CHAPTER 3 - MUNICIPAL SOLID WASTE INCINERATION TECHNOLOGIES

Incineration offers a means of managing MSW, thereby reducing landfilling requirements, and recovering the energy present in the materials being burned. Incineration technology has evolved dramatically during the past 15 years with the introduction of new system designs. Each modification of these systems has the potential to influence the physical and chemical nature of the residue streams. An appreciation of the differences in technology and how these differences can affect residue quality is necessary to developing an understanding of MSW incinerator residues and the options available for managing them in a sound environmental manner. The technology review in the next two chapters provides an overview of the various combustion and air pollution control alternatives currently in use, along with a discussion of their effects on residue streams and the handling of the waste products.

MSW incinerator facilities typically contain several process sections:

- a waste receiving and storage area
- a waste feed system to charge the incinerator
- a combustion system
- a boiler to convert the heat of combustion to usable energy
- an air pollution control (APC) system
- an ash handling system.

These processes can be arranged as shown in Figure 3.1. Each part of the system has a unique function and several sections of the plant are responsible for the generation of residue streams:

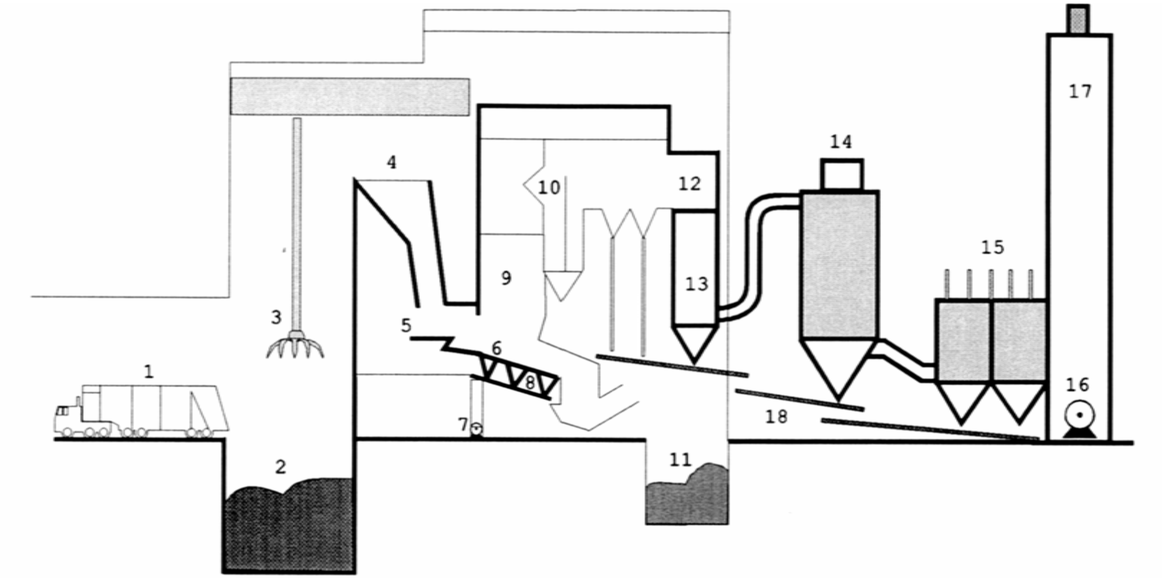
- The combustion unit produces the bulk of the residues, generally termed bottom ash.
- The heat recovery and APC systems generate smaller portions of the residue.
- The waste storage area and the ash quenching areas generate wastewater.
- The APC systems emit stack gases after cleanup.

Residue characteristics can be affected by operations in all parts of the process. The descriptions that follow detail each operation and its potential effects on residues.

3.1 FUEL RECEIPT AND HANDLING

MSW is normally delivered to an incineration facility in the trucks used for local pick up. These receipts might be augmented by larger loads from intermediate collection stations where waste is off-loaded from the local vehicles, processed to remove selected materials such as corrugated paper and construction debris, and reloaded into

Figure 3.1 Generic Incinerator Plant Schematic



1. Refuse Collection Vehicle
2. Refuse Storage Pit
3. Refuse Handling Crane
4. Feed Hopper
5. Feeder
6. Grate
7. Forced-Draft Fan
8. Undergrate Air Zones
9. Furnace
10. Boiler
11. Ash Bunker
12. Superheater
13. Economiser
14. Dry Scrubber
15. Fabric Filter Baghouse
16. Induced-Draft Fan
17. Stack
18. Fly Ash Conveyor

Courtesy Martin GmbH

larger transfer trailers. Under either circumstance, most incineration facilities require storage facilities because they only receive waste for a limited period during the day but operate around the clock. The storage facility provides a continuous source of material to the process. Commonly, storage facilities hold up to five days of fuel. This is sufficient to continue plant operation during holiday periods when there is no waste pick up.

The majority of plants utilise a storage bunker in the form of a pit. This normally runs the full width of the incinerator installation. Trucks are off-loaded into the pit and a grapple crane is used to transfer materials from the pit to the charging hopper of the incinerator. An alternative used in smaller plants is the flat dumping floor. In this case a large open area is used to store waste which is stacked by front-end loaders to a height of 4 to 5 meters. The same loaders are then used to transfer waste to the incinerators.

Steady operation of the incinerator requires continual loading of the unit with a relatively uniform fuel. Since most incinerators burn “as-received” MSW, an inherently heterogeneous material, the waste must be mixed to reduce the variability of the charged fuel. The operators perform this function in the storage area and at the same time remove large non-combustible components such as appliances and furniture.

There is one major difference between the pit and the flat floor. During the mixing and retrieval operation of a pit system the finer fraction of the waste stream is sifted to lower levels in the pit. The nature of the grapple precludes removing all this material from the pit and some build-up of fines is inevitable. Fines, as discussed in Chapter 2, contain elevated levels of trace metals and charging higher quantities of these materials will produce variations in residue chemistry. With the flat floor system the waste mixing operation tends to mix the fines back into the bulk of the waste and the potential for segregation of fines and variations in residue chemistry is reduced.

3.2 AVAILABLE COMBUSTION ALTERNATIVES

Although there are numerous systems available for the incineration of MSW and the generation of usable energy, combustion systems can be divided into two broad categories:

- mass burning: the “as-received” MSW is fed directly into the furnace and burned on a grate or hearth without any pretreatment such as size reduction, shredding or material separation prior to burning.
- refuse derived fuel (RDF): a fuel of a more homogeneous nature is prepared on-site and either burned in a "dedicated" furnace at the same location or sold to outside customers who utilise the fuel in their furnaces

Mass burning was adopted in Europe at the turn of the century and has evolved favourably over the past twenty years. Removal of oversized material is critical to the smooth operation of mass burn facilities.

The RDF process involves the separation of certain materials from the waste to improve the combustion characteristics of the material. Various levels of processing are possible but they all involve some basic operations. The MSW is usually shredded to reduce the size of the material, sorted to remove non-combustibles and burned in semi-suspension or suspension fired furnaces. Ferrous metals may be recovered using magnetic separators, and glass, grit and sand may be removed by screening. Further processing using air classifiers, rotary drums or advanced separation techniques can remove additional non-combustible materials and certain plastics and aluminum materials.

During processing, the material is mixed to improve its homogeneity. In fact, some facilities process waste before feeding it to conventional grate type incinerators and consider the extra cost to be warranted because the system runs more smoothly. Any processing of the waste stream has the potential to change the nature of the fuel and thus change the residue streams. Later in this chapter, consideration is given to the changes processing can induce in the physical and chemical nature of the residues.

There is no simple answer as to which incineration method is better. Each situation has to be considered on in its own merits, taking into consideration the institutional, environmental and economic issues. A summary of the key technical features of the systems follows.

3.2.1 Mass Burning Systems

Mass burning is a well-established technology. Two types of mass burn systems are available: the European type system and the modular type system.

European Type Systems

The European systems have proven to be rugged as well as reliable and have been constructed in sizes ranging from 100 to 840 tonnes per day (Mg/d). This mass burning technology can be applied in almost all situations, however, it does not compete well with other incineration systems at design capacities below 300 Mg/d because of the high capital cost per tonne of waste burned.

The European mass burning incinerator can be either of the refractory lined or the waterwall design. In a refractory lined furnace, combustion temperatures are regulated by using high excess air rates (100 to 200% excess air). In a waterwall furnace, the combustion temperature is maintained by circulating water in closely-spaced tubes located on the furnace walls. Most waterwall furnaces operate at a lower excess air rate (about 80%), than refractory lined furnaces. This results in a reduction of both the furnace volume and the size of the air pollution control equipment.

The basic combustion process in European mass burn furnaces, as described in detail in a later chapter, consists of layered burning of the waste on a grate that transports the material through the furnace (as shown in Figure 3.2). The fuel passes through various temperature regimes while on the grate. On the initial grate section both under-fire air supplied to the furnace and radiant heat from the furnace combine to dry the waste. Once dry, the waste begins to pyrolyse prior to burning. The pyrolysis and combustion process at this stage consumes the waste but generates significant quantities of hydrogen, carbon monoxide and unburned hydrocarbons. Additional air is required to complete the conversion to carbon dioxide and water vapour. This air is supplied above the material on the grate (over-fire air). The last section of the grate completes the reaction, driving the balance of the combustibles from the bed material. The material leaving the burnout section of the grate passes through a quench tank before being dewatered and conveyed to a bottom ash storage bunker. To maintain high combustion efficiency, sufficient time must be allowed for the last stage of combustion to go to completion thereby reducing residual carbon levels in the residue. Excessive feed rates, or insufficient air in the final stage will result in incomplete burnout and elevated carbon levels in the bottom ash.

