions of air pollution control strategies must address both approaches because no modern plant can rely exclusively on one alternative. Good combustion control is the corner stone of most MSWI regulations issued in the past 6 years. Its application is standard in all new plants. This has led to a change in certain residue stream characteristics. Further changes have resulted from post-combustion control measures which, regardless of the degree of combustion control present in any plant, remove materials from the flue gas stream.

To provide a basis for discussion of the changes in ash and residue quality a brief discussion of combustion control follows.

### 4.1 COMBUSTION CONTROL

#### 4.1.1 Theory

Combustion control must compensate for:

- the natural variability in fuel quality; and,
- the controlling factors that govern the rate of chemical reactions.

**Compensation for Fuel Variability**

MSW is not a homogeneous material. As shown in Chapter 2, MSW is a mix of paper, plastics, other organic materials and non-combustibles. Each component has its inherent energy content and this must be matched with sufficient oxygen to ensure proper combustion. Because the mix of components changes from season to season, week to week and indeed from bag to bag, some means must be provided to allow the system to handle this variability. The first step in most facilities is to ensure that the arriving waste is well mixed before being charged to the furnace. The operators thus attempt to combine both the wet leaves and the plastic discards from a commercial establishment and average the energy level of materials entering the furnace. The well-mixed charge will still vary, but this variability can be handled in a well-designed furnace.

The European mass burn systems generally utilise combustion control systems to compensate for the variability in the fuel. These systems sense the rate of heat release in the furnace and adjust the supply of combustion air to compensate for especially high or low heat-release rates. The means by which the designer accomplishes the adjustment is generally seen to be the most critical aspect of the control of the emissions of trace organic compounds. Modular systems generally rely upon maintaining a large quantity of fuel in the primary chamber to damp out the variability in the waste quality. The amount of fuel on the bed is typically greater than in either of the other designs. The production of RDF provides the ultimate control for fuel variability. The nature of RDF is different: the sizes of individual pieces of waste are more uniform; the non-combustibles have been removed; and, in the process the materials are thoroughly mixed. These characteristics make the control of the furnace less critical than it is in other combustion processes.

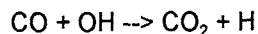
Differences in the waste fed to the systems and the degree of control the operator has over the combustion process are reflected in variations of the residues streams resulting from the different types of systems. These aspects are addressed later in this chapter.

**Factors Controlling the Chemical Reaction Rate**

The thermal destruction of organics is not a simple process. Many intermediate steps are involved in the oxidation of long chain hydrocarbon materials to the products of complete combustion namely carbon dioxide (CO<sub>2</sub>) and water. The reaction that occurs on the bed of any incinerator is one of gasification, with the garbage being exposed to air while being heated. The amount of air added under the bed of material and the degree of agitation of this material controls the rate of gas generation. The gases that leave the bed are rich in carbon monoxide and hydrogen and contain many unburned hydrocarbons. When provided with additional air, these gases burn readily. This additional air, referred to as overfire air, is supplied above the bed. The degree to which the combustion process is completed is a function of how well the air and the gases are mixed. The amount of carbon dioxide generated defines the extent of combustion completion and is generally referred to as the level of combustion

efficiency. Complete combustion will result in the generation of  $\text{CO}_2$  and water vapour, however, 100% combustion is difficult to achieve in most combustion processes.

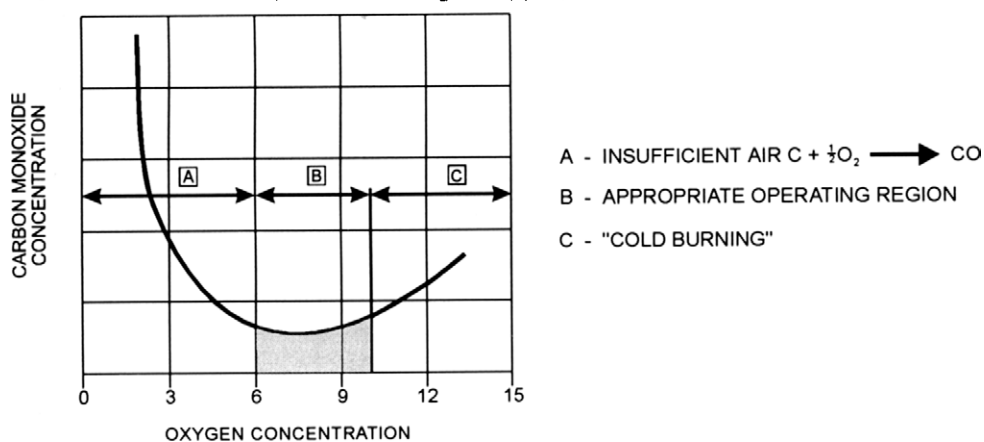
Carbon monoxide (CO) is the most refractory species in the oxidative chain from hydrocarbon to carbon dioxide and water. The oxidation of CO to  $\text{CO}_2$  is accomplished much faster in the presence of hydrogen. Miller and Fisk (1987) suggest the dominant reaction in the chain is:



The concentration of hydroxyl radicals is very important in the reaction. However, the reaction between hydroxyl radicals and hydrocarbons is faster than that between CO and OH and it is necessary to consume all the hydrocarbons before the system can maximise the conversion of CO to  $\text{CO}_2$ . Thus high levels of CO are generally correlated with higher levels of hydrocarbons, illustrating the rate-limiting steps in the reaction.

If excessive air is present in the furnace, the combustion temperature and the concentration of hydroxyl radicals are reduced. In turn, the organics react with the OH radicals and the CO oxidation does not occur. Conversely, insufficient air can lead to pockets of fuel rich gas that lacks sufficient oxygen to oxidise the CO. It is possible to establish an appropriate range for the concentration of oxygen in any system. A typical curve is shown in Figure 4.1 and illustrates the limited extent of the appropriate or "good" operating region. Operation in this zone minimises the release of CO and thus also minimises trace organic releases. The establishment of this range is most important because, once determined for a system, it can be used for the purposes of ensuring that the system is operating at its most efficient level.

Figure 4.1 Relationship of CO and  $\text{O}_2$  for Appropriate Operating Regions



(from DBA, 1986 as presented by Seeker et al., 1987)

Good combustion conditions leading to reduced organic emissions are those that:

- ensure complete mixing of the fuel and the air;
- maintain sufficiently high temperatures in the presence of sufficient oxygen;
- prevent the formation of quench zones or low temperature pathways that would allow partially-reacted solids or gases to exit from the combustion chamber.

These design conditions must be combined with good operating conditions to ensure that the performance is maintained and organic constituents are reduced to basic elements.

Combustion control addresses the destruction of organic compounds but it also has an influence on the downstream partitioning of inorganic materials in the incinerator. Higher temperatures in the furnace can influence the compounds formed in the furnace and the degree of volatilisation that occurs. Trace metals are neither created or destroyed in the combustion process; their form and speciation can be changed by the reaction and thus their eventual partitioning in the incinerator can be influenced. Higher temperatures and more complete combustion result in trace metals being found further down the system, particularly in the APC residue stream. These situations do not change the handling of MSW incinerator residues from the furnace or the heat recovery sections but they can have an effect on the ultimate management of these streams as the chemical composition changes.

The conditions that lead to a reduction in organic emissions also can cause an increase in the generation of  $\text{NO}_x$ . The formation of  $\text{NO}_x$  is attributed to two mechanisms: the oxidation of the fuel nitrogen to  $\text{NO}_x$ ; and, the combination of nitrogen and oxygen in combustion air at high temperatures, the thermal  $\text{NO}_x$  portion. The conversion of fuel nitrogen to  $\text{NO}_x$  is dependent upon the local oxygen availability to volatile species, the amount of fuel-bound nitrogen and the chemical structure. The thermal  $\text{NO}_x$  reaction is strongly temperature dependent because it is formed by the combination of radicals of the two species. It has been shown that the conversion of fuel nitrogen can range from 5% to 50% controlled largely by the extent of mixing and the amount of oxygen present.

Some combustion systems have been developed to reduce the levels of  $\text{NO}_x$  created. These include reburning where flue radicals, primarily CH species, can reduce NO to molecular nitrogen. These processes were discussed by Seeker et al. (1987), and, more recently it was suggested that this technique can improve the destruction of trace organics (Seeker et al., 1991). Combustion control arrangements for  $\text{NO}_x$  reduction in MSW incinerator systems have not progressed beyond the demonstration stage at this time. Reburning technology is most effective in those conditions where the use of the extra fuel is justified by improved thermal performance of the system but cost effectiveness may be improved when used in combination with other techniques. These other methods of  $\text{NO}_x$  reduction include catalytic and non-catalytic techniques which are addressed later in this chapter.

If gas temperatures are not reduced in the APC system, volatile metallic species may be released from the stack. Regardless of the combustion control effectiveness, post-combustion control is necessary to limit metallic species emissions.

Improved combustion control, aimed at reducing both emissions and operational problems such as high temperature corrosion in the reducing zones of the furnace, has placed more emphasis on combustion uniformity. This has improved the residue characteristics exhibited by newer units.

