CHAPTER 10 - CHARACTERISTICS OF HEAT RECOVERY SYSTEM ASH

In some jurisdictions, the consideration of energy recovery may be secondary to incineration as an MSW management tool. Nevertheless, the economic benefit of recovering energy and the technical benefit of being able to control flue gas temperatures prior to the air pollution control system has resulted in virtually all new MSW incinerator facilities being designed with energy recovery capabilities.

As explained in Chapter 8, the presence of the heat recovery units adds an obstacle to the path of the flue gas stream, thereby creating the potential for another ash stream to be collected. The existence of separate heat recovery ash streams is dependent on the configuration of the incinerator (see Chapter 3). In some incinerator systems, the boiler banks (such as semi-suspension combustion systems) are directly above the furnace bed and the only way to access this material is to collect ash impinged on the boiler tubes or the walls during furnace maintenance periods. In other systems, the heat recovery units are quite separate from the furnace and access to these ashes is relatively simple. Since boiler ash is usually mixed with bottom ash in the quench tank, comparatively few studies have been conducted on the characteristics of separated ashes from heat recovery systems.

In order to understand some of the characteristics of heat recovery system ashes, it is important to review the mechanisms by which deposition occurs. Some of these mechanisms are described in Chapter 8. Because the mechanisms represent a complex interplay of physical and chemical processes, they are explained in further detail in this chapter.

Since each type of incinerator offers a unique set of conditions under which deposition occurs, the characteristics of heat recovery system ashes are also unique. The physical and chemical data presented here focus on the influence that incinerator type and operation have on ash quality. Wherever possible, the data have also been separated into the constituent ash streams within the heat recovery system, i.e. boiler ash versus economiser ash. It is important to note many of the inferences made in this chapter draw upon the discussions of heat recovery systems given in Chapter 3 and the fate of elements in Chapter 8.

10.1 ASH DEPOSITION MECHANISMS

The flue gas stream exiting the combustion chamber of an MSW incinerator contains particles in a vapour, liquid or solid phase. Along its path, the flue gas stream encounters boiler tubes which disrupt its flow. The heat transfer surfaces are much cooler than the prevailing temperatures in the flue gas stream. On a macroscopic scale, the denser particles entrained in the flue gas tend to fall out of suspension as the velocity of the flue gas permits and collect in the hoppers below the boiler. Some particles also collect on the walls of the boiler, while others impinge or condense on the heat transfer surfaces. Only the finest sized particles remain entrained in the flue gas stream and are carried over into the air pollution control system.

A study at three German mass burn facilities was conducted to monitor the hold up of particulate matter in the boiler between soot blowing events (i.e. loosely impinged fly ash on boiler tubes and boiler walls). The data given in Table 10.1 indicates with lower waste loading rates, and hence lower flue gas velocities, the proportion of fly ash retained in the boiler increases. It was also noted there was a threefold increase in particle loading to the flue gas stream during soot blowing, which was carried downstream to the APC system. This is corroborated by operational experience at another modern German mass burn facility where the ratio of fly ash released into the flue gas stream and fly ash collected in the boiler hopper during soot blowing was about 2:1.

Table 10.1
Summary of Boiler Ash Hold Up in Three Different Incinerator Facilities

Facility	Waste Feed Rate (Mg/hr)	Fly Ash Loading (kg/Mg of Waste)*	% Captured in Boiler
A	12	20	7.4
	10	20	12.5
B	10	30	11
C	10	5	27

Vehlow and Schneider, 1991

Typically, ash from the heat recovery system of modern, well-operated incinerators is a dust-like or fine granular material, ranging from black-grey to beige-tan in colour. The particles range in size from submicron to greater than 400 microns in diameter. In some instances, much larger chunks of boiler ash can be observed. These chunks are formed on the boiler tubes by agglomerated particles and condensed constituents from the flue gas stream which "freeze" onto the heat transfer surfaces, forming a hard, sometimes rocklike material which is difficult to remove via normal on-line cleaning processes (soot blowing or rapping).

The presence of the heat transfer surfaces provides a unique set of circumstances for a number of complex physical and chemical deposition mechanisms to occur. While the degree of deposition (or "fouling") which occurs varies depending on the type of incinerator, the basic principles behind the formation of deposits are the same. One major study conducted by the National Engineering Laboratory (NEL) in Glasgow investigated gas-side fouling and developed models to predict deposition within an incineration system based on the integration of a number of chemical and physical processes (Ewart, 1988; Glen et al., 1988; Glen and Howarth, 1988).

As mentioned in Chapter 8, fouling is generally classified into four major categories, 1) condensation, 2) chemical reactions, 3) corrosion and 4) particulate. Vapour, fluid or solid particles entrained in the flue gas stream can be deposited on the heat transfer surfaces through complex interactions of the physical mechanisms defined in Table 10.2.