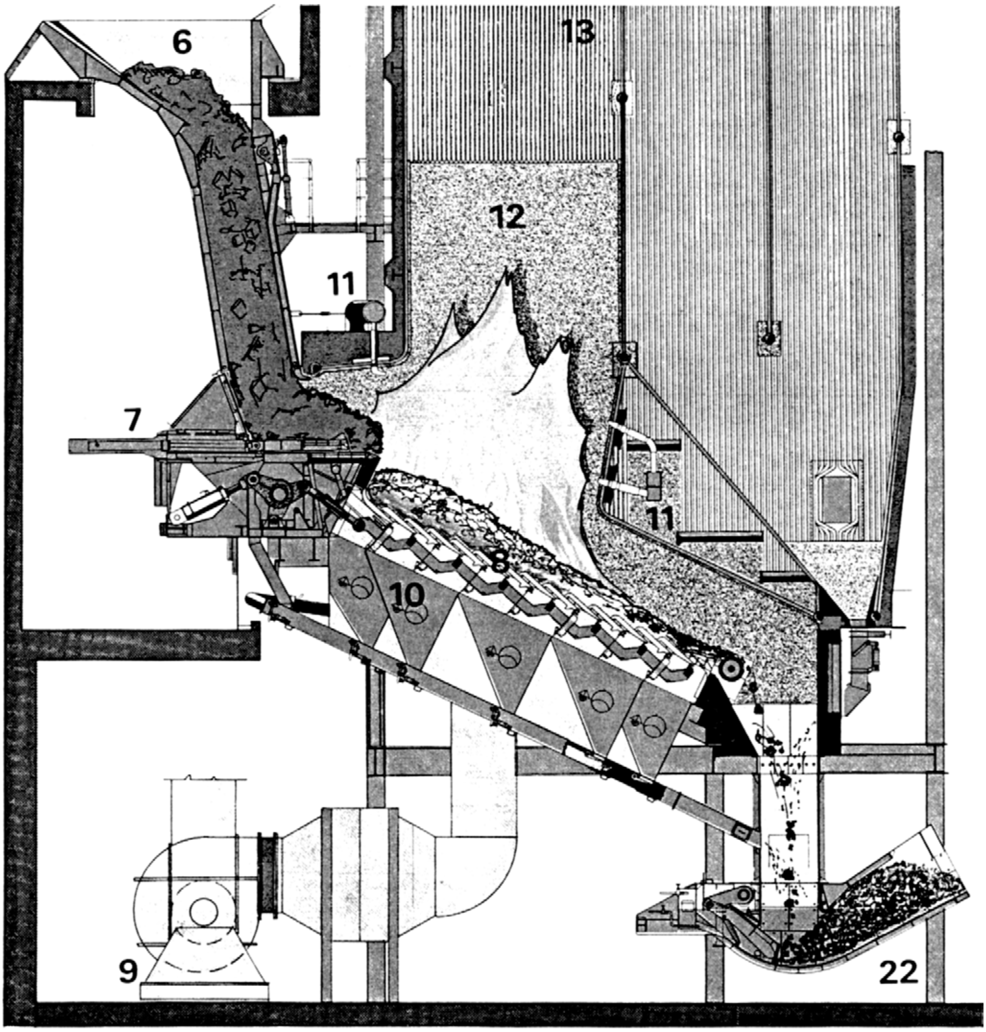
The balance of under-fire to over-fire air, the waste nature and the control of the system can influence the way the material burns and affect both ash quality and the air emissions. In order to promote good combustion, manufacturers of furnaces try to compensate for the natural variability of MSW by using different grate configurations and specialised air control systems. The grates agitate and move the waste through the furnace. Air control systems provide varying flows of air to different regions of the grate and to different areas of the zone above the grates.

Maintaining uniform conditions reduces the possibility of operational problems caused by ash slagging or corrosion in the combustion zone. The manufacturers achieve their goals in various ways but the main variables they try to control are:

- bed coverage: maintaining a uniform distribution of waste on the grate
- combustion air flow: adjusting the initial combustion zone air to match the burning characteristics of the solids
- furnace configuration and the location of over-fire air ports: developing good mixing above the bed and enhancing the combustion effectiveness.

Generally, the grate manufacturers provide the grate system and design the furnace configuration above the grate. When combined with their proprietary air control systems, the grate systems can meet guarantees of the appropriate level of combustion for the waste being burned. The energy recovery system downstream of the furnace can be supplied by any one of several boiler manufacturers. Companies manufacturing mass burning furnace systems that utilise either waterwall or refractory wall designs include:

Figure 3.2 Schematic of the Combustion Zone, Mass Burn Incinerator



6	Feed Hopper	11	Secondary Air Nozzles
7	Feeder	12	Furnace
8	Reverse Acting Grate	13	Boiler
9	Forced Draft Fan	22	Bottom Ash Discharger
10	Undergrate Air Zones		

Courtesy Martin GmbH

- Alberti
- Bruun and Sorensen
- CEC
- de Bartolomeis
- Detroit Stoker
- Deutsche Babcock
- EVT
- Heenan Nichol
- Martin
- Steinmüller
- VKW
- Vølund
- Von Roll
- Widmer and Ernst (now ABB W+E Umwelttecknik AG)

Differences in grate and furnace design or operating philosophy are based on the manufacturer's experience. To illustrate how different manufacturers address these issues, mass burn incinerator grates and furnace configuration are discussed in some detail.

Grates

The grate forms the bottom of the furnace and supports the burning bed of waste as it moves through the furnace. In designing the grate, care is taken to ensure that high temperature and fine ash do not affect its operation. Air flow through the grate acts to cool the grate bars and protect them from the high temperatures encountered in the furnace. The action of the grate, regardless of its design, will cause some sifting of the finer material downwards. Depending on the grate design, the degree of movement of this fine material (grate siftings or riddlings) into the under-fire air plenums can vary. Grate siftings are typically removed from these plenums and combined with the bottom ash in the ash extraction system.

The efficiency of the grate system, as defined by consumption of carbon, depends upon its ability to provide combustion air to all the waste by means of a revolving and agitating movement. Manufacturers have various means of adjusting the flow of air through the grate. The provision of adjustable dampers and splitters that distribute air evenly to all parts of the grate is important. More important is ensuring a good pressure drop through the grate itself so that any variability in waste loading on the grate does not cause a shift of air away from a particular part of the grate. The net result of good combustion efficiency is a reduced level of carbon in the bottom ash residue stream. Most grate systems are some variation of one of the three forms of grates: rocking grates, reciprocating grates or travelling grates. Other alternatives, such as the roller grate are also marketed.

a) **Rocking Grates** The grate sections, Figure 3.3a, are placed across the width of the furnace. Alternate rows are mechanically pivoted or rocked to produce an upward and forward motion, advancing and agitating the waste.

b) **Reciprocating Grates** This design, Figure 3.3b, consists of sections that span the width of the furnace but are stacked above each other. Alternate grate sections slide back and forth while the adjacent sections remain fixed. Waste tumbles off the fixed portion and is agitated and mixed as it moves along the grate. Numerous variations of this type of grate exist some with alternating fixed and moving sections, others with combinations of several moving sections to each fixed section. In the latter case, the moving sections can either move together or at different times in the cycle.

c) **Travelling Grates** The travelling grate, Figure 3.3c, which consists of a continuous metal belt conveyor or interlocking linkages, moves along the longitudinal axis of the furnace. With a reduced potential to agitate the waste because it is only mixed as it is transferred from one belt to the next, the travelling grate system is seldom used in modern facilities.

d) **Roller Grates** The roller grate, Figure 3.3d, consists of a perforated roller that traverses the width of the grate area. Several rollers are installed in series and a stirring action occurs at the transition when the material tumbles off the rollers.

The majority of grate systems in use in modern facilities are reciprocating and the quality of the burnout achieved by these systems is generally excellent. As noted earlier, inappropriate loading rates contribute to higher combustibles in bottom ash. It is worth discussing several variations of the reciprocating grate to illustrate how waste movement and combustion can be controlled.

The Martin grate, Figure 3.3b, is a reciprocating grate which operates in the reverse direction to the flow of material on the grate. The grate is sloped from the feed end toward the residue discharge end and is comprised of fixed and moving grate steps. The moving grate steps perform a slow stirring stroke ensuring that the burning refuse layer is continually rotated and mingled to form an even depth of bed, and red-hot mass is pushed back toward the feed end of the grate. The intense fire builds up at the front end of the grate, with all combustion phases taking place simultaneously. The grate is divided longitudinally into several zones to enable under-fire air to be controlled. This air enters through both the bars and the narrow gaps between adjacent rows of bars. The gaps are restricted to ensure a high pressure drop across the grate.

The Von Roll grate, Figure 3.4a, features a push forward block arrangement installed at a steep angle. In the case of low calorific value material the grate can be modified with steps to improve the separation of clumps of refuse. The grate is designed to operate with a high pressure drop for the under-fire air supply thereby ensuring good air distribution regardless of bed depth.

The Widmer & Ernst (now ABB Umwelttecknick AG) grate, Figure 3.4b, is installed horizontally and the waste is transported along the grate solely through the "overthrust" action of the grate bars. The double motion tends to cause ignited particles to drop over the face of the fixed grate sections as the motion starts and then the grate below the fixed bar forces the burning material under the unburned waste above, thus prompting ignition from the bottom of the bed. Air flow is controlled through a high pressure drop through the grate.

Figure 3.3 Diagram of Various Grate Types

Figure 3.3a Rocking Grate

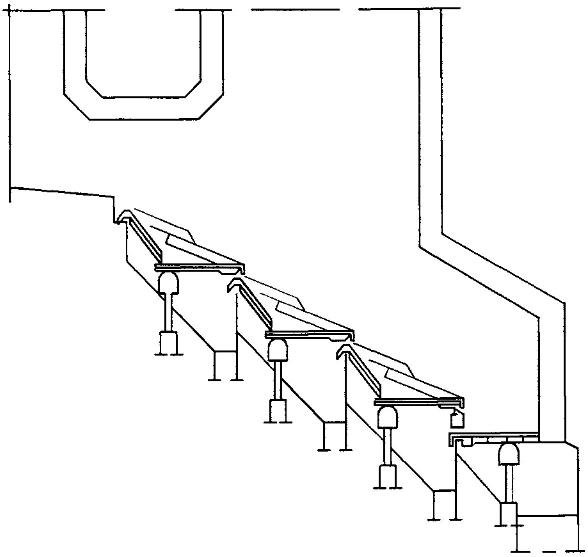


Figure 3.3b Reciprocating Grate (Martin)