## 4.2 POST-COMBUSTION CONTROL

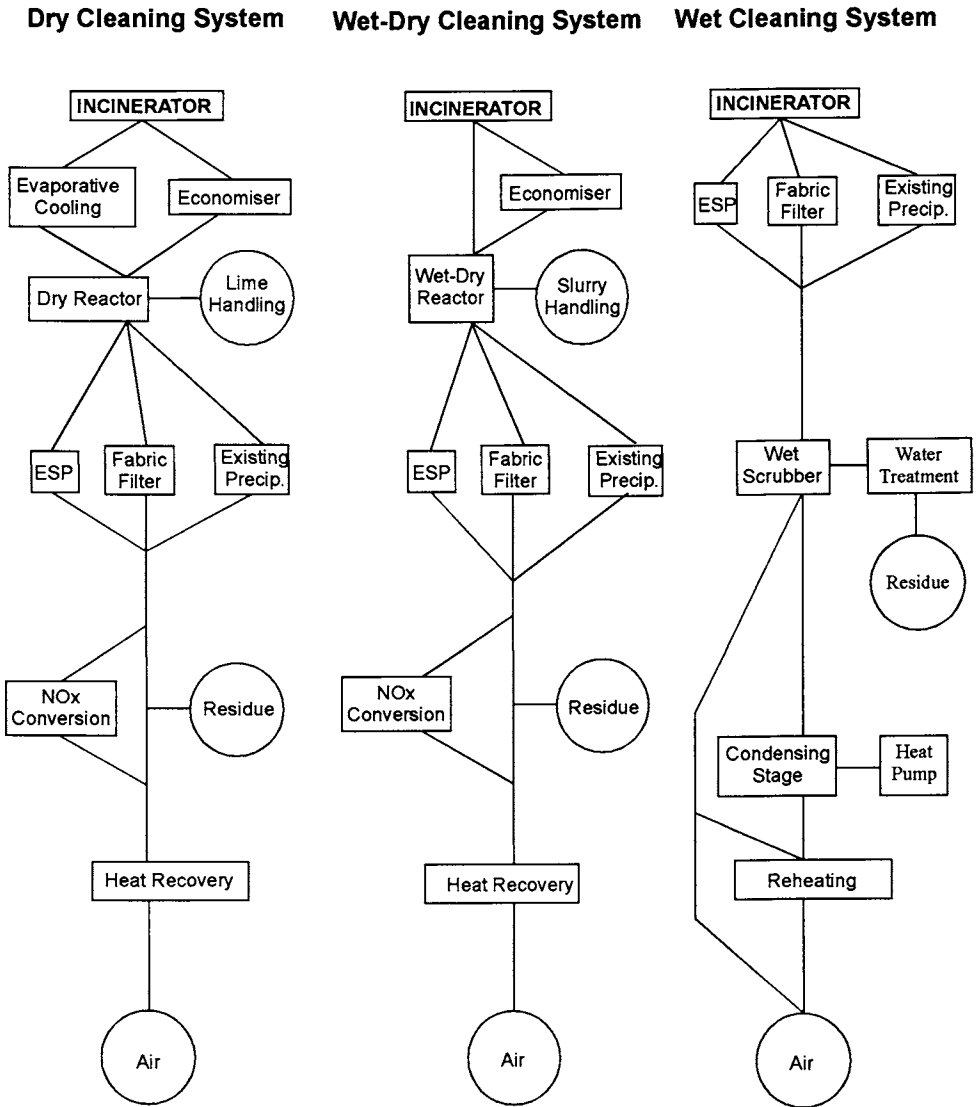
Post-combustion control through the use of air pollution control (APC) systems will remove unwanted contaminants such as trace metals and various acid gases from the flue gases. Trace organics can also be reduced through the use of such systems (Environment Canada, 1986). There are three key aspects to the operation of these systems: the reagent used; the temperature control level; and, particulate removal efficiency. All have the potential to influence the characteristics of the solids found in the APC residue stream.

APC systems rely upon both physical and chemical unit processes involving different solids removal and chemical conversion steps to effect control of unwanted emissions. These processes are combined to achieve the desired flue gas quality at an acceptable capital and operating cost. Different types of systems can change the quantity of residues resulting from the flue gas cleanup, thereby influencing disposal costs. Figure 4.2 provides a schematic of various APC system options as devised by Fläkt (1991). Table 4.1, adapted from Fläkt (1991), provides a generalised comparison of the variations between the alternatives. The order of use of the various processes is governed by the selection of the process steps. These tools provide a relative comparison between different options and should not be used to selection purposes. For instance, apparent anomalies such as wet scrubber performance compared to other systems relate to Fläkt's concerns about the need to clean the effluent from wet scrubbers. The heat potential category relates to the desire to use available heat for other purposes and in this case, the wet scrubber offers the best potential. However, if NO<sub>x</sub> control is to be used, some of this potential may not be realised.

APC system development has changed over the years. The systems and methods discussed in this chapter represent the most current technologies in use throughout the world. Older technologies may be used in some locales but are being phased out. Since information on the characteristics of residues from these systems is not as readily available, only limited comment is provided.

Individual unit processes are discussed in the following sections. These discussions outline the benefits and weaknesses of various types of devices for each of the process steps, with emphasis on the residues generated.

Figure 4.2 Comparison of Various APC Alternatives



After Fläkt, 1991

Table 4.1  
Comparison of Operating Features of Various APC Alternatives

CLEANING PRINCIPLE	DRY	WET-DRY	WET
INVESTMENT COSTS	low	medium	usually high
OPERATING COSTS			
lime consumption	medium	low	low
soda consumption	none	none	medium (if use special SO <sub>x</sub> stage)
energy consumption	low	medium	medium
maintenance requirements	very low	low	medium
COLLECTION EFFICIENCY			
dust	very high	very high	high
HCl and HF	very high	very high	very high
SO <sub>x</sub>	medium	medium	high (with special stage)
NO <sub>x</sub> (without special add-on stage)	low	low	none
heavy metals	very high	very high	medium
hydrocarbons	very high	very high	medium
HEAT POTENTIAL	high	medium	very high

After Fläkt, 1991

#### 4.2.1 Unit Processes for Air Pollution Control Particulate Matter Control Systems

In the previous chapter, reference was made to various particulate removal mechanisms that result in the collection of particles in the boiler hoppers of MSW incinerators. A major physical mechanism responsible for this removal is settling. Settling requires low gas velocities and its effectiveness is limited by the size of the chamber required to remove fine particles from the gas stream. To increase the removal, early incinerator systems were equipped with cyclone separators that employed inertial forces to separate materials down to approximately 5 µm in size. Other mechanisms were then utilised to remove the finer particles from the gas stream.

Liquids can be used to enhance the removal efficiency of fine particles from the gas stream. Two principal mechanisms remove aerosols:

- wetting the particles by contact and having the wetted particle impinge on a surface from which they are subsequently removed by the liquid; and,
- impinging dry particles on a wetted surface and then washing them off the surface.

This removal mechanism depends upon establishing intimate contact between the particles and the wetting solution. This is accomplished either through impingement by spray droplets; diffusion; or, condensation. Impingement relies upon spraying the gas stream with liquid; its removal efficiency being proportional to the number of droplets and the force with which they are generated. Diffusion relies upon Brownian motion to bring dispersed particles in contact with liquid surfaces. Increasing the gas stream's turbulence will increase the removal efficiency and thus the frequent use of venturi devices combined with water sprays for high removal efficiencies. Condensation processes occur when the gas is cooled below its dew-point. In this condition, the particulate matter in the gas stream serve as nucleating sites for droplet formation and the particles are removed with the liquid.

Conventional wet scrubber systems are effective at removing particles down to 1  $\mu\text{m}$ . The removal of smaller particles requires another generation of control devices, the electrostatic precipitator (ESP), or the fabric filter (FF). The use of these devices has become dominant in modern incineration facilities.

### **Electrostatic Precipitators**

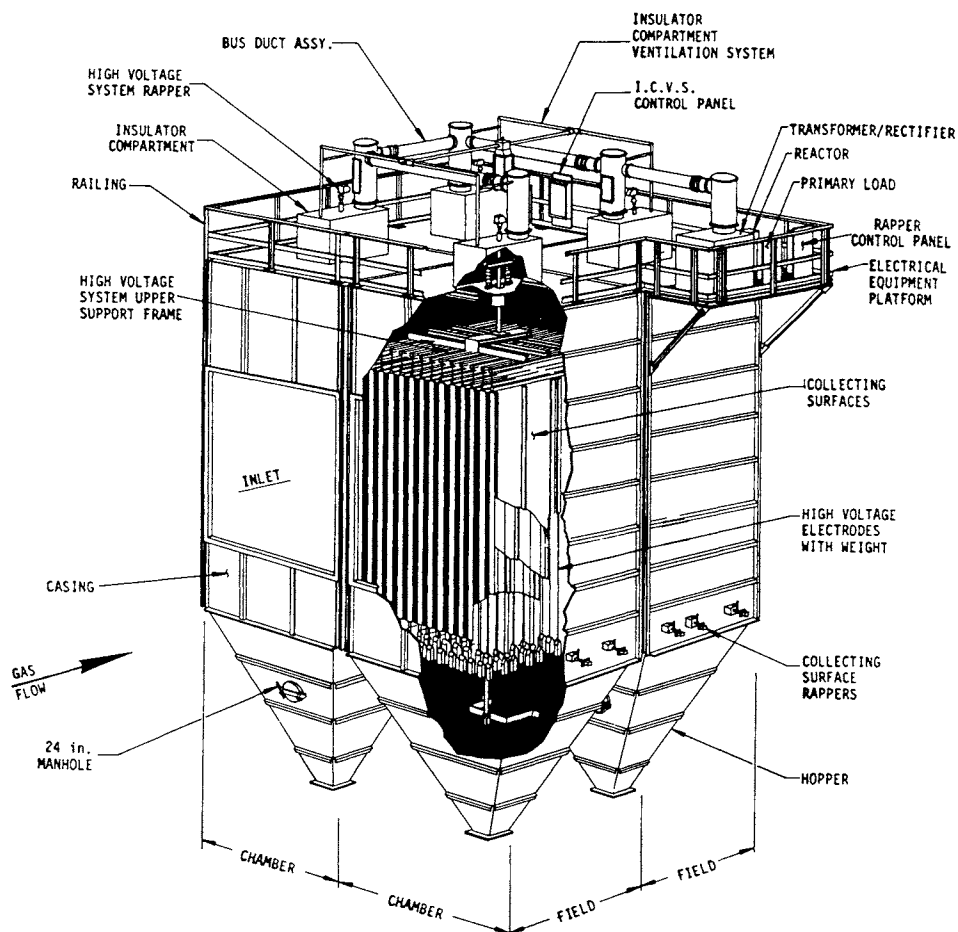
Electrostatic precipitators (ESP) operate as follows:

- The gas stream passes through a series of discharge electrodes. These highly charged units impart a negative charge to the particles in the gas stream.
- A grounded surface, or collector electrode, is placed adjacent to the discharge electrode. The charged particles collect on the grounded surface.
- Particles are removed from the plates usually by rapping on the collectors. The removed particles drop into a hopper and are periodically removed.

It is critical that material be removed from the collectors to prevent it from forming an insulator over the collector and reducing collection efficiency. Figure 4.3 shows a typical ESP system.

The efficiency of ESPs is sensitive to variations in gas temperature and humidity and to changes in the nature and resistivity of the particles. Velocities through the precipitator usually range from 0.7 to 1.3 m/s. At these rates, the removal effectiveness is a function of the number of banks of precipitator fields used in the design. Manufacturers will quote efficiency factors as high as 99%+ if sufficient fields are used.

Figure 4.3 Typical ESP Installation



Typical wire-weight electrostatic precipitator with top housing.  
(Courtesy of Western Precipitation)

(from U.S. EPA, AP 40)

The ESP is efficient in the collection of material in the 0.1 to 10 micron ( $\mu\text{m}$ ) size range, although it does have some limitations in the 0.1 to 1.0  $\mu\text{m}$  range. Removing finer material also requires the use of extra fields. High efficiency ESP installations will remove 100% of the  $>50 \mu\text{m}$  material,  $>99\%$  of the  $5 \mu\text{m}$  material and 98% of the  $1 \mu\text{m}$  and smaller material. Unlike fabric filters, emissions from ESPs can vary depending on the concentration of particulate matter in the flue gas stream.

ESPs can be designed for temperatures as high as  $375^\circ\text{C}$  although more commonly they operate at about  $200^\circ\text{C}$ . Some volatile metals will escape capture in ESPs operating at elevated temperatures because they will not condense and form particles that can be removed. Without an appreciable temperature drop volatile organic and metallic species will flow through the system. This is particularly the case for mercury as shown in Environment Canada's NITEP studies (Environment Canada, 1986). In addition, since trace metallic and organic species tend to condense on surfaces and the ESP has only limited fine particle control, the removal effectiveness for species condensing on the surfaces of the fine particles is reduced. Furthermore, ESPs operating at elevated temperatures have been shown by Vogg et al. (1990) to be likely to have enhanced PCDD/PCDF in their residue streams. This finding suggests that *de novo* synthesis of these compounds occurs at the operating temperatures found in some units. On the other hand, ESPs operating at low temperatures ( $<200^\circ\text{C}$ ) can experience premature failures due to corrosion damage.

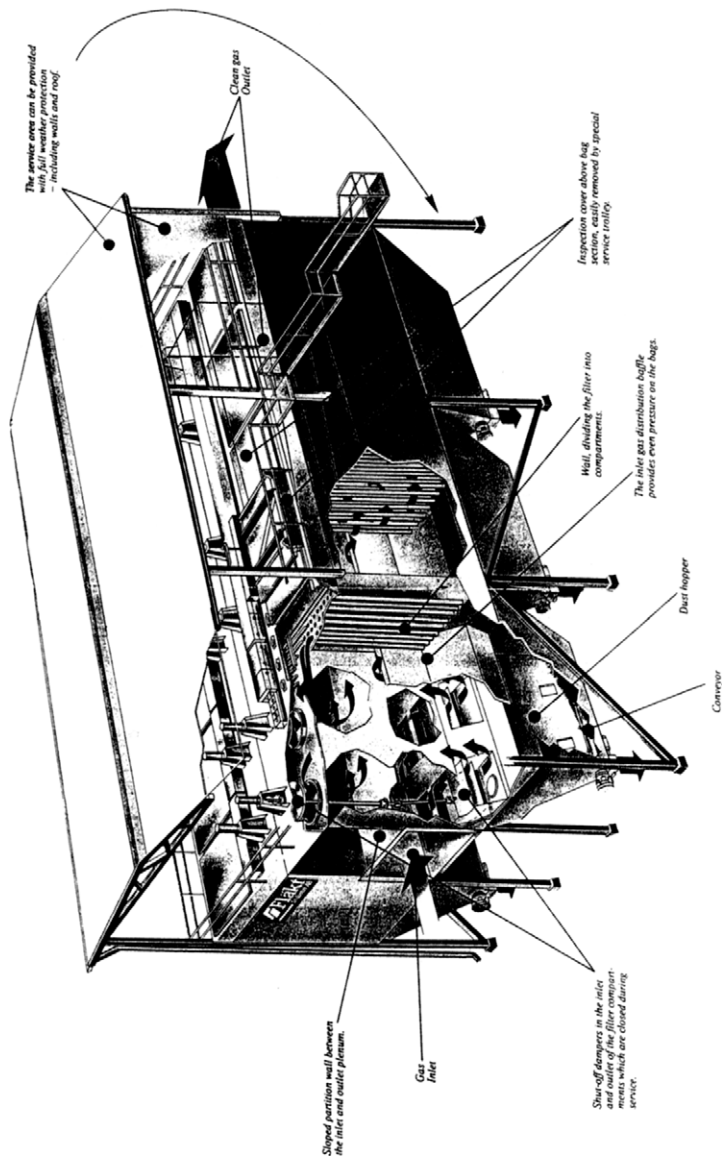
The most marked difference between the ESP and other types of high efficiency particulate matter control devices is cost. The initial cost of a high efficiency ESP unit will be substantially greater than that of most other types of control devices with similar performance, however, the operating costs are much lower. Pressure drops through ESP units are very low and thus the power expended for removal is low. With few moving parts, ESP maintenance concerns are usually a function of the type of materials being removed from the flue gases; sticky or corrosive fumes tend to raise the maintenance requirements. Although, as mentioned above, operating temperatures and flue gas composition must be considered if corrosion is to be avoided.

### **Fabric Filter (Baghouses)**

Fabric filters, or baghouses, are used in all types of industrial applications. They are essentially a set of permeable bags which allow the passage of gas but not the particulate matter entrained in the gas. They are effective for removing particles in the submicron range and their removal efficiency is typically better than that of the ESP.

The fabric filter, Figure 4.4, consists of a large housing which may or may not be divided into a series of compartments. Each compartment contains a set of long cylindrical woven bags fitted over a wire mesh support. The bags and their support frame are fastened to a support rack which effectively seals the inlet gas stream from the exhaust or filtered stream. Gas is introduced into the inlet side of the compartment,

Figure 4.4 Typical Fabric Filter System



(courtesy Asea Brown Boveri Inc.)

passes through the bag material where the particulate material is filtered out by a combination of processes and is then exhausted from the outlet side of the compartment. As the process continues, the particulate matter removed from the gas stream forms a layer on the surface of the bag, generally called the cake, and the pressure drop across the filter increases. Periodically this cake must be removed from the filter either by mechanically shaking the bags or through the use of reversed or pulsed air flow. The residue released from the filter falls into a hopper under the unit and can be removed for disposal.

The mechanisms governing removal on the fabric filter include:

- direct interception;
- inertial impaction;
- diffusion;
- electrostatic forces;
- weak molecular interaction forces; and,
- gravity.

The presence of the cake on the bags enhances the removal efficiency of the system because it improves the interception of particles. Thus, the removal efficiency of fabric filter systems with newly installed bags can be lower than that of systems that have operated for several months. Some of this deficit can be overcome by using bags with natural fibres such as wool which provides a greater surface area to intercept particles than that found with bags woven of man-made fibres. The latter systems have better durability to acid gases and therefore, typical materials used for fabric filters in the MSW applications are glass fibre or Teflon. Typically an air-to-cloth ratio of 4:1 ( $\text{m}^3/\text{m}^2$ ) is specified for pulse jet systems, but other types of systems incorporate a range of air-to-cloth ratios from 2:1 to 10:1. The air-to-cloth ratio defines the flow rate through the filter material. A ratio of 4:1 implies that 4 cubic metres of gas per minute are filtered by every square metre of cloth in the filter compartment.

The nature of the cake on the filter fabric is important to the performance of the filtering system. Even after cleaning, the bag will continue to retain a significant quantity of residue; bags can retain 10 to 20 times as much material as they filter out during any given filter cycle. This is beneficial when these systems rely on chemical and physical transformations for pollutant control. When unspent reagent is retained on the bag it provides additional acid gas control capability.

Unlike the ESP, the fabric filter also has an ability to cope with fluctuations in both the particulate matter loadings and gas flow rates through the system. The fact that the emissions from typical MSW incineration processes are not consistent (since the feed material is not uniform) suggests that the fabric filter is a preferred particle control device if high removal efficiencies are required.

Numerous factors can affect fabric filter performance. These include:

- flow rate;
- operating temperature;
- moisture levels;
- particle size range; and,
- particle characteristics.

As noted earlier, typical flow rates for pulse jet systems are in the range of 4 m<sup>3</sup>/minute/m<sup>2</sup> of fabric. Higher flow rates increase the pressure drop and reduce bridging potentials, whereas lower flow rates reduce impaction processes. Gas temperature control is important to the removal of volatile materials. This is often accomplished by evaporating water in the gas stream, however, excess humidity in the flue gas can lead to filter blockage problems. Since fabric filters are frequently used in conjunction with lime addition for acid gas control, the residue removed on the bags can have a high percentage of hygroscopic salts. If the temperature and the humidity are not balanced properly, the nature of the residue layer on the bags will change. What should be a light, fluffy material that is easily removed during cleaning can become a sticky, dense layer that raises pressure drops across the system and leads to other operational difficulties such as:

- increases in energy costs due to higher pressure drops;
- a decrease in flow rate; and,
- reduced bag life due to adhesion and the abrasion properties of the particles.

Current performance specifications for fabric filters on MSW incinerators suggest that the systems should have a routine performance capability below 0.008 grains per standard cubic foot of gas. This translates to an emission level of 18-20 mg/Rm<sup>3</sup> (dry gas at 25°C, 101.3 kPa, and 11% O<sub>2</sub>).

### **Gaseous Controls**

Particulate matter control is only one aspect of post-combustion control through the use of APC systems. Acid gases, particularly HCl, SO<sub>2</sub> and HF require control and volatile materials, both organic and metallic, require special consideration if they are to be successfully controlled. The removal of gaseous phase acidic components can be accomplished by neutralisation. This requires the addition of chemical reagents either in liquid or dry form, hence two types of systems generally exist:

- wet systems, where the gases are passed through a liquid solution; and,
- dry systems, where the gas stream does not reach saturation.

Special measures are required for NO<sub>x</sub> control.

### **Wet Systems**

There are numerous types of wet collectors, ranging from modified cyclones containing water sprays to venturi scrubbers and packed tower units. Considered separately,

none of these systems is capable of performing at the level required of a modern APC system; rather they are frequently used in combination with other devices to achieve the required performance. An example of such a system is the dual wet scrubber required for acid gas control. Because wet systems operating at a low pH to remove HCl, HF, HBr and Hg do not remove SO<sub>2</sub> effectively, a second stage, operated at neutral pH levels, is required. The advantage of wet systems is that they operate close to stoichiometry thereby reducing the quantity of residue generated in comparison to dry/semi-dry systems.