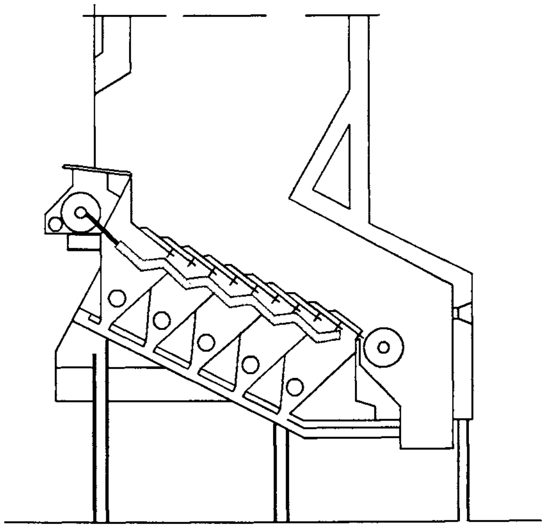


Figure 3.3c Travelling Grate

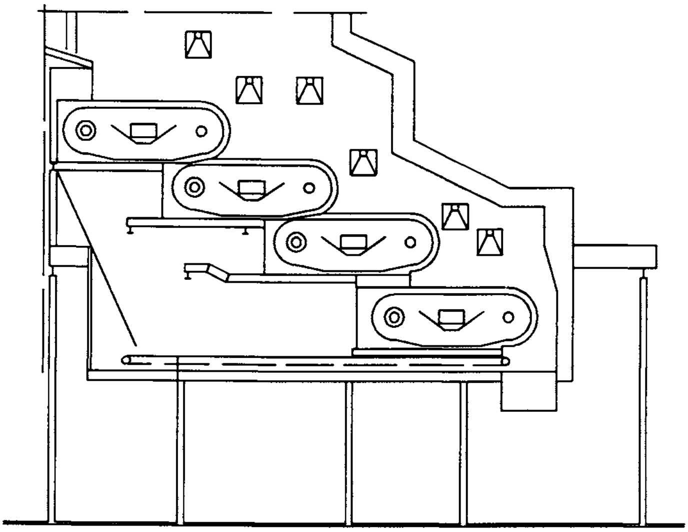


Figure 3.3d Roller Grate

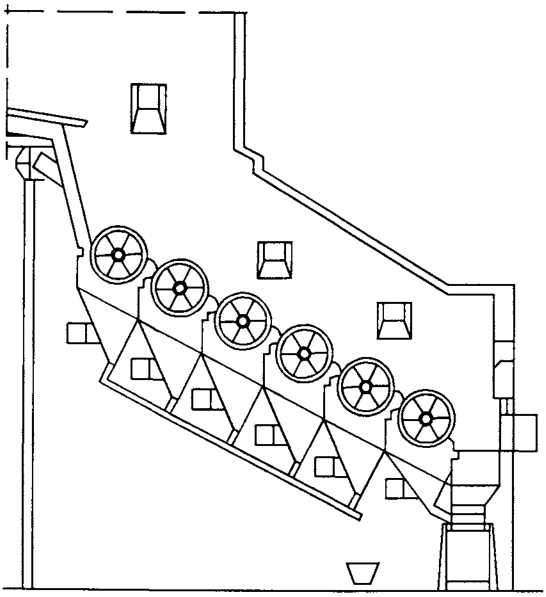
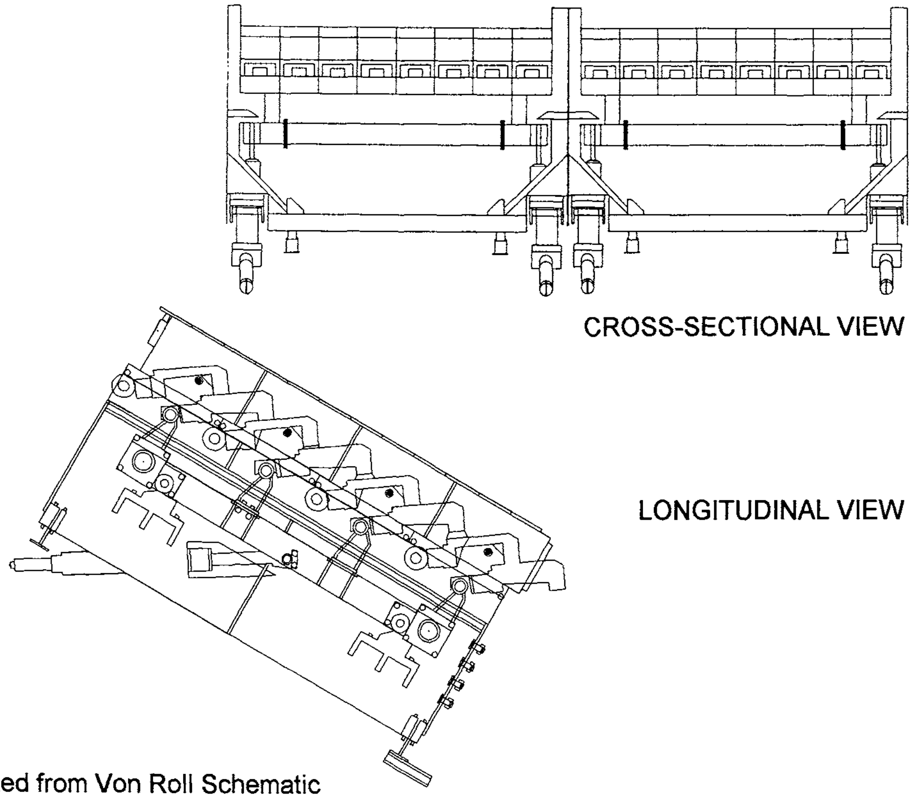


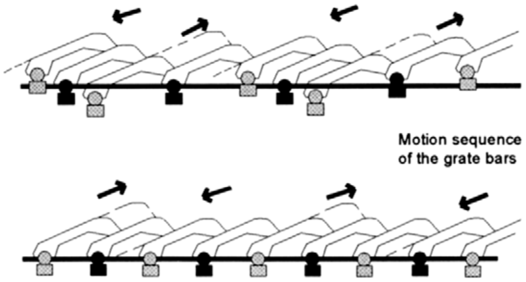
Figure 3.4 Types of Reciprocating Grates

a) Von Roll



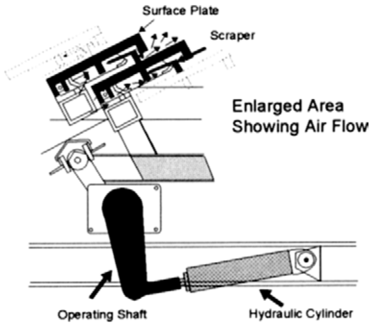
adapted from Von Roll Schematic

b) W + E



Seeker et al., 1987

c) de Bartolomeis



Seeker et al., 1987

The de Bartolomeis grate, Figure 3.4c, is unique in that it can be installed at any angle from horizontal to 21°, the angle being determined by the nature of the waste. The unit is a forward thrust grate. The three part design of the system incorporates a scraper that cleans the lower surface plate and controls the air flow to the grate.

Variations on these grate designs are used to feed waste materials into the furnace. Waste is commonly fed into these furnaces through a chute. The chute is kept full of waste to minimise infiltration into the furnace. At the bottom of the chute a feeder system is used to meter the waste into the furnace. Figure 3.5 provides several examples of feeder systems. Figure 3.5a shows a travelling grate feeder; Figure 3.5b, a hydraulic ram type unit. In both cases, the furnace controls provide a uniform feed of material to the grate with the rate of feed being governed by the quality of the waste. Unlike grates inside the furnace, waste feed grates are not equipped with air supply systems.

At the discharge end of the grate, the ash is transferred to a water quench system that serves to seal the discharge end of the furnace. Some manufacturers modify the end of the grate to extract the slag and transfer it to the quench tank; others merely allow the material to fall into the quench tank. Since manufacturers of all types of systems view bottom ash handling in a similar manner, the in-plant handling of residue is discussed after the various furnaces are reviewed.

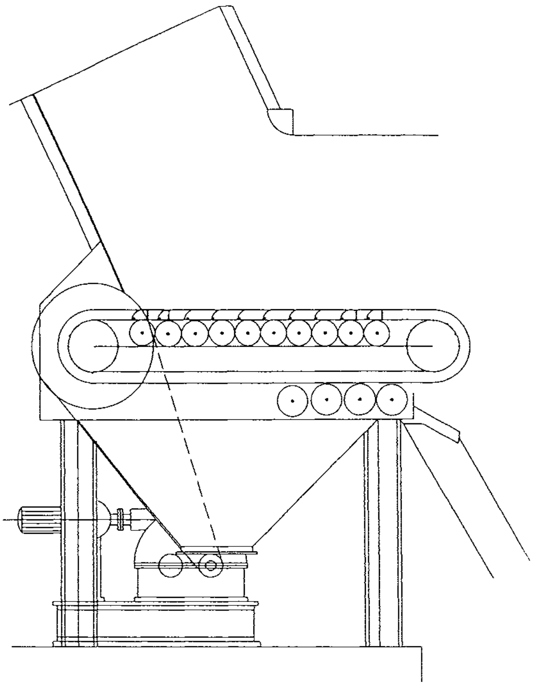
Furnace Design

Mixing the waste on the grate and controlling the distribution of air to both the under-grate and over-grate regions are important factors in achieving the desired rate of combustion efficiency and ensuring minimal trace organic emissions. The furnace configuration also plays an important role in the ease with which combustion can be controlled and the quality of the ash leaving the grate. The path that the combustion gases take after they leave the burning waste is very important in ensuring uniform and complete combustion.

There are several general configurations for the furnace. These are classified both as a function of the location of the furnace throat with respect to the grate and the flow direction of combustion products in the furnace relative to the waste flow. These classifications are based upon Deutsche Babcock Anlagen (DBA) studies that developed furnace geometries for particular types of wastes (Seeker et al., 1987).

Figure 3.6 shows three possible furnace configurations. The parallel flow situation has the gases moving with the waste due to the presence of a hood or arch over the drying portion of the grate. This arrangement is recommended for highly volatile waste. At the other end of the scale, the contra flow system has the hot gases from the volatilisation zone flowing over the waste on the drying grate and increasing the removal of moisture from this material. The extra drying capability makes the contra system suitable for wet waste or waste with a high ash content. The drying effect of the furnace can be enhanced by adding heated air to the under-fire area. Both the wet

Figure 3.5 Types of Feed Grates
a) Travelling Grate



b) Hydraulic Ram

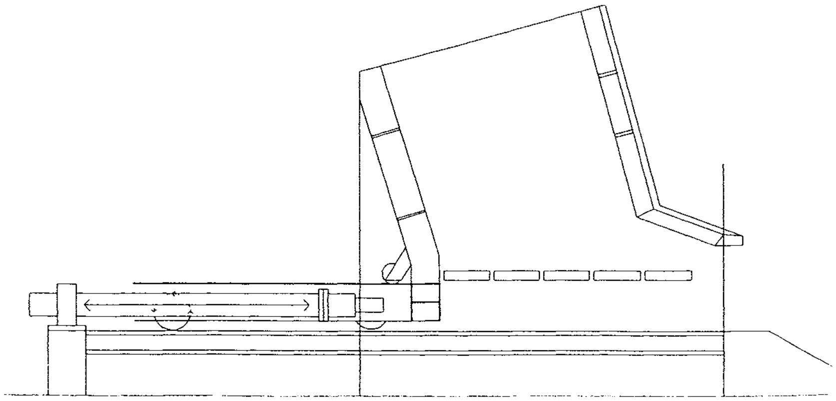
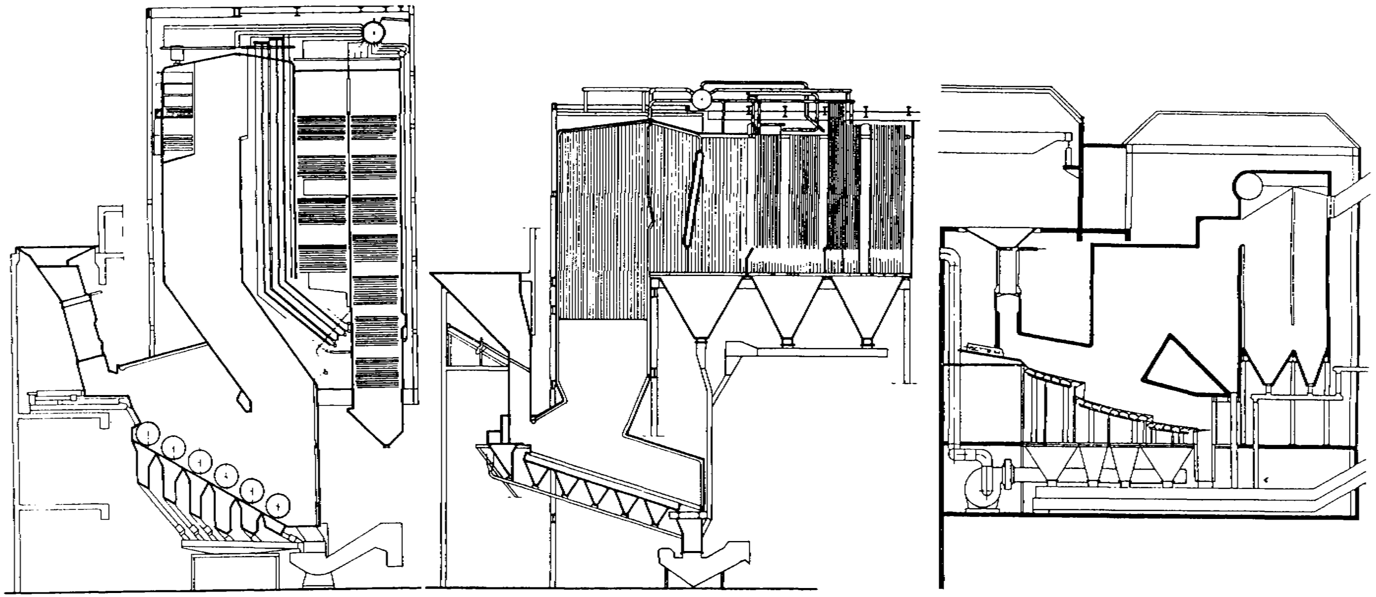


Figure 3.6 Variations on Furnace Geometry



a) parallel flow
Dusseldorf #6

b) contra flow
Frankfurt Nordweststadt

c) centre flow

and high ash wastes have a lower heating value than the material suited to the parallel configuration. The centre flow arrangement is more flexible than the other two having the throat located over the zone of volatile thermal decomposition.