The major limitation of many wet systems is their inability to remove fine particles effectively unless the energy expended in the system is sufficiently high. This is why wet systems are commonly used downstream of a conventional dust removal device. Corrosion of the materials in the quench stage of the wet system can lead to major maintenance requirements, but is frequently overcome by using fibreglass reinforced plastic (FRP) vessels and ceramic nozzles and cladding.

As a single component system, the packed tower is a common wet system encountered in modern incinerator facilities. As its name implies, the packed tower is a vessel with a bed of granular or fibrous material which traps the particles. The liquid used in the system washes the material off the packing and prevents re-entrainment. Coarsely packed granular material will remove particles that are larger than 10 µm and the velocity through the bed should be below 2 m/s. Finely packed beds can remove particles in the 1 to 5 µm size range but the velocities through the bed must be kept below 0.25 m/s. Finely packed beds are prone to plugging with particles. These limitations tend to result in packed towers being applied to neutralise the gases after primary particle removal systems.

Examples of liquids introduced into these systems include water, lime slurry (calcium hydroxide) and caustic (sodium hydroxide). Hydrogen chloride and the other halogens show a high affinity for water, readily combining to form hydrochloric acid and similar substances. The introduction of lime slurry results in the removal of both HCl and SO<sub>2</sub>. Caustic easily combines with SO<sub>2</sub> resulting in high removal efficiencies but is less efficient for HCl. The alkali addition leads to the formation of an aqueous salt/slurry, which increases waste volumes and can present some difficulties with particulate matter emission rates. Very fine particles of salt in the gas stream cannot be removed by the conventional inertia separators used to control moisture release from wet scrubbers. Downstream removal of these fine particulates requires sophisticated control devices.

Introducing liquids into the gas stream reduces the temperature of the gas stream and evaporates substantial quantities of liquid. Thus, the stack gases have high levels of moisture. This situation can cause rapid cooling of the plume resulting in loss of buoyancy and local impingement which can lead to reduced visibility, icing, or elevated odour levels. Plumes with high moisture levels are often interpreted by the public as polluting the environment. To overcome these limitations, wet systems can include a

condensation stage to remove moisture and a reheat stage to heat the gases before they exit the stack.

Wet scrubber systems can consume substantial amounts of scrubbing solution. The removal of the various contaminants from the gas stream converts an air emission concern into a potential wastewater treatment concern. This can be significant because most jurisdictions do not permit discharge to sanitary sewers without pre-treatment. Some discussion of pre-treatment systems is included in the example systems presented later in this chapter.

Alternatives do exist that limit the need to treat the liquid effluent. In some cases the effluent from the wet scrubbers has been re-injected into the gas stream to promote cooling prior to the primary particulate control devices. These units, electrostatic precipitators in most cases, remove the particles formed during the evaporation process and they are collected in the normal manner. To prevent damage to the particle control systems, the gas temperature entering the evaporation zone is normally higher than it would be for normal energy recovery, thus there is some potential loss of energy efficiency in the system.

### **Dry Systems**

In the context of this report, dry systems will be defined as those that release a gaseous effluent that is not saturated with water. This reduces the concerns about corrosion, visible emissions and plume sag associated with wet scrubbers. The operation of dry systems may involve humidification of the flue gases in an evaporative cooling section; however, the gas stream does not become saturated. Several types of dry systems exist:

- pure dry sorbent addition into the furnace, duct or reactor;
- semi-dry systems where the sorbent is:
  - injected in dual nozzle atomisers that mix water with dry sorbent; or,
  - injected as a slurry; and,
- combination systems utilising a gas conditioning system with a wet spray humidifier followed by dry sorbent injection in a venturi reactor.

Furnace sorbent injection has only limited application in the MSW field although it is considered commercially proven given significant application on coal fired utility boilers. Typically, limestone or calcium hydroxide are injected into the high temperature zone of the furnace where the temperature causes the material to calcine to produce lime (CaO). This lime then combines with HCl, HF or SO<sub>2</sub>, to produce various salts. The particulate salt is removed in the particulate matter control device. Furnace injection systems have been shown to be effective for SO<sub>2</sub> removal but not for HCl and HF removal (Zmuda and Smith, 1991). Removing these latter compounds with lime requires lower operating temperatures. With its low capital cost and ease of retrofit this method could be appropriate for upgrading facilities. Its drawbacks include low removal efficiency and significant increases in particulate matter loading to the control devices.

Several North American facilities, (Claremont, NH and Davis County, Utah) inject sorbent directly into the gas ducts after the furnace. These are called Duct Sorbent Injection [DSI] systems. At Claremont, lime is the sorbent of choice but the removal efficiencies are less than 70% for both HCl and SO<sub>2</sub>. Recent tests at the Davis County facility have included the use of water injection to cool the gas stream prior to sodium sesquicarbonate injection. This sorbent is readily available in Utah. The lower temperature results in higher removal efficiencies and lower reagent consumption.

Ease of installation and lower capital cost are the main advantages of DSI systems; high sorbent use and high waste volumes are disadvantages. The choice of sorbent is a local decision based upon costs for supply and disposal of waste materials, and the removal efficiency of the particular material. Both sodium bicarbonate and sodium sesquicarbonate provide a higher removal efficiency at lower equivalent injection rates than lime, but they can be more costly.

The semi-dry injection systems are commonly used in the U.S. and Europe and on hazardous waste facilities. The addition of the lime sorbent in a slurry combines the effects of moisture addition and sorbent addition and tends to result in slightly smaller installations than the combined systems discussed in the next paragraph. The chemical reactions are similar to those discussed in previous paragraphs.

The third type of system has been installed in numerous North American and European plants and could be considered "purpose-built" duct sorbent injection system. The gas is cooled in an evaporative cooling tower by the injection of water and the cooled gas then passes through a venturi reactor vessel where lime is added to the gas stream in the highly turbulent zone created by the venturi. This type of system, along with the slurry injection system, produces higher removal efficiencies at lower sorbent injection rates than do the standard duct or furnace injection systems.

Regardless of the system chosen, there will be dry powder in the gas stream. This dry powder combines readily with the HCl in the stream to form CaCl<sub>2</sub> which can be trapped in the particle removal system. As mentioned earlier, fabric filter systems provide an additional benefit over ESPs when considering acid gas removal. The cake formed on the fabric filter contains unreacted lime which can combine with the residual HCl to increase the neutralisation efficiency. The fabric filter cake acts as a polishing step for HCl removal and allows an average lime addition rate to be used to maintain control during periods of higher than normal flue gas HCl concentration.

### **Metals Control in Dry Systems**

Volatile metals and organics demonstrate a high affinity for surface sorption, thus introducing a finely divided acid gas reagent into the flue gases provides an additional benefit for the removal of trace metallic and trace organic species by providing a large surface area in the form of fine particles in the APC system. This is illustrated by reduced emissions of volatile species from modern APC systems, however, some

limitations exist. ESP installations are less efficient in collecting fine particles and have relatively higher emission rates than in comparable fabric filter installations. ESP systems also suffer from changes in particle characteristics. If the particle resistivity changes, the removal efficiency can be influenced. Furthermore, the adsorption effects are temperature dependent and regardless of the particulate matter control device, higher temperatures reduce the capture efficiency. Lastly, in some dry injection systems, the recycling of the fabric filter dust to the venturi reactor to increase SO<sub>2</sub> removal efficiencies and lower reagent costs can result in an increase in the concentration of salts and trace species in the residue stream. The advantage of recycling the residue streams is that the partially expended sorbent is more capable of removing SO<sub>2</sub> from the gases than the raw hydrated lime. Recent studies suggest that this might be because the SO<sub>2</sub> removal process requires more moisture to be effective and the partially expended sorbent contains CaCl<sub>2</sub> which has a high affinity for moisture.

### **Mercury Control with Activated Carbon**

Regardless of particulate matter control device or operating temperatures, mercury removal efficiencies are fairly low in most systems. This metal has a high vapour pressure and mercury compounds can remain in the gas phase at temperatures less than 180°C. Indeed, NITEP testing at Quebec City in 1986 addressed the influence of temperature on the removal of mercury in the wet spray humidifier, dry lime injection, fabric filter APC system (NITEP, 1986). These data were instrumental in the CCME committee's recommendation for APC inlet temperature found in the MSW guidelines (CCME, 1989). Lowering the temperature was effective, introducing at least a 40% reduction in mercury emissions but further reductions were deemed necessary.

In Europe, wet systems have added TMT reagent to trap the mercury and remove it from the gas stream. To meet the emissions limits in its permit, the Burnaby B.C. facility used sodium sulphide injection into the APC for a period of time. This was replaced by activated carbon injection to reduce the risks to plant workers who were handling the sorbent (Guest and Knizek, 1991). Activated carbon has been used for mercury removal in a number of European facilities and was introduced into the APC system of the new Amsterdam plant to reduce PCDD/F emissions. One European manufacturer has developed a fixed activated carbon bed scrubber to be installed at the end of the APC system to polish the gases and remove trace organics and mercury. The activated carbon in this system must be periodically removed and disposed either by incineration or by another method.

Activated carbon appears to be a very effective mercury sorbent and improve removal efficiencies to the high 90% range. An additional benefit reported in some test data is an increase in PCDD/PCDF removal rates when activated carbon is used.

During development of the new regulations in the US, the EPA conducted tests on numerous control techniques to establish their performance and efficacy. Two

activated carbon injection tests were conducted at the Stanislaus County facility in California and at the Camden County facility in New Jersey. Initial data from Stanislaus showed that 80-percent mercury reduction was achievable and subsequent testing produced higher Hg reductions with increased the carbon feed levels. This analysis concluded that, at a carbon injection rate of approximately 100 mg/dscm of flue gas (0.33 kg carbon/Mg MSW), the proposed limit of 57 mg/Rm<sup>3</sup> or 85 percent reduction would be achieved (US EPA, 1995BID). Using these and other data, Rigo (1993) developed an equation to relate carbon charge rate to mercury removal efficiency. This suggested that approximately 250 mg of carbon/DSCM of flue gas should achieve a five test average removal efficiency of in excess of 90% with outlet concentrations of 57 µg/Rm<sup>3</sup> given typical inlet data.