Additional air must be added to the gases leaving the fuel bed to complete the combustion process. Typically, 60 to 80% of the air added to the furnace comes from the under-fire system. With limited over-fire air, its addition must be carefully controlled to achieve the desired mixing. Proper design of the furnace throat and the over-fire air injection system ensures proper air mixing and leads to the control of organic contaminants in the flue gas and the APC residues. The throat causes a flow constriction, enhancing turbulence and providing the best location to ensure the complete mixing of the over-fire air and the combustion products. It is important that the over-fire air does not short-circuit or create temperature depressions if low emissions are to be achieved.

Operating Philosophy

The location and configuration of the over-fire air ports are made more critical by variations in the waste and the need to follow the steam load curve in EFW plants. Several control philosophies are employed:

- Von Roll monitors the steam production rate and controls the ram feeder frequency and the amount of primary air to the middle region of the grate, the pyrolysis region, to maintain the correct steam rate. Von Roll also monitor the furnace temperatures in the radiant region to control the secondary airflow rates. If the temperature drops, the secondary air can be reduced to restore temperatures to the correct level.

- Martin uses O_2 levels in the flue gas to control the refuse ram feeder rate and the grate speed, thus controlling the MSW feed rate. A second control loop monitors steam rate and adjusts the under-fire air to control the steam production rate.

Most of these combustion control measures are aimed at maintaining low organic emission rates from the furnace. However, optimizing these conditions can influence the trace metal partitioning between the furnace and the APC system. These influences are illustrated by data collected during Environment Canada's 1986 National Incinerator Testing and Evaluation Program (NITEP) study of the Quebec City facility in Canada.

Quebec City Modifications and Ash Quality

The NITEP tests run on the Quebec City incinerator provide an indication of the effects of design and operation on general ash parameters (Environment Canada, 1988). The Quebec City incinerators, based upon a Von Roll design, were installed by Dominion

Bridge in 1974. The units were modified in 1978 by the addition of a lined waterwall arch over the burning grate and a refractory chicane over the end of the burning grate. The configuration was very similar to the centre flow furnace arrangement discussed earlier. After the modification, it was found that the gas flow rates up the rear wall of the furnace were very high and this resulted in gas flow stratification in the furnace. This was judged to be unacceptable and further modifications were undertaken.

These modifications, completed in 1986, lowered the roof over the burning and finishing grates and added both lower and upper bull nose sections on the rear wall of the furnace (Figure 3.7). This was intended to improve the ash quality by increasing the radiation reflection onto the burning and finishing grates. The modifications also served to reduce the flow of combustion gases leaving the finishing grate zone and enhance the burning of the volatile gases. The new arrangement could be be described as a contra flow furnace.

During the latter set of modifications, the grate system was modified to provide dampers and flow monitoring/controlling systems to permit automatic control of the air split to the grates. This was prompted by observations that significant flow variations lead to unstable operation during periods of varying bed depth. The modifications allowed independent and automatic flow control to each of the grate hoppers thus maintaining the desired proportions on each grate section, and the correct total primary air flow to maintain good combustion and steam flow rate.

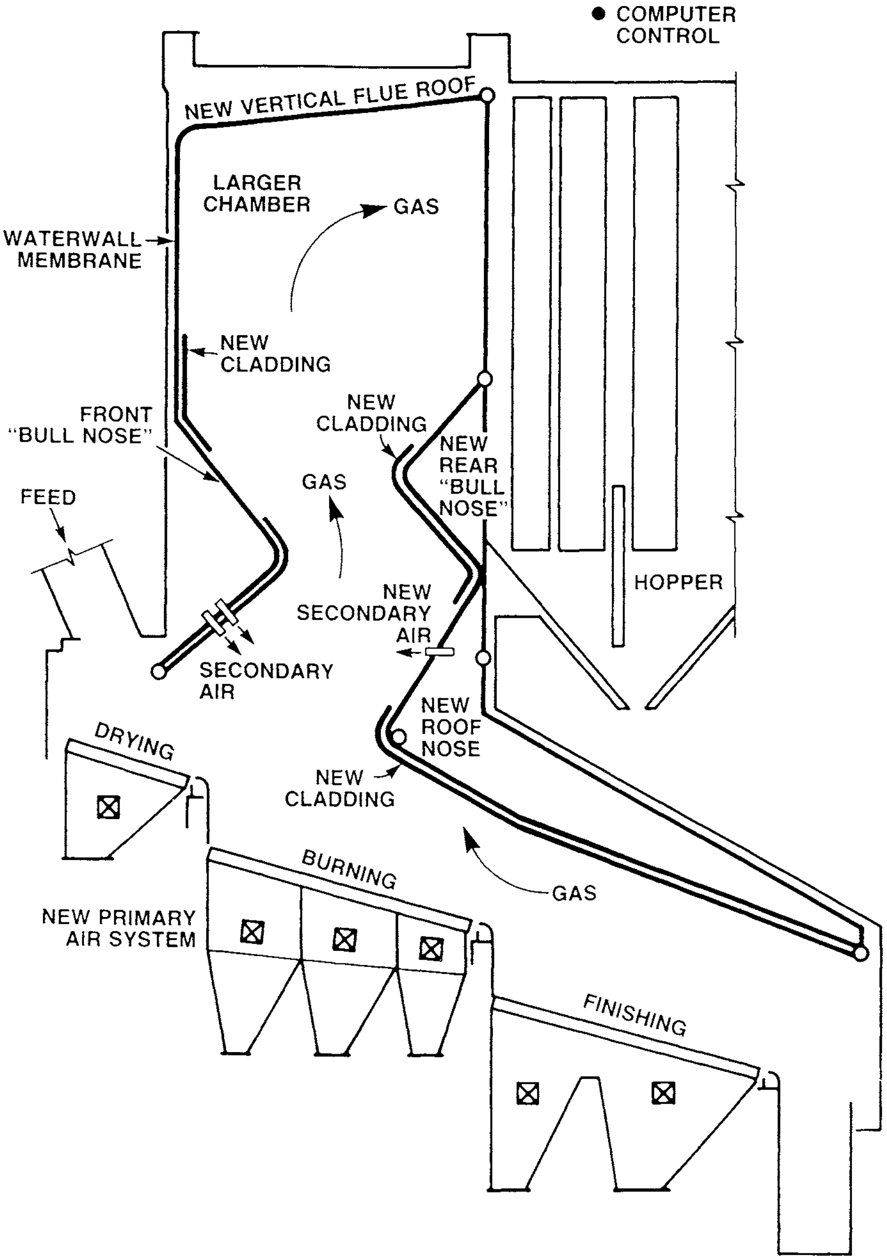
Additional control modifications included a grate hydraulic control system that varied the grate operating frequency with respect to the steam flow, oxygen monitor feedback to the grate control system, primary airflow control by steam set-point and excess air level, and controlling both secondary air flow and front to rear air ratio as a function of temperature readings in the upper part of the radiation chamber.

The modifications are reported to have resulted in the following changes in the ash:

- increasing the air to the first stage of the burning grate reduced the finishing grate bed thickness and improved ash quality through greater burnout. Raising the velocity through the bed increased the carry-over into the boiler, raised the level of combustible materials in the boiler ash, and particulate matter emission rates at the stack. Other studies have shown that these conditions can result in distinctly different chemical and leaching characteristics in the ash. It was concluded that control of primary air flow rates is critical in achieving low CO levels and low particulate emissions.

- increasing the total under-fired air to the finishing grate lowered upper radiation chamber temperature and produced high excess air levels. Reducing the air flow to the front of the finishing grate resulted in reducing the burning rate in this area and increasing the bed depth. This resulted in a decline in ash quality.

Figure 3.7 The Quebec City Incinerator Cross-Section



Environment Canada, 1988

- refuse bed depth indirectly establishes the amount of primary air required but also influences the extent of burnout. For a specific steam requirement, a thick refuse bed requires less primary air to supply the energy necessary to meet the steam demand. With the increased bed depth the primary air decreases, resulting in incomplete combustion and an increase in the amount of unburned material in the ash.

- while automatic grate speed control had been incorporated into the modifications test data suggested that manual control of the finishing grate speed resulted in improved ash quality.

Clearly, there are many factors that influence ash quality from mass burn facilities, and both the designers and the operators need to become familiar with these cause/effect relationships if plants are to be run under optimum conditions.

Modular Incineration Systems

Modular incineration systems are usually designed to burn MSW in an "as-received" state without size reduction or any other pretreatment operation. Typical modular incinerators for MSW applications range in capacity from 10 to 100 tonnes per day.

The modular incinerator, also referred to as the controlled-air incinerator, makes use of a two-stage combustion process. It usually consists of a primary chamber and a secondary combustion chamber. The mode of operation of the primary chamber is used to classify controlled-air incinerators as either excess-air or starved-air (sub-stoichiometric) units. The difference in these two modes of operation are summarised below:

a) **Starved-Air Incinerator** The primary chamber of this incinerator is run without sufficient air to complete the burning process (below the stoichiometric requirement). Typically 30 to 80% of the stoichiometric requirement is provided. Without sufficient air, pyrolysis gases are formed in the primary chamber. Excess air is provided in the secondary or afterburner section of the incinerator to complete the combustion process.

b) **Excess-Air Incinerator** The primary chamber in these units has more than the stoichiometric requirement of air. Typically 60-200% excess air is supplied to these units and this promotes almost complete combustion in the primary chamber (in the order of 90-95%). Gas-phase combustion is completed in the secondary chamber where additional air is added on an as-required basis.