Burnaby, which has a recirculation system with a fabric filter, consumes between 13,000 and 17,500 kg/year of carbon (VanWaters & Rogers, Pers. Comm.). This translates to a usage rate of approximately 2.4 kg/h, or 0.08 kg/t of waste and agrees well with the feed rates, 2 kg/hr, used during testing of the Burnaby facility in 1993. At that time the outlet mercury concentration was measured at 16-22 µg/Rm<sup>3</sup>, or in excess of 95% removal efficiency (Guest, 1993). These data were collected in February, when the amount of yard and garden waste at the Burnaby facility would be anticipated to be low. Thus, consistent performance at these values should not be anticipated; the mercury emission levels will depend upon the amount of mercury in the waste.

Besides the EPA tests, five U.S. MSW incinerators that began using activated carbon injection technology after 1994 (Union County, Lee County, Onondaga County, Falls/Bucks County, and Hennepin County) are meeting the proposed US limits for mercury (US EPA, 1995BID).

The limitations of powdered activated carbon relate mainly to typical chemical reaction parameters: contact time; temperature of the flue gases; dosing rates; and, the type of carbon (Heath, 1995). The process loses efficiency if the stack gases are not cooled below 200°C (NORIT, Pers. Comm.). This reduction has not been extensively charted but data recently collected at the ESP equipped facility in Davis County, Utah suggests that the removal efficiency difference between 300°C and 150°C is about a factor of 2. That is, less than a 50% reduction was seen when 30 kg/hr of PAC was added to the high temperature gases but when the temperature was reduced the removal efficiency increased to over 90% (ASME, 1996). Residence time in the system is also important and fabric filter systems have a distinct advantage because PAC will be retained in the cake and improve the utilisation of PAC thereby maximising removal efficiency at any given addition rate.

PCDD/F removal also occurs when activated carbon is introduced into the APC system. Heath (1995) reports removal efficiencies of 77-80% at an ESP equipped facility. Licata (1994) reports on the Wurzburg tests and notes that PCDD/F emissions were reduced 200 fold. Preliminary evaluation of the Davis County tests suggests that, at low temperatures, in excess of 80% of the PCDD/F is removed from the gas stream.

The US EPA (1995BID) concluded from all the tests it evaluated, 12 units at 5 new plants that are equipped with SD/FF/SNCR/CI controls, that an additional 50-percent or greater reduction of PCDD/F emissions can be achieved with carbon injection.

The characteristics of the APC residues generated by the use of activated carbon are also of concern. The removal of additional mercury from the gas stream will raise the concentration of mercury in the APC residues. Limited testing has shown that the mercury removed on the activated carbon is fixed to this medium and less environmentally available, at least when tested with certain regulatory leach test procedures, than the material trapped in lime only injection systems. Lanier (pers. comm.) has reported that in limited tests of PAC injection at a hazardous waste incineration facility, the increase PCDD/F's in the APC residue was greater than the amount of PCDD/F removed from the gas stream. This suggests that the addition of PAC may increase the production of PCDD/F's in the APC systems. This is similar to performance noted by Sierhuis and Born (1994) when they examined test data from the new Amsterdam facility.

The residues collected from the dry systems contain all the contaminants normally measured in stack gases. These systems have removal rates for most compounds in excess of 99%. The residue is finely divided and has the appearance of lime powder, unless high levels of particulate carry-over from the boiler occurs, causing the colour to change to buff or grey. The residue has a high percentage of  $\text{CaCl}_2$  and thus is hygroscopic in nature. Care must be taken to maintain the temperature of the material above the dew point to minimise condensation and the formation of solid blocks of material in the storage hoppers and transfer lines. All transfer lines should be sealed and insulated to minimise problems with moisture in the residue.

### **NO<sub>x</sub> Removal**

As noted earlier, many of the combustion control techniques used to minimise trace organic emissions can lead to increases in emissions of oxides of nitrogen (NO<sub>x</sub>). Conventional lime-based scrubber systems will not control emissions of NO<sub>x</sub>; however, other techniques are successful. These techniques include reburning that occurs in the combustion chamber; and post-combustion technologies including selective catalytic reduction (SCR) processes and selective non-catalytic reduction (SNCR) processes; or wet chemical techniques. Reburning involves a modification of the combustion process in the furnace to reduce NO<sub>x</sub> generation. The SNCR and SCR control processes are based upon the reduction of NO<sub>x</sub> through the addition of ammonia either at high, furnace temperatures, (SNCR); or at lower temperatures where a catalyst is used, (SCR).

The wet chemical techniques involve ozone and alkali absorption, complex absorption or reactions with sulphite solutions and organic compounds. The latter methods produce products that must be disposed of in an additional process step. Utilisation of the by-products as fertiliser is prohibited due to acid salts and ammonia salts which

are acidic in nature. The SCR and SNCR processes result in the generation of  $N_2$  and only trace amounts of reaction products, and thus are preferred methods. Care has to be taken, however, to prevent the production of  $N_2O$ .

Experimental reburning of the flue gas with natural gas has proven to be successful in reducing  $NO_x$  levels by 65% (Seeker et al., 1991). The process has not progressed to commercial application. An 85% reduction in  $NO_x$  can be achieved when re-burn was carried out with  $NH_3$  injection into the furnace. The latter is a form of SNCR.

The reburning process has been applied successfully to commercial utility boilers firing coal in the United States, Japan and the Ukraine as well as natural gas, oil and MSW combustion processes (Karil et al., 1992). The Japanese appear to be the most advanced in the application of this process. Karil et al. report on a recent MSW demonstration of this concept in Malmö, Sweden. During the Malmö project the furnace was divided into three zones. In the first the main fuel, MSW, is burned under fuel lean conditions and provides 80 to 85% of the released heat. The  $NO_x$  formed in this zone is due to fixation of atmospheric nitrogen or oxidation of fuel nitrogen. In the second zone, natural gas is introduced into the furnace to produce a slightly fuel rich reburning zone where  $NO_x$  formed in the first zone is reduced. This fuel supplies 15 to 20% of the energy input to the system. The third zone of the furnace received additional air to complete the combustion process by oxidising CO and fuel fragments and producing an overall fuel-lean condition. Some difficulties were experienced during the testing with the production of higher CO levels. The authors conclude that both the lower furnace and reburning zones will require careful optimisation to achieve the ultimate goal of low CO and low  $NO_x$  emissions. Overall they predict a 50% reduction in  $NO_x$  is possible.

Thermally based SNCR technologies include Exxon's De $NO_x$  process. This process utilises  $NH_3$ , injected with a carrier gas, either air or steam, at a point specifically selected to provide optimum reaction temperature and residence time. The injection is accomplished with specially designed nozzles strategically placed in the walls of the furnace to achieve adequate mixing (Hurst and White, 1986). SNCR technologies operate most effectively at flue gas temperatures of 850°C and furnaces that do not have temperatures in this ranges are unsuitable for this application (Hartenstein & Licata, 1996).

McDonald et al., (1991) provide a discussion of three applications of the Thermal De $NO_x$  technology at California plants. Several issues are raised, including the need for: stable conditions in the furnace; good mixing; and the right temperature, to ensure good performance. Difficulties experienced at three plants included the generation of false particulate matter in the stack testing samples. The presence of ammonia and water lead to the formation of an alkaline solution in the sampler that removed residual  $SO_2$ , HCl and  $NO_2$  and caused the formation of ammonia salts. Furthermore, any excess ammonia combines with the HCl present in the stack gases to form  $NH_4Cl$  which condenses in the atmosphere and results in the generation of a visible plume. Because

there is a possibility of forming ammonia salts in the process, trace increases in these compounds could be found in the APC residues from plants equipped with this technology. Lastly, it was evident that the injection location needed to be carefully selected to ensure that the ammonia was not burned in the furnace, thus increasing the emissions of  $\text{NO}_x$ . Thermal De $\text{NO}_x$  is estimated to be capable of achieving reductions in  $\text{NO}_x$  levels of 50 to 85%.

Other SNCR technologies which have been applied or proposed include: urea injection (NO $_x$ Out developed by EPRI and licensed to NALCO FUELTECH); cyanuric acid (RAPENO $_x$ ) and ammonium sulphate. NO $_x$ Out has been applied on a demonstration basis in the MSW incinerator in Frankfurt (Hofmann et al., 1990).

With selective catalytic reduction (SCR) technology, a catalyst is used to increase the low temperature reaction of ammonia and oxides of nitrogen to create nitrogen and water vapour. Efficiencies of up to 80% have been recorded in thermal power plants although operating experience on MSW incinerator applications suggests it is lower. However, on the Munich plant Fläkt have recorded emission values well within the German standard (184 mg/Rm $^3$  @ 11% O $_2$ ). Difficulties with catalyst-based systems include:

- sintering where the microsurface disappears as the catalyst's pores collapse due to elevated temperature reformation of titanium;
- poisoning when a molecule or atom of an alkali metal permanently attaches to an active site;
- plugging by capillary condensation or dust blockage; or,
- erosion due to HCl attack.

The latter situation can be overcome by placing the systems after the HCl removal device but this requires reheating the gases to the catalyst's optimum operating temperature of range of 300°C to 410°C. Operating at temperatures above 350°C is not recommended because of limitations induced by catalyst brittleness and ash softening. Outside the temperature range the efficiency of the conversion process suffers. To overcome removal efficiency limitations more catalyst can be used, however cost and installation space pose problems. These have partially been overcome by recent developments in Europe where a new generation of Low Temperature SCR [LTSCR] systems are being employed. These systems have increased vanadium pentoxide concentrations in the catalyst and operate with more effective conversion efficiencies at temperatures that range from 150 to 180°C (Hartenstein & Licata, 1996). They are not without their limitations the most significant of which is the control of sulphur species in the gases introduced in the LTSCR. There are currently 15 operating APC trains equipped with LTSCR technology in Europe.

The presence of ammonia in the gas stream results in the generation of ammonia bisulphate. This material limits the potential for reuse of the APC residues. The extent of this problem is illustrated by increases in the ammonia content of the APC residue

of 10 to 20 mg/kg with only a 5 ppm of ammonia being present in the gas stream. This level of ammonia, known as the 'Ammonia Slip' is not uncommon because precisely matching the requirements with the addition of the reagent is difficult. Furthermore, the ammonia slip will increase as the performance of the catalyst decreases. As a guide, Fläkt recommends replacement of the catalyst when the catalytic activity drops below 60% (Herrlander, 1990). Catalyst manufacturers will accept used catalyst for recycling purposes.