Of the two types of controlled-air incinerators, the starved-air unit appears to be the more widely used. The success of the starved-air design has in large part been due to its ability to reduce the entrainment of particulate matter in the flue gas. This has been attributed to:

- minimising disturbance of the fuel bed by limiting the number of grates
- maintaining a slow rate of volatilisation by reducing air flow into the chamber
- consuming any liberated particles in the secondary chamber.

Most starved-air modular systems feature a stepped series of solid hearths with limited air injection points. This is different from European mass-burn and excess-air modular units that feature air introduction through the grate and numerous moving grate sections.

Units are normally batch fed using a hopper/ram assembly or double ram system to minimise the infiltration of air into the primary chamber during charging. The waste is moved through the starved-air furnace by transfer rams placed along the stepped bottom of the furnace. This system retains a large mass of partially combusted material in the furnace at all times, thereby effectively equalising the energy release rate from heterogeneous waste streams. The controlled-air concept provides faster response to temperature fluctuations, with easier operating control than large conventional mass burning units.

Historically, the limited disturbance of the bed and low air levels in the starved-air system resulted in poorer burnout conditions in the furnace and higher residual energy levels in the ash than commonly found in the ash from other technologies. Changes to the latest generation of starved-air units have included supplying air to the last hearth in the furnace to improve ash burnout. This has reduced the ash volume and lowered the unburned carbon levels to below 6% (Peel Resource Recovery Inc., 1992). This facility has noted increased particulate flows to the secondary chamber compared to operational experience at other facilities. It is not clear if this has resulted in changes to the concentrations of inorganics in the heat recovery and APC residues because comparsion data are limited.

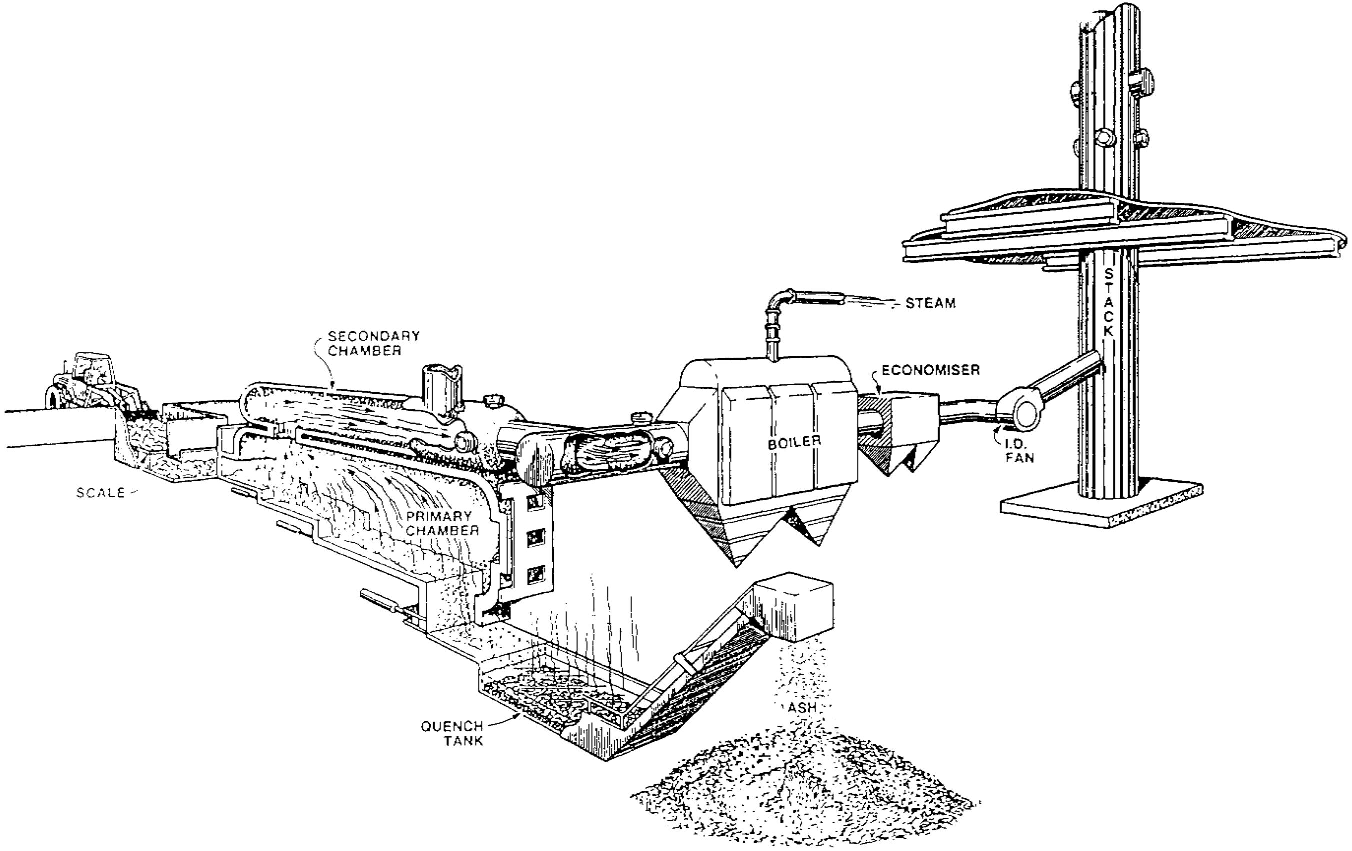
Modular incineration systems have a lower capital cost per daily tonne of waste burned compared to mass burning operations. However, the energy recovery efficiency is also lower; typically 55 to 60% compared to 65 to 70% for mass burning. The quantity of bottom ash generated from these unit is normally higher than from grate type systems, due in part to the lower burnout. Modular MSW incineration systems also have relatively low excess air requirements which can reduce the size of APC equipment.

Controlled-air incinerators are manufactured by several vendors including Basic, Consumat, Morse Boulger, Smokatrol, and Simonds. A schematic of the Consumat modular incinerator are provided in Figures 3.8. These units are supplied as standard models but can be modified to suit the specific needs of a customer.

Other Mass Burn Variants

Several other mass burning technologies are in limited use throughout the world. Among these technologies are variations of the rotary kiln.

Figure 3.8 Schematic of Consumat System



Environment Canada, 1985

Rotary kilns can be of waterwall or refractory wall design and can also include ignition grates. Systems in current operation or under development include the Vølund rotary furnace, and the Westinghouse/O'Connor rotary kiln. A schematic of a rotary kiln system incorporating a drying grate and an ignition grate is presented in Figure 3.9.

a) **Vølund System** The Vølund system utilises a refractory wall rotary kiln design. The rotary kiln is used in conjunction with ignition grates located upstream of the kiln, although there are some cases where this may be reversed. Primary combustion air is introduced at the entrance of the combustion unit, while secondary air is injected at the exit end of the kiln. This technology is said to improve burnout of high moisture level materials. This is accomplished largely through increased residence time in the tumbling action of the rotary combustor section.

b) **Westinghouse/O'Connor System** In the Westinghouse/O'Connor system, a waterwall rotary kiln is used as the main combustion unit. With this particular waterwall design (Figure 3.10) the rotary kiln has a cylindrical pinhole grate mounted over water tubes. During operation, the refuse travels downwards through the furnace as it burns. Combustion air is introduced along the entire length of the grate through air plenums between the boiler tubes. The unit operates at significantly lower excess air levels than conventional mass burn facilities.

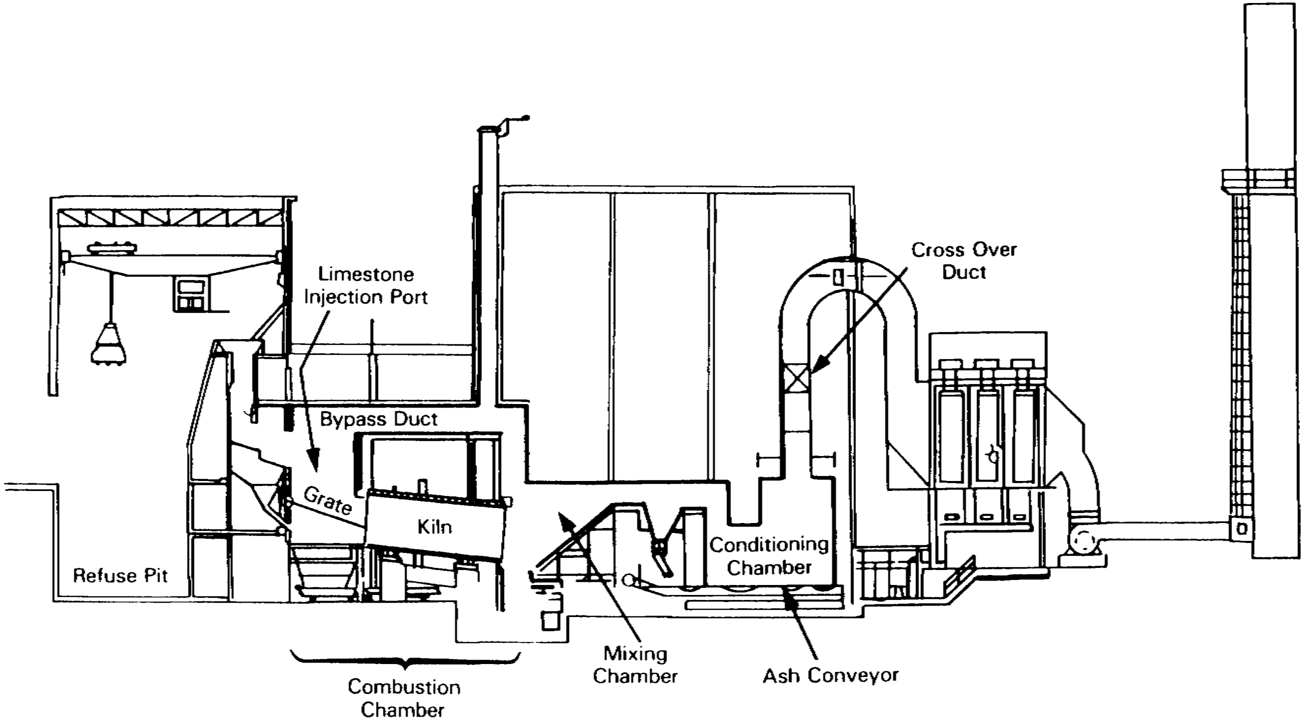
3.2.2 Refuse Derived Fuel Systems

Unlike the mass burn systems, Refuse Derived Fuel (RDF) systems fire a waste that has had its physical characteristics altered. The first step in this alteration is usually size reduction and this can be followed by various stages to remove non-combustibles and further reduce the size, or alternatively produce a more dense material.

The American Society for Testing Materials (ASTM) Committee E-38.01 on Resource Recovery Energy (Seeker et al., 1987) defines seven categories of RDF processing:

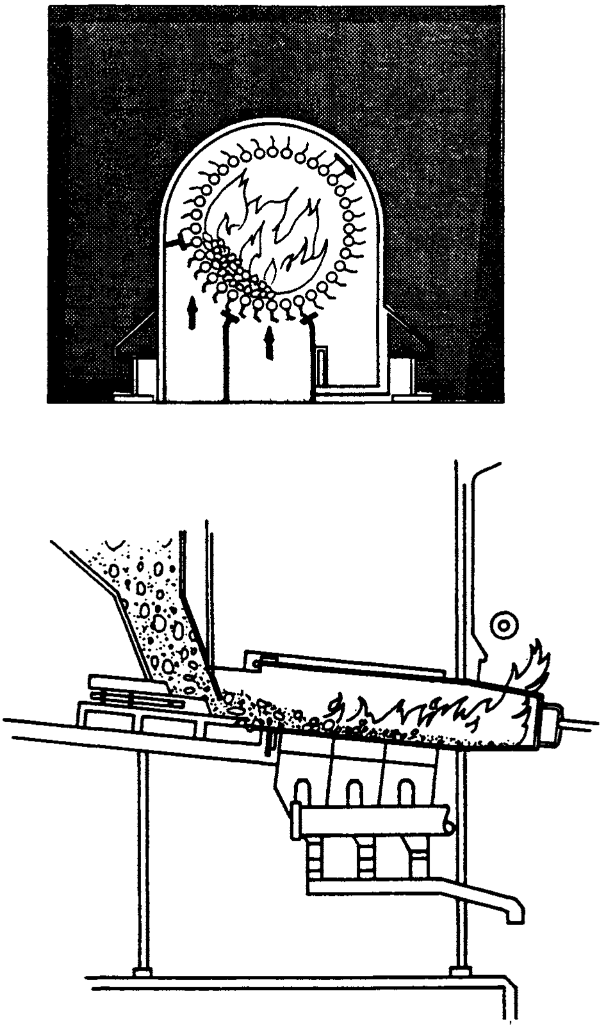
1. oversize material removed
2. size reduction to minus 15 centimetre mesh with or without iron removal
3. shredded (minus 5 centimetre) with metal, glass and other inorganics removed
4. powdered form minus #10-mesh (0.2258 centimetres square)
5. densified into briquettes, pellets, etc.
6. processed to liquid fuels
7. processed to gaseous fuels.

Figure 3.9 Schematic of Vølund Rotary Kiln Incinerator



Radian Corporation, 1989

Figure 3.10 Schematic of Westinghouse/O'Connor System



Seeker et al., 1987

The unit processes incorporated in RDF systems include primary shredding, ferrous metal recovery, screening or air classification to remove non-combustibles, secondary classification and storage (Figure 3.11). The net effect of RDF systems on ash quality is a reduction in the quantity of ash per tonne of waste introduced into the facility since many of the non-combustibles are removed in the process. The removal of materials such as ferrous and fines changes the composition of the ash. Furthermore, removal of some materials from the feed stream can change the characteristics of the combustion process and result in changes in partitioning as waste moves through the furnace. A number of demonstration and commercial scale RDF systems have been established in North America within the last decade. RDF systems typically have lower capital costs per daily tonne of waste processed than other energy-from-waste systems; however, operating costs are considerably higher. In addition, there are currently a number of problems associated with the establishment and operation of RDF facilities, including limited market for RDF and breakdowns in the waste handling/ processing system. Furthermore, RDF may cause problems in storage (bridging or spontaneous combustion) and due to the typically high ash content, may overload the ash handling system on suspension-fired boilers.

Densified or pelletised RDF has been suggested as a substitute for coal in the power generation field, however there are concerns about the variability in combustion characteristics of the material, the potential for increased air emissions, and the potential for increased fouling problems particularly with small boiler units (Glen and Howarth, 1988). Successful operating history has been limited by the many problems that these systems have encountered

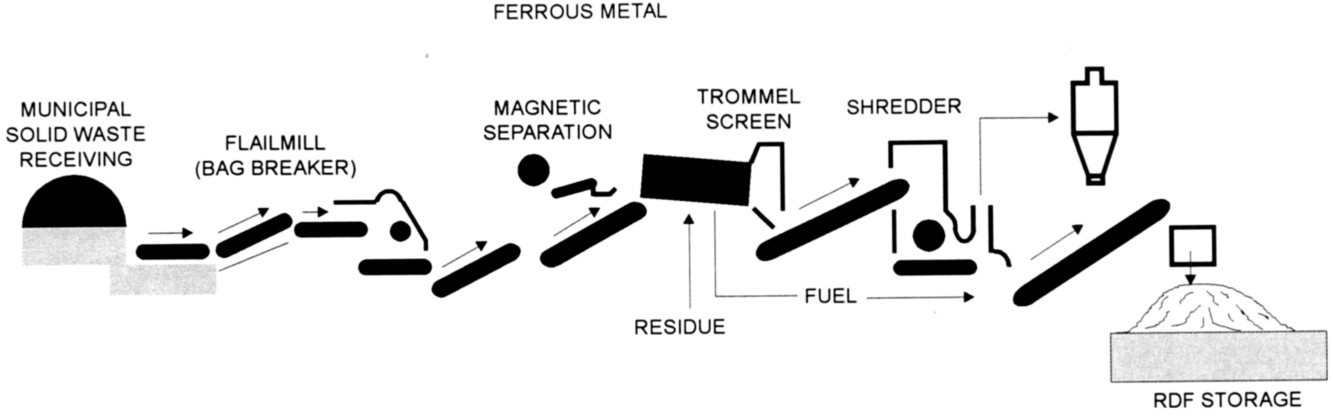
The RDF fuel is generally fired in suspension, stoker or fluidised bed incinerators. The most common of these are the suspension and stoker arrangements.

Semi-Suspension Burning Systems

Typically, semi-suspension RDF burning systems require size reduction and the removal of non-combustible materials from the waste stream prior to burning. These units are also used to burn wood waste. Operating experience with MSW on a large scale has been limited until recently when Combustion Engineering started the Hartford facility (Figure 3.12). The fuel is injected into the furnace through wall ports. Once in the furnace it ignites and burns while falling to the grate. These furnaces are generally equipped with a travelling screen grate system where final burnout occurs.

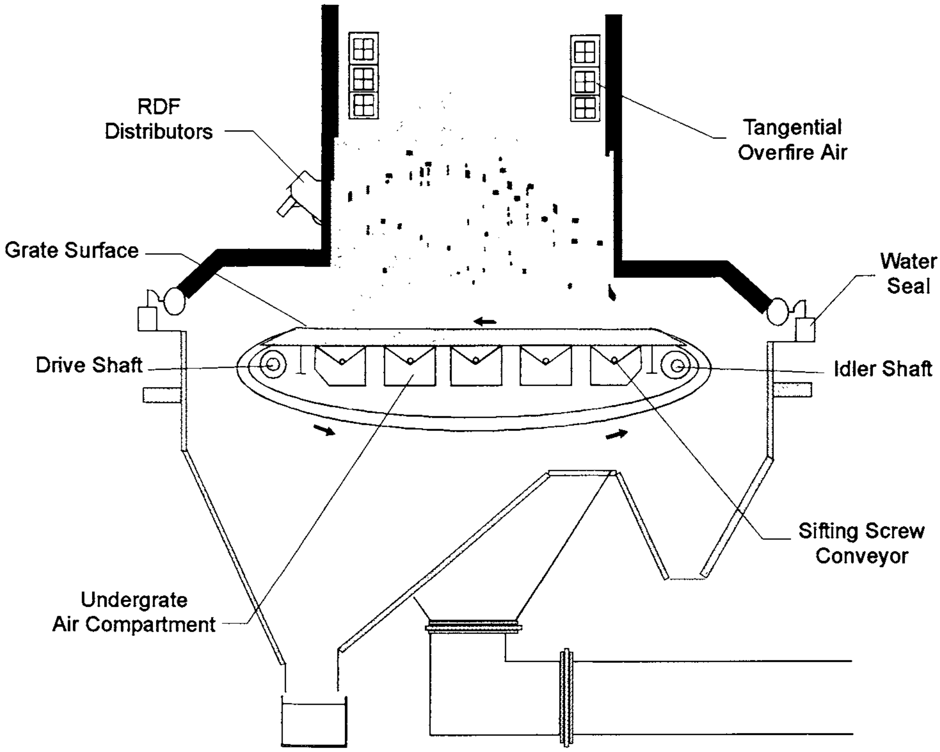
The major design consideration with these systems is to ensure that the fuel is injected in such a manner that it builds an even bed across the grate, similar to the desire for uniform bed characteristics in the mass burn system. To accomplished this, the designers ensure heavier materials travel further across the furnace before they fall to the grate, and they design the injection system to spread the injected material across the grate.

Figure 3.11 Schematic of an RDF Processing Facility



Environment Canada, 1991

Figure 3.12 Cross-Section of a Semi-Suspension Combustion Unit (Mid-Connecticut)



Environment Canada, 1991

Typically RDF burning offers higher energy recovery efficiency, lower excess air requirements and lower capital cost expenditures than mass burning systems. Despite these advantages, semi-suspension burning has limited economic benefits below 400 Mg/d.

Stoker Fired Systems

Stoker fired boilers are common in the utility industry. Their adaptation to burning MSW or combined MSW and coal was an early development that benefitted both the utilities by supplying fuel and the municipalities looking for MSW disposal options. This older technology is not used widely, but still represents a portion of the installed capacity.

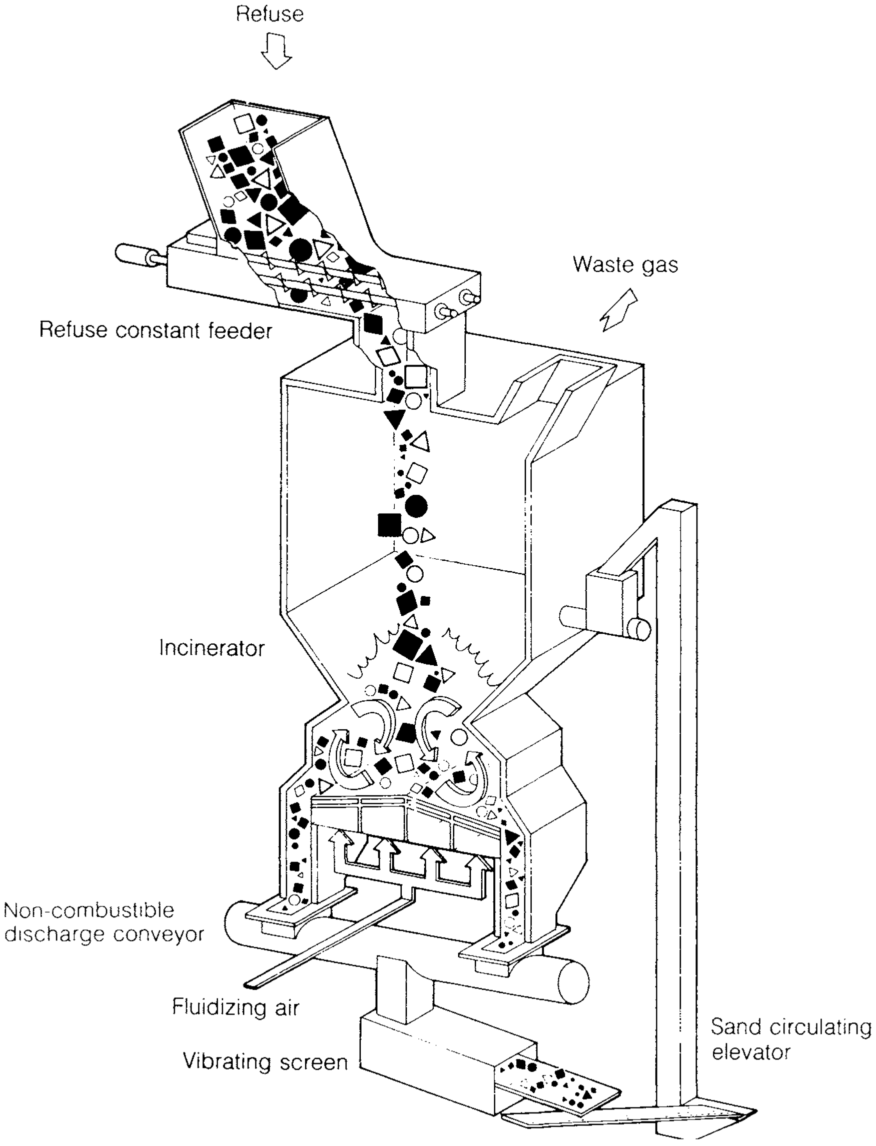
In stoker fired systems the RDF is injected into and distributed in the furnace by intercepting the fuel in the feed chute with a stream of high pressure air. The stoker system also contains a travelling grate and fresh fuel is injected onto the clean part of the grate. The distribution across the grate is controlled by the distribution air nozzle. Unlike older semi-suspension grate systems where the under-fire air is supplied by one plenum, the typical modern spreader stoker has several plenums to enhance air distribution on the grate. Over-fire air introduction into these systems is accomplished through a tangential entry system.