### **4.3 TYPICAL APC INSTALLATIONS**

As noted earlier, it is possible to combine APC processes to enhance emission control. The most common APC systems involve the use of sorbent injection, with or without gas conditioning, followed by some type of particulate matter control device, either an ESP or a fabric filter. It is possible to include SCR type systems after the particulate matter control device and lower the NO<sub>x</sub> emissions. On the other hand, systems incorporating an initial particulate removal stage followed by various stages of wet scrubbing and condensation and SCR have also been applied. This section will provide a brief overview of several systems as they are installed in MSW incinerator facilities, emphasising the different effects these combinations will have on the resulting residues and wastewater streams.

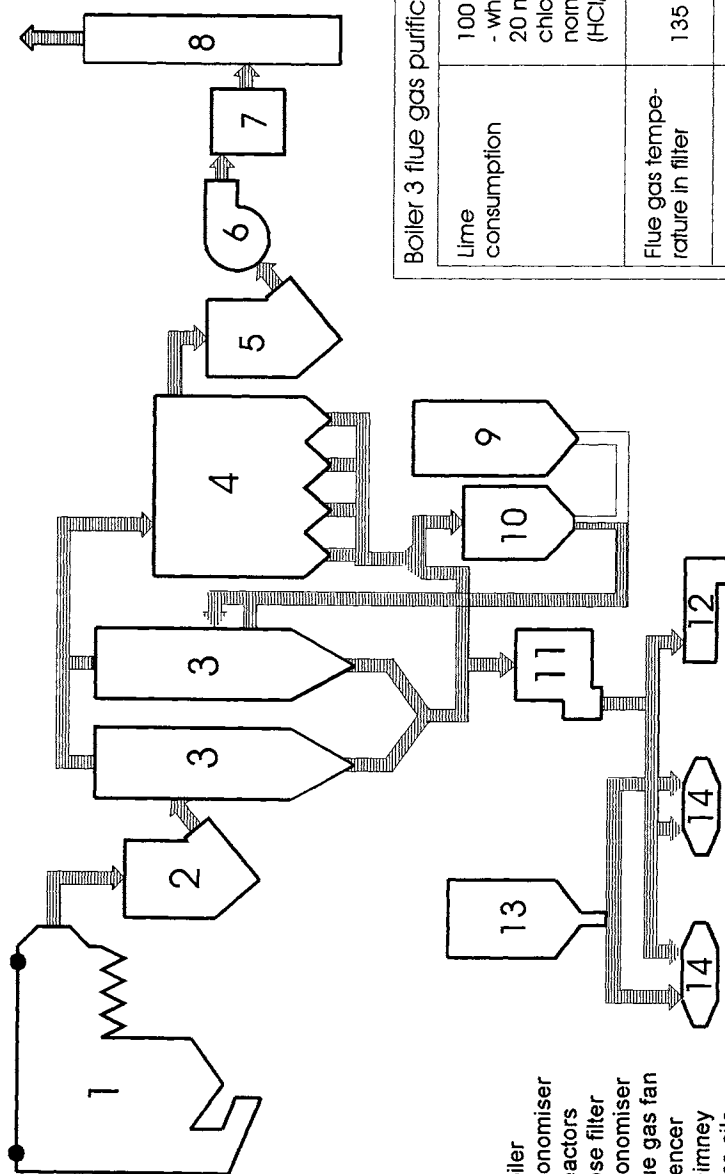
#### **4.3.1 Hogdalen, Sweden**

An example of an early wet spray humidifier/dry reactor/fabric filter APC system is the installation at the Hogdalen plant in Stockholm, designed by ABB Fläkt. A schematic of this plant is shown in Figure 4.5. The system is similar to that installed in four Canadian plants and used in numerous European facilities. While similar, the majority of installations in the United States utilise slurry injection systems for sorbent injection. There are several places in the Hogdalen system where dry residues are collected. In the cooling tower, heavy particles settle into the hopper at the base of the unit. From here the material is transferred to the residue treatment system. A limited amount of residue is also collected at the base of the dry reactor. This material and the residue from the fabric filter are directed toward either the recycle silo or the disposal system. The system at Hogdalen incorporates a residue treatment system, which involves storage of the spent sorbent in a silo until it is mixed on-site with cement and formed into a thick slurry for transport and disposal.

#### **4.3.2 Munich South, Germany**

Fläkt was also involved in the Munich South installation in Germany that started operation in January 1990. A schematic of the system is provided in Figure 4.6. In this case, the conditioning and dry reactor are combined in one tower, a schematic of which is shown in Figure 4.7. Note the addition of sodium sulphide to the reactor for the

Figure 4.5 Process Flow Sheet - Hogdalen Plant



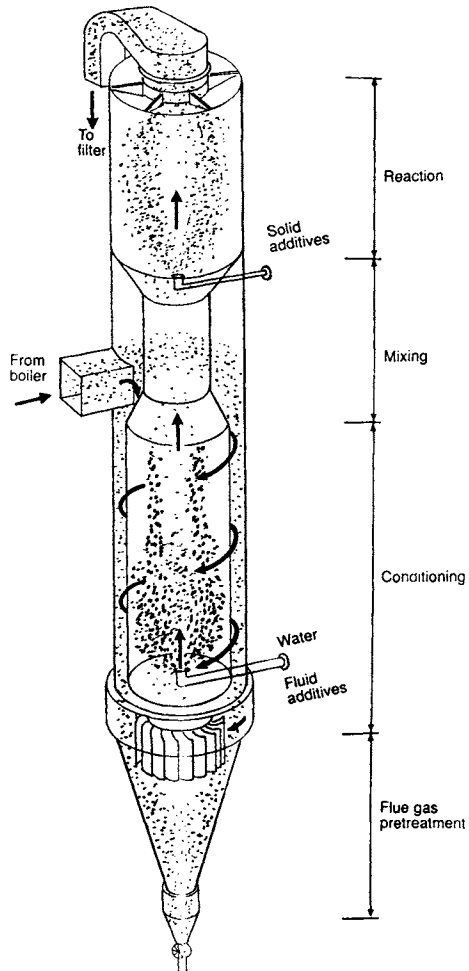
1. Boiler
2. Economiser
3. Reactors
4. Hose filter
5. Economiser
6. Flue gas fan
7. Silencer
8. Chimney
9. Lime silo
10. Recovery dust silo
11. Dust silo
12. Dust humidifier
13. Cement silo
14. Mixer

Lime consumption	100 kg/h - when emitting 20 mg hydro- chloric acid per normal cu. m. (HCl/Nm <sup>3</sup> )
Flue gas temperature in filter	135 °C
Filter clearing	3-5 pulses/hour
Sodium sulphide dosage	2 kg/hour

(adapted from Hogdalen Information published by Stockholm Energi)



Figure 4.7 Schematic of CDAS Reactor



**CDAS reactor. The flue gas is first cooled with water to suitable temperature, then mixed with dry sorption agent.**

(courtesy Fläkt Review, 1990)

control of mercury, which causes the mercury to condense out in the form of mercuric sulphide.

The back end of this system is equipped with an SCR reactor for  $\text{NO}_x$  control. To operate the SCR system, the gas passes through a heat exchanger and burner to raise the gas temperature to the appropriate operating temperature. The  $\text{NH}_3$  is added and the gas passes through the SCR reactor prior to being discharged to the stack. No dust control is installed after the SCR reactor and ammonia salts will not be present in the plant residues.

The fabric filter dust from the APC system is recirculated similar to the Hogdalen application until such time as it transfers to the waste silo. From here the material is wetted only to prevent dusting during transport to the disposal site.

#### **4.3.3 Warren County, New Jersey, USA**

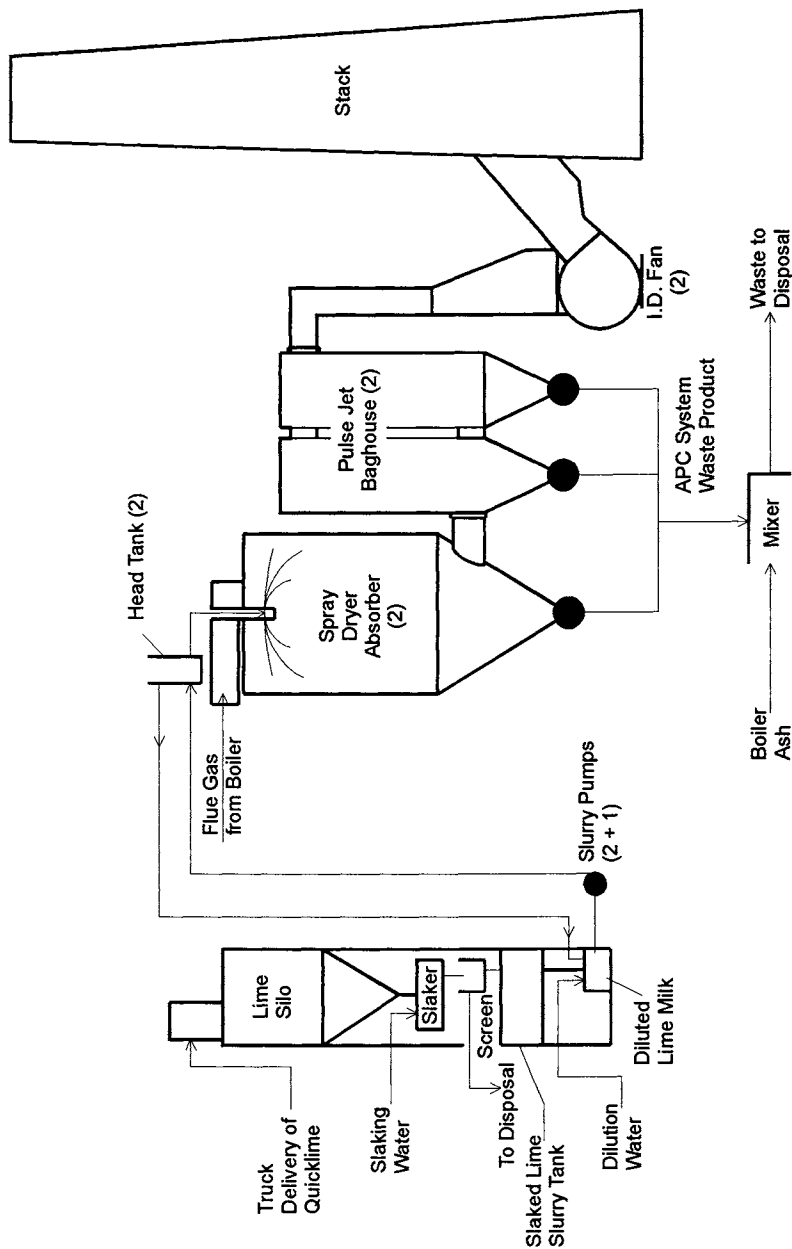
Typical of many facilities in both the US and Europe, the Warren County facility utilises a spray dry absorber (SDA) for acid gas and trace compound removal, Figure 4.8 (Jorgensen et al., 1991). The system was supplied by Environmental Elements Corporation. Lime slurry is introduced into the SDA where it neutralises the acid gases and serves as nucleating sites for the condensation of trace materials. The particulate matters in the gas stream are then removed in a fabric filter. Typical of many U.S. installations, the APC residues are combined with the bottom ash before being transported to the disposal site.

#### **4.3.4 Zirndorf, Germany**

The schematic for this plant's APC system, Figure 4.9, illustrates the use of a wet scrubber system in a retrofit situation (Beckert and Jungmann, 1992). The retrofit was performed by ABB W+E Umwelttechnik in combination with ABB Fläkt-Umwelttechnik. The existing ESP and HCl scrubber were upgraded with the addition of a wet  $\text{SO}_2$  scrubber and an absorption stage. The residue from the absorption stage is returned to the incinerator where any organics are destroyed and residual mercury is liberated to be trapped in the organic sulphides in the HCl wet scrubber.

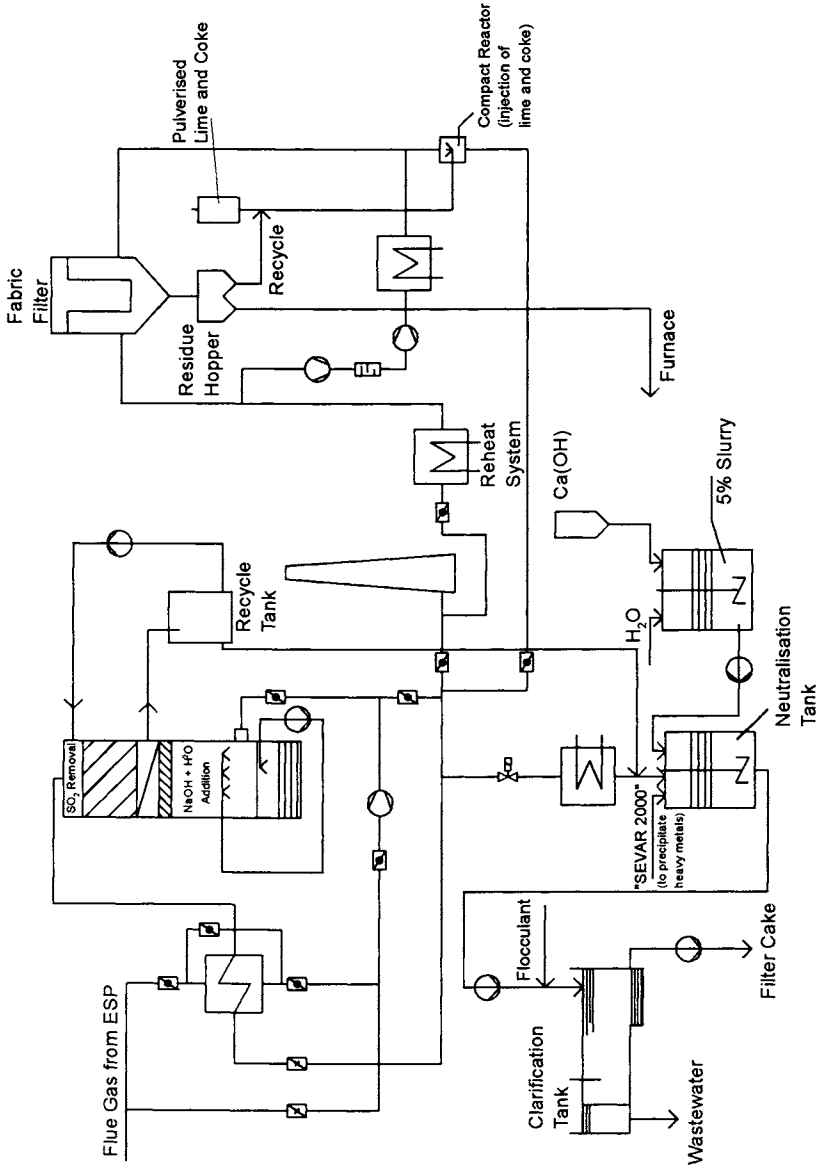
A heat exchanger removes heat from the gases before they pass to the HCl scrubber and transfer the heat to the gas leaving the scrubber system. The HCl scrubber uses water as the scrubbing media in a contact tower. A bleed from this system maintains the pH of the solution at an appropriate level. Organic sulphides are added to the scrubber liquid to improve the separation of trace metals, particularly mercury. The sump of the scrubber is the eventual sink for all trace metals in the system with the bleed from this circuit combined with that from the  $\text{SO}_2$  scrubbing circuit. In the wastewater treatment system the pH is adjusted with a lime slurry and forms gypsum and organic sulphides which precipitate and are filtered from the effluent.

Figure 4.8 Process Flow Sheet - Warren County



The absorption stage is returned to the incinerator where any organics are destroyed and residual mercury is liberated to be trapped in the organic sulphides in the HCl wet scrubber  
 Jorgensen et al., 1991

Figure 4.9 Process Flow Sheet - Zirndorf, Germany



Beckert and Jungmann, 1992

The SO<sub>2</sub> scrubber is a packed tower system. Sodium hydroxide in softened water is used as the scrubbing liquid. A bleed from this system maintains the salt content of the scrubber liquid at an optimal level.

The gases are reheated before passing to a compact reactor where fresh lime and powdered activated carbon are added to the gas stream to remove trace organics and residual trace metals such as mercury. The sorbents are then captured in a fabric filter where the filter cake serves to polish the acid gas removal process and remove trace organics and trace metals. The filter cake is recirculated in the system and then eventually disposed by introducing it into the high temperature zone of the furnace where trace organics are destroyed.

The only residue from this system is the filter cake from the wastewater treatment plant.

#### **4.3.5 Vestforbrænding, Copenhagen**

The APC system at this plant represents one of the latest wet scrubber concepts, Figure 4.10. The system was designed by Götaverken of Sweden. The existing hot side ESP has been maintained and is followed by an economiser, gas/gas heat exchanger, quench system, and HCl and SO<sub>2</sub> scrubbers. The latter scrubber is designed to operate at 50°C to generate hot water and recapture energy while condensing much of the moisture out of the stack gases. The gases are reheated before exiting to the stack.

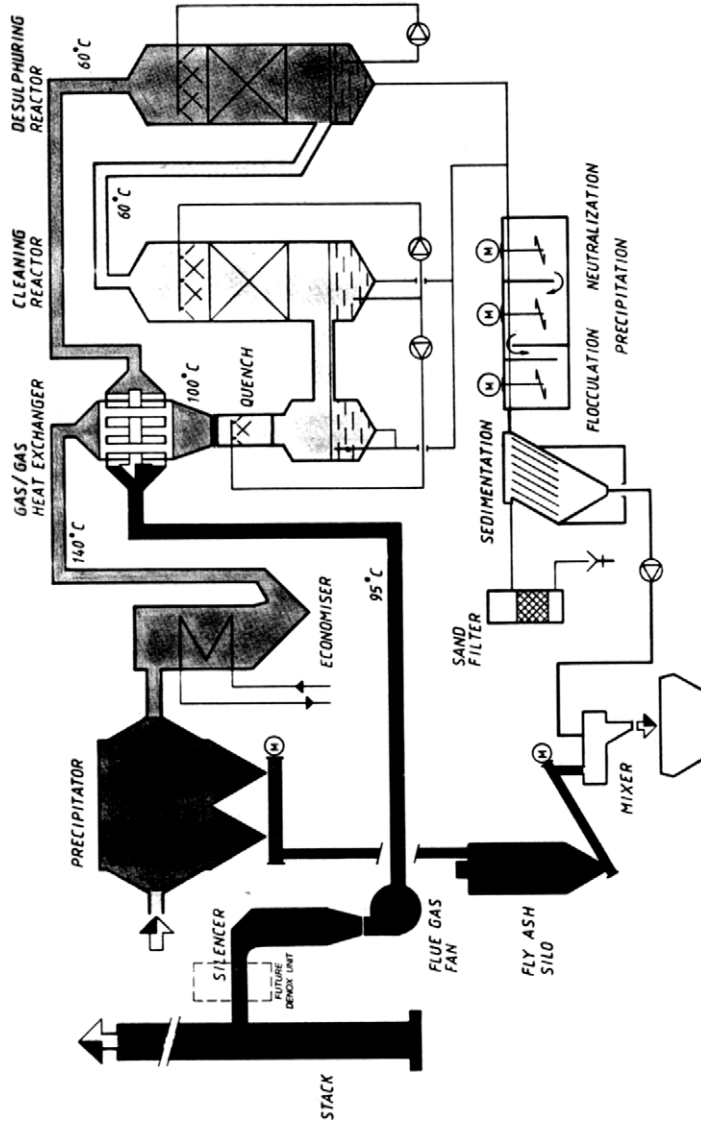
Wastewater treatment in this system includes limestone coarse pH adjustment, lime slurry fine pH adjustment along with organic sulphide to bind trace metals, and polymer addition to aid settling and separation of the suspended particulate matter. The sludge from the system is mixed with the ESP residue and landfilled.

#### **4.3.6 Lausanne, Switzerland**

The LAB system installed at Lausanne is one of a range of systems manufactured by this company. The systems are applied with different levels of equipment to achieve the emissions limits required. Figure 4.11 shows a typical installation of the EDV 7000 variant. In this case the scrubbers are open vessels without packing. Proprietary nozzles are used to generate a high density water curtain in the vessel that neutralises the gases. The gases then pass to electrofiltering modules where the particles are charged. Particles are removed from the gas stream by a water spray. The system is completed by a water droplet removal device based upon centrifugal force.