Fluidised Bed Systems

The fluidised bed reactor (Figure 3.13) is capable of destroying a wide range of wastes including sewage sludge, petroleum waste and paper industry waste. The units have been adapted to fire RDF materials and have shown promise in both Europe and Japan. Two new systems are under development in the United States. Sweden has five operating fluidised bed systems, but they tend to be small, handling 4,500 to 11,200 tonnes per annum (RVF, 1988).

The reactor usually consists of a vertical refractory lined steel vessel containing a bed of granular material such as silica sand, limestone, alumina or ceramic material. The bed material is supported by a refractory lined grid. This grid is perforated to allow air to be injected through diffusers located below the grid. The air passing through the grid expands the bed by 80 to 100%, causing it to become fluidised. Wastes can be injected into the bed pneumatically, mechanically or by gravity. The constant moving action of the fluidized bed causes quick uniform mixing of wastes and bed material, resulting in good combustion conditions, and relatively high heat transfer rates. Furthermore, the movement in the bed and its inherent thermal storage capacity increases the burnout of material and minimizes bottom ash generation. This movement and the generation of fine particle in the bed leads to substantial quantities of fine ash being carried out of the bed by the air movement in the furnace. Thus, these systems generally require additional particulate removal devices in the gas stream ahead of boilers and air pollution control systems.

Figure 3.13 Schematic of a Fluidised Bed System



A typical fluidised bed reactor has a height to diameter ratio of 1.25:1 with the expanded bed occupying about 20% of the height. The bed material functions as a heat sink capable of absorbing large amounts of heat generated during the combustion process. Bed temperatures are typically maintained in the range of 760°C to 870°C which is lower than the operating temperatures of other types of systems. These lower gas temperatures and a lower excess air requirement minimizes the formation of nitrogen oxides.

Fluidised bed systems may require auxiliary burners located either above or below the bed to maintain bed temperature, however other options are available to maximize thermal efficiency. The reactor can be operated either as a cold windbox in which the fluidising air is injected directly into the reactor or as a hot windbox in which the air is preheated in a heat exchanger or recuperator prior to injection depending upon the nature of the waste and the need to supply additional heat.

Because of its simple design concept, the fluidised bed reactor has a low capital cost, a relatively long service life and low maintenance costs. In addition, this unit can tolerate large fluctuations in both waste composition and the rate of feed due to the high thermal inertia of the fluidised bed, typically in the order of 596,000 kJ/m^3 (16,000 Btu/ft^3). Some of the potential problems and special considerations of the fluidised bed incinerator include the build up and removal of residual material from the bed, the formation of eutectic mixtures that fuse in the furnace, and bed degradation.

3.3 HEAT RECOVERY SYSTEMS

Although incinerators can be used solely to reduce the volume of MSW requiring disposal, the economic and operational benefits of recovering energy and lowering flue gas temperatures has resulted in most modern MSW incinerator facilities being designed with boilers. Boilers installed downstream from the furnace are used to transfer heat from the flue gases to water and the hot water or steam is then used for space or process heating or converted to electricity using steam driven turbines. In North America, energy generation can account for up to 25% of the revenue for an incinerator facility. With the exception of some facilities in Japan and a few older facilities in North America, most incinerator plants now in operation recover the heat energy generated during incineration.

As noted in the preceding sections of this chapter, the introduction of air into the bed of fuel can cause solid material to be released into the flue gas stream. This fine material is carried downstream until either a sharp change in flow direction or a drop in gas velocity causes it to be removed from the flow stream. Materials that volatilise on the grate also travel with the gas stream until the gases cool and the volatilised materials condense. Both these removal processes occur in the boiler where the gas flows past banks of tubes set perpendicular to the flow direction. As a result, residues are trapped in the heat recovery systems.

Several operational aspects of the heat recovery systems influence the nature of the residues collected in the heat recovery sections of the plant. These are addressed in this section, whereas the mechanisms responsible for residue deposition in boilers are discussed in a later chapter.

A typical heat recovery system (Figure 3.14) includes:

- a radiant section where heat is recovered by radiation heat transfer from the flame zone in the furnace. The mechanism of heat transfer does not rely on convective heat transfer at this point. Generally this heat is removed by the water in the walls of the large mass burn facilities. However, it is possible to have the superheater discussed below in this section of the furnace as well.
- the convection section where the boiler tubes are perpendicular to the flow direction. This section recovers the majority of the available heat and produces saturated steam.
- the economiser section, which is placed after the convection section, and is similar in construction to the convection section. This section operates at a lower temperature generally to heat the feedwater for the boiler.
- the superheater section, used to add additional heat to the steam generated in the convection section of the furnace. It can be placed either before the convection section or before the economiser section. The selection of the location is a function of mass flow and the amount of energy the designer wants to remove from the gas stream.

In most installations there are hoppers installed under of the heat recovery system to collect particulate matter. The hoppers are commonly equipped with double valves to allow the material to be removed without introducing air into the boiler during the on-going operation of the unit.

Heat recovery systems are operated to maximise heat recovery while minimising operating problems. The most common operating problem is boiler tube fouling caused by high flue gas temperatures entering the boiler. At higher temperatures, volatilized metals in the gas stream condense onto the tube surface and form a hard, tough deposit that resists removal by all but the most aggressive means. Gas inlet temperatures below 900°C reduce the degree of fouling on the tubes. Lowering the temperature results in the condensation of the volatilised materials in the gas stream and the transport of the fine particles further into the boiler where they do not appear to be as prone to forming a hard deposit on the tubes.

Condensation reactions are not the only removal process occurring in the boiler. Impaction, settling and other deposition processes also remove materials from the gas stream through a combination of velocity and momentum changes. Some of the materials settle out of the gas stream and fall to the bottom of the boiler. Material impacted, but not condensed on the boiler tubes can be removed during operation by mechanical cleaning. This is accomplished by injecting high pressure steam or air onto the tubes or by mechanically rapping the tubes to dislodge the deposits. The dislodged materials settle to the hoppers located at the bottom of the boiler and can be removed while the system is operating.

The nature of the boiler residue is dependant upon the temperature in the various sections of the boiler as this influences the condensation process. The typical temperature profile in the boiler ranges from inlet values of 900°C to economiser exit gas temperatures in the region of 180°C.

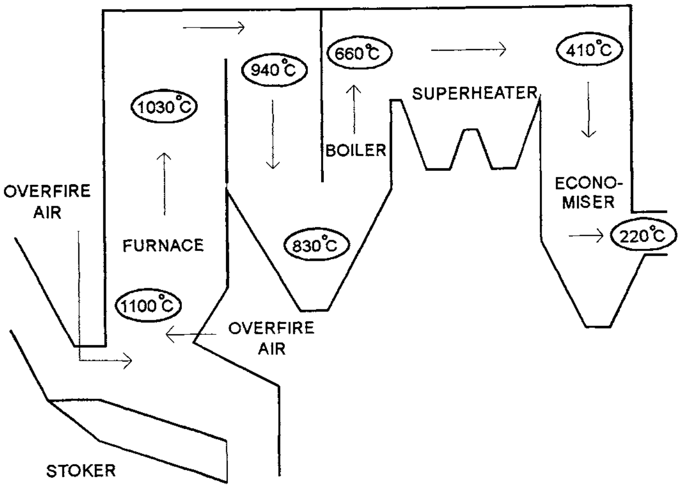
3.4 IN-PLANT RESIDUE MANAGEMENT

Solid residues, commonly referred to as ash, slag, or fly ash, are generated at various points in the incineration process. These materials require handling and eventual disposal. To complete the general introduction to residues, this section examines the common types of waste handling systems employed in MSW incineration plants and the nature of the material from each of the discharge points.

For ease of presentation, the incinerator residue streams are defined as follows:

- bottom ash or slag
- grate siftings
- heat recovery system residues.

Figure 3.14 Typical Heat Recovery System



3.4.1 Bottom Ash

The non-combustible fraction of the waste charged to the furnace forms a residue on the hearth. This material is generally referred to as bottom ash but is also called slag, grate ash or clinkers. Fluidised bed furnace bottom ash is commonly referred to as bed material.

Removing the bottom ash from the incinerator must be done in a manner that minimises the ingress of air, maintaining control of the combustion process. The seal on the furnace is generally provided by a column of water. Since bottom ash may still contain carbon that would continue to smoulder after leaving the grate, the water serves to extinguish any remaining combustibles and cool the ash. Furthermore, large pieces of clinker fracture when quenched, reducing their size. Material discharged from the quench tank is normally transferred to an ash storage bunker where further dewatering takes place before a crane is used to transfer the material to containers or vehicles destined for utilisation or disposal sites. Bottom ash is normally wet when it leaves the plant thereby minimising fugitive dust emissions. To minimise leakage of contaminated water onto roads and into streams, the containers or vehicles are typically covered and designed watertight.

The major design difference between various facilities is the mechanism used to remove the bottom ash from the quench tank. Different extraction devices influence the characteristics of the bottom ash. All extraction devices need to be designed to minimise operational difficulties induced if large non-combustibles are fed into the furnace and jam the ash removal mechanism.

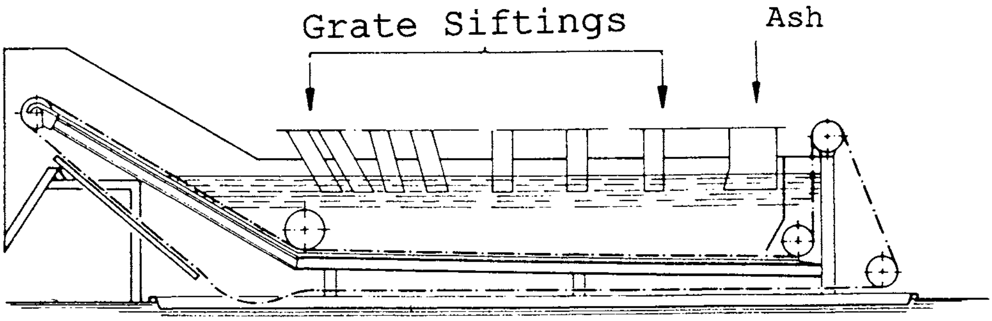
Several types of ash removal systems exist:

- drag-chain conveyors
- plate conveyors
- hydraulically ram type systems.

The drag-chain conveyor, Figure 3.15, consists of a series of scrapers attached to a chain. The scrapers cover the width of the quench tank and move along the floor of the tank before riding up a slope to the discharge point. They then return overhead or under the tank back to the input end of the tank where they again enter the water. Ash discharged to the tank settles to the bottom and the scraper moves it as it passes through the tank. The inclined discharge chute allows the free water to drain back to the quench tank. Floating ash tends to build up on the surface of the quench tank in these systems and only limited amounts of this material are removed with each operational sequence of the conveyor. Eventually the system must be shut down and drained to clean the tank.

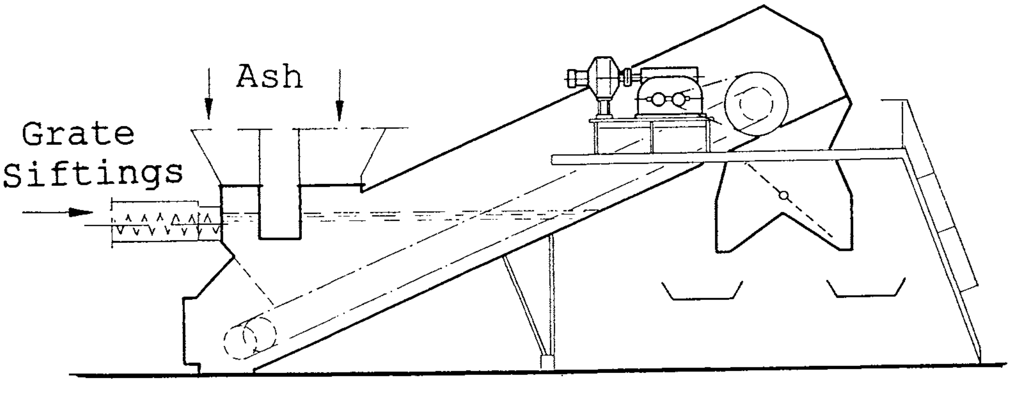
Plate type conveyors, Figure 3.16, are similar in concept to the drag-chain conveyor. However, the plates are fully immersed in the quench tank and ash landing on the plates is transported out of the tank.

Figure 3.15 Diagram of Drag-Chain Conveyor System



Beseitigung von Abfallstoffen durch Verbrennung

Figure 3.16 Diagram of a Plate Conveyor



Beseitigung von Abfallstoffen durch Verbrennung

Hydraulic rams and sweeps are becoming a preferred technology, particularly on larger incinerators. In most cases these robust devices are capable of overcoming the problems associated with large non-combustible components charged to the furnace. Martin offers their ash discharger, Figure 3.17, for use on numerous services including MSW and coal-fired systems. The unit connected to the discharge of the furnace by a vertical inlet chute that is partially filled with water, consists of a curved bottom plate and inclined discharge chute. The ram inside the discharger continuously reciprocates along the bottom plate pushing the slag ahead of itself. The slag is compressed through the discharge chute, facilitating dewatering and reducing the size of any large clinkers or large compressible materials. The moisture content of the ash leaving this discharger is substantially lower than that leaving most drag-chain conveyor systems.

The Simonds hydraulic sweep design, Figure 3.18, consists of a sweep arm that traverses the bottom of a curved tank during the discharge cycle and returns to the starting point of the cycle by a shorter radius route. This path minimizes disturbance in the tank thereby allowing ash to settle to the bottom.

The design of the quench tank and ash removal system can influence the moisture of the bottom ash leaving the quench tank; however, the ash itself has a major influence on moisture levels. High residual carbon content in bottom ash will enhance the moisture holding capacity. For example, ash from drag chain conveyors on controlled air incinerators has been found to contain up to 50% moisture. Under any circumstances the quenched bottom ash is wet enough to negate fugitive dust emissions within the facility or during transport.

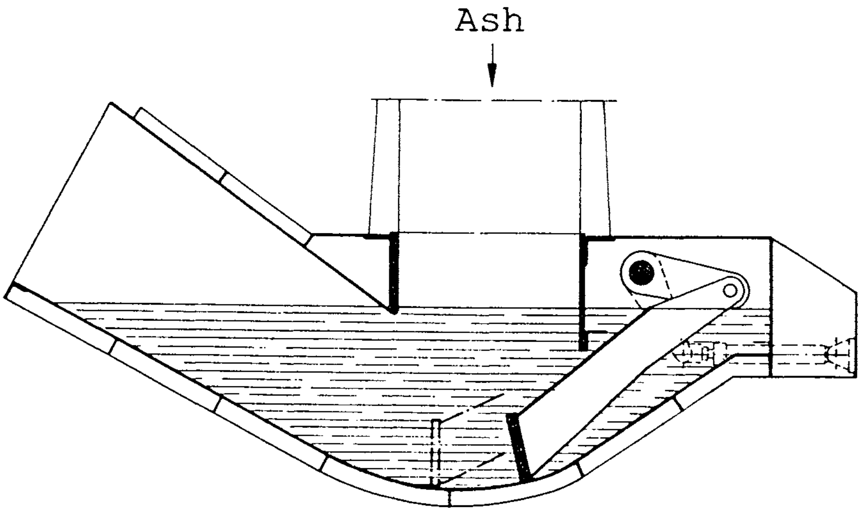
Metal and glass make up a significant portion of the total ash mass. Ferrous metal in bottom ash can be recycled, so it is not common for the ferrous material to be extracted using magnetic separation prior to the bottom ash being discharged to the ash bunker. This reduces the mass and volume of material that needs to be managed.

Bottom ash can also be screened to remove the oversize or fine materials and enhance the physical properties of the ash, facilitating utilisation. In some cases the material may need to be crushed prior to screening to remove the large size fraction that is unsuitable. In Europe, ash destined for use as an aggregate is stockpiled outdoors and allowed to age for a period before placement. Ash destined for disposal is frequently discharged to an ash bunker where a crane is used to transfer the material to containers for transport to the disposal site. Bottom ash is normally wet when it leaves the plant and, to prevent leakage of contaminated water onto roads and into streams, the trucks are typically covered and watertight.

3.4.2 Grate Siftings

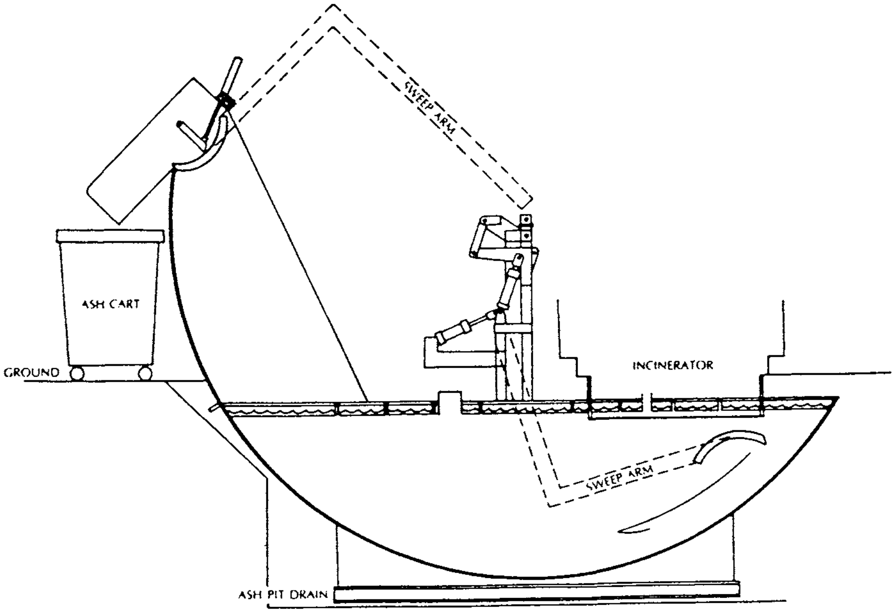
The material that passes through the openings in the grate, either because of its size or because it melts, and is trapped the under-fire air plenums located below the grate

Figure 3.17 Diagram of the Martin Discharger



Courtesy Martin GmbH

Figure 3.18 Diagram of the Simonds Discharger



Courtesy Simmonds

is referred to as grate siftings. The siftings are normally conveyed to the quench tank for mixing with the bottom ash. During normal shutdowns it is necessary to clean the plenums to remove materials that freeze on the cooler surfaces. Aluminum and lead are two metals commonly found in grate siftings.

3.4.3 Heat Transfer System Ash

As discussed earlier, some of the metals volatilised from the waste on the grate pass through the furnace and are condensed on the cooler surfaces of the boiler and other heat transfer equipment. This material acts as an insulator reducing heat transfer rates and must be removed to maintain process efficiency. When removed, it falls into the hoppers under the boiler along with other materials discussed previously. The ash collected in the hoppers of the boiler is dry and can be removed through air lock valves. In many plants the boiler ash is transported by screw conveyors to the bottom ash discharge sump but in newer plants it is being discharged separately or mixed with the APC residues for treatment and management. When collected separately, the material is transferred to containers for shipment to disposal sites.

Boiler/economiser ash removed during operation is generally a fine material, smaller than sand. The material can be sticky or tacky by nature and may be difficult to handle. Although on-line cleaning can remove a substantial amount of residue from the boiler sections, over a period of time the ash coats the boiler tubes and results in a decrease in heat transfer capabilities. When heat transfer is impeded, exit gas temperatures rise and steam production falls, necessitating unit shutdown and cleaning. When the boiler has cooled, workers enter the boiler chamber and using a combination of air, water and mechanical cleaning procedures or explosive charges remove the residue coating the tubes. In large mass burn facilities this process can occur as often as quarterly but generally once or twice a year; in smaller starved-air facilities it could be as frequent as every 6 to 8 weeks. The material removed during maintenance activities tends to be sintered into large pieces.

Several precautions should be taken in handling these materials. The heat recovery ash is fine and can easily become airborne. This material poses a potential health and safety problem to the workers in the plant and at the disposal site and to members of the public located adjacent to the plant, landfill or transportation routes. To minimise the potential for such fugitive emissions, it is common to wet the fly ash to the 5 to 15 % moisture level. The material is transported in covered trucks to minimise release to the environment and once at the disposal site is compacted and covered quickly.

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