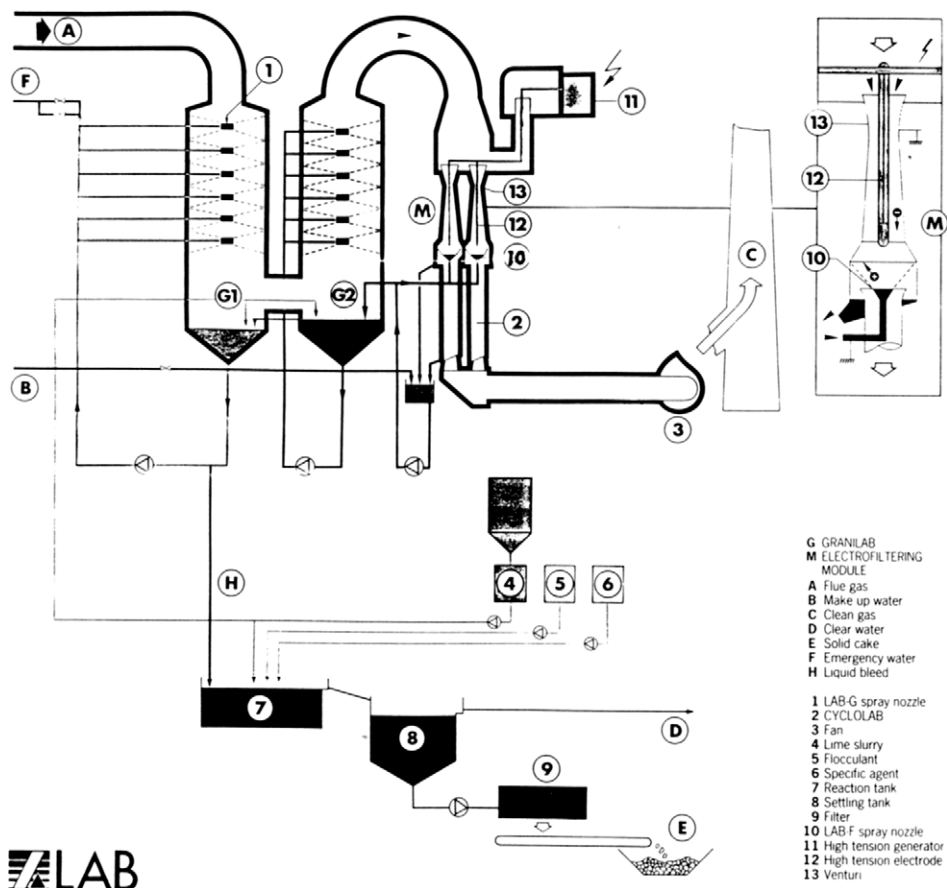
The wastewater treatment system is similar to those seen in other plants outlined above, and produces a sludge requiring disposal.

Figure 4.10 Process Flow Sheet - Vestforbrænding, Copenhagen



(courtesy Götaverken Miljö AB)

Figure 4.11 Process Flow Sheet - Typical LAB EDV 7000



(courtesy LAB S.A.)

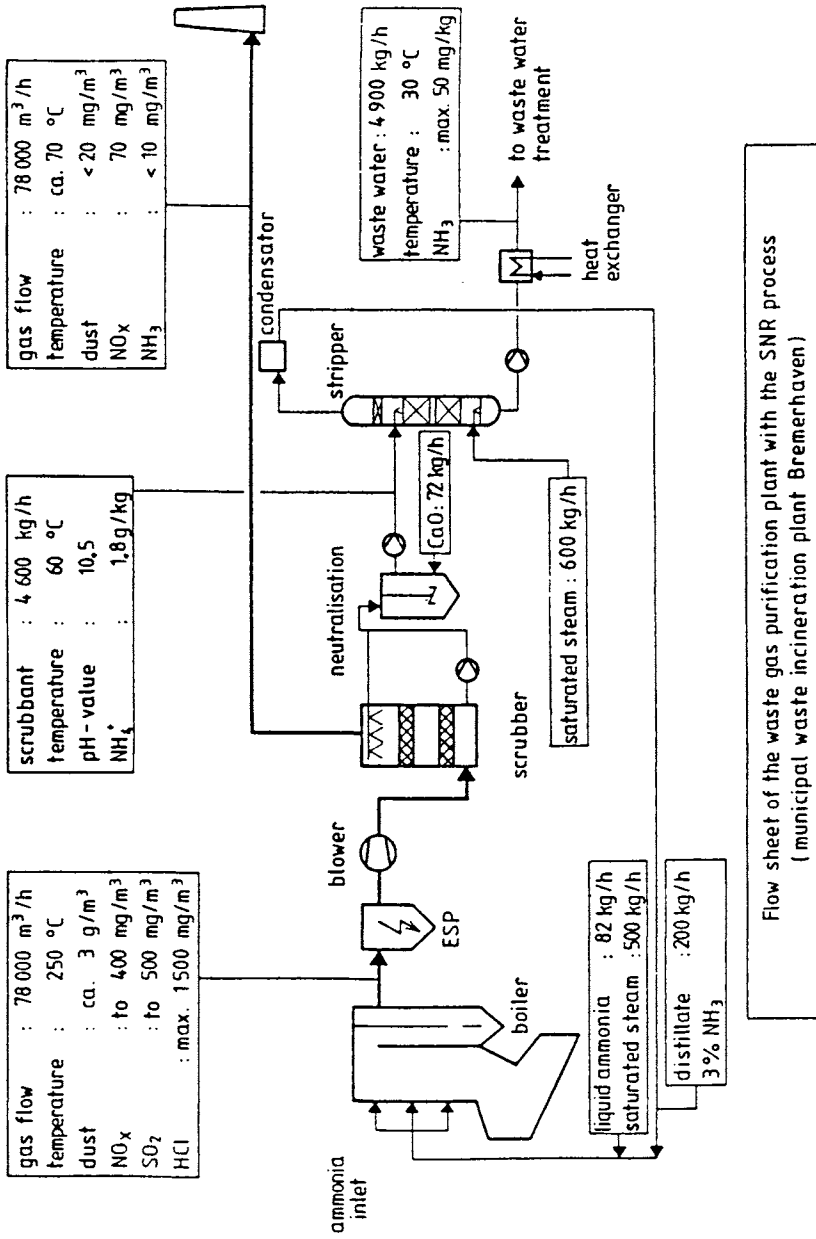
#### **4.3.7 Bremerhaven, Germany**

Detailed flow sheets for two German installations, Figures 4.12 and 4.13, show variations in APC strategy (Lange, 1992). Figure 4.12 illustrates the system used at Bremerhaven. The use of SNCR  $\text{NO}_x$  control through the injection of ammonia into the furnace is similar to that shown in other facilities. The unique part of this installation is the steam stripping of the scrubbing solution from the wet scrubber to recover ammonia which is then reused in the  $\text{NO}_x$  control system. The quantities illustrate the low ammonia level in the flue gas. An ESP is used to remove the particulate matter from the flue gas leaving the furnace and clean it before it enters the scrubber. A wastewater treatment facility is noted, but no details of the system are available.

#### **4.3.8 Stuttgart, Germany**

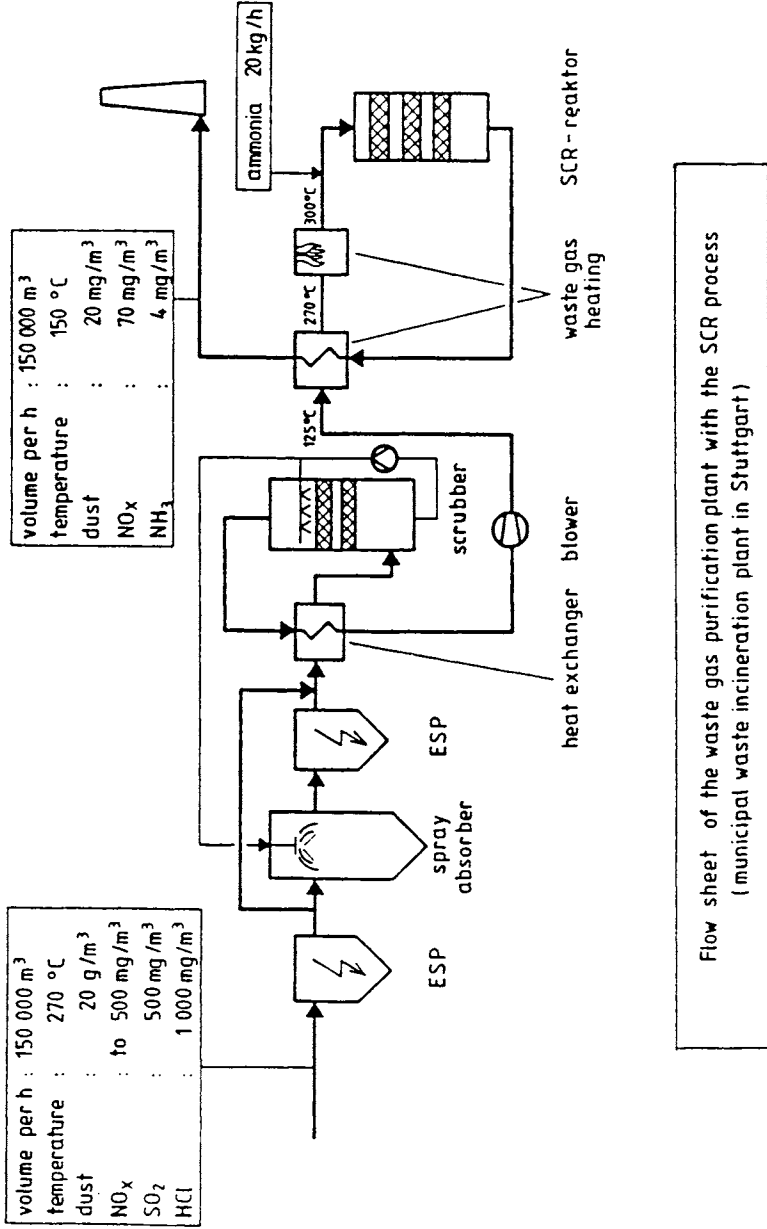
This facility utilises a spray dryer/absorber followed by an ESP to treat the scrubber solution from the APC system, Figure 4.13, after Lange (1992). The SCR  $\text{NO}_x$  control system on the plant is similar to the installation shown for Zirndorf.

Figure 4.12 Process Flow Sheet - Bremerhaven, Germany



(Lange, 1992)

Figure 4.13 Process Flow Sheet - Stuttgart, Germany



Flow sheet of the waste gas purification plant with the SCR process  
(municipal waste incineration plant in Stuttgart)

(Lange, 1992)

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