Table 10.2
Physical Mechanisms Responsible for Deposition of Particles on a Solid Surface

Mechanism	Definition
Inertial impaction	deposition due to particles too large to follow the flow of the flue gas around the solid surface
Interception impaction	deposition caused by particles of a finite size which follow the stream flow around an object and are intercepted by another solid object
Brownian forces & eddy diffusion	deposition caused by random velocities of small particles which deviate from the stream flow and increases potential contact with the solid surface
Fickian diffusion	deposition of a vapour from the gas stream onto a surface that has a temperature below the prevailing dew point
Gravitation	deposition of particles which are sufficiently dense to settle out under a given velocity
Thermophoresis	deposition by the force exerted by the thermal gradient caused by gas particles on the higher temperature side of a particle having greater kinetic energy, thereby exerting a greater force on the gas molecules on the cooler side of the particle
Diffusiophoresis	deposition by the net force exerted on a particle by the flux of a condensing vapour toward a cool surface

Glen and Howarth, 1988

Typical operational experience has shown the upstream or leading edge of boiler tubes can become coated with a very hard, fused material, whereas the trailing edge is generally encrusted with a more friable dust-like material. These differences are attributed to the degree to which any one deposition mechanism will occur, given the orientation of the heat transfer surface in relation to the flow of the gas stream (Glen and Howarth, 1988). For example, the leading edge of a boiler tube would be susceptible to thermophoretic deposition in the early stages of use. However, inertial impaction could progressively become the most dominant deposition mechanism over time as the layers built up on the leading edge. The downstream edge of a boiler tube would consist of more particles deposited through interception and diffusion than the other mechanisms, thereby imparting the friable characteristic on the material.

The degree to which fusing of material occurs in smaller incinerator systems, especially two-stage systems, is much greater than that which occurs in mass burn or semi-suspension combustion systems. This is due to the difference in their operational modes. The thermal gradient between the flue gas and the heat transfer surfaces in a two-stage system is much greater than the gradient in either a mass burn or RDF combustion system. The collection of radiant heat in the waterwall boilers on most mass burn and RDF systems results in much lower temperatures of the flue gas entering the boiler (<800°C) compared to the temperature of the flue gas stream entering the boiler of a two-stage system directly from the secondary combustion chamber (>900°C). The higher thermal gradient in the two-stage systems results in a much higher degree of deposition occurring due to thermophoresis and diffusiophoresis impaction than any of the other mechanisms. As a result, the fused material becomes a condensed, compacted layer which is too hard to be removed via conventional on-line cleaning operations.

The particulate loading in the flue gas stream from a two-stage system is much lower than the other systems. Consequently, the layer of fused material on the leading edge of the boiler tubes thickens mostly through continued thermophoresis and diffusiophoresis impaction rather than inertial impaction. The hardening of the fused layer is further compounded as the layer thickens, due to the increased temperature of the outer leading edge which increases the potential for melting and fusing of material (Glen and Howarth, 1988). The built-up layers also increase the surface area disturbing the gas stream, thereby increasing the turbulence and enhancing deposition of particulate via interception and diffusion (Brownian and eddy) impaction mechanisms. The overall result is a substantial build-up of material within a relatively short operating period. Two-stage systems are generally shut down for boiler maintenance once every 8 to 12 weeks, whereas mass burn or RDF combustion systems may operate normally for up to a year or more prior to scheduled cleaning maintenance of the heat recovery units. Since the build-up of hardened layers in the latter two types of systems is relatively thin (e.g. between 3 and 10 mm in a modern mass burn incinerator), even after long periods of operation these layers are typically left on the tubes as a coating to protect against further corrosion (Vehlow, 1991).

Another unique characteristic of boiler ash from two-stage systems is that the material is generally more tacky or sticky in nature than ashes from large mass burn or RDF combustion systems, especially on the trailing edges of the heat transfer surfaces. This stickiness is mainly due to the enhanced sulphate concentrations in the residues (see below and Chapter 8).

10.2 PHYSICAL CHARACTERISTICS

10.2.1 Particle Size Distribution

As mentioned earlier, the size of particles captured in heat recovery systems can vary widely. For example, the particle size distribution data determined by weight for boiler ash collected from a modern mass burning incinerator is given in Table 10.3. The optically determined frequency of the particles for the different size ranges is also given. The data indicate the most prevalent particle size of friable ash by population is the size range 5 to 20 microns, whereas the greatest proportion of particle mass was in the 40 to +200 size fraction. This inverse relationship of the lowest population of particles representing the greatest proportion by weight corroborates observations by Glen and Howarth (1988) (Figure 10.1).

Table 10.3
Particle Size Distribution Data of Boiler Ash from a Mass Burning Incinerator

	% of Particles in Each Size Range (microns)				
Test (on 3 reps)	2 - 5	5 - 10	10 - 20	20 - 40	40 - +200
By Mass	0	0	4	11	85
	0	1	2	11	86
	0	0	2	0	97
By Frequency	64	9	16	5	5
	76	12	5	4	4
	80	9	7	0	4
Average Mass	0	<1	3	7	90
Average Frequency	74	10	10	3	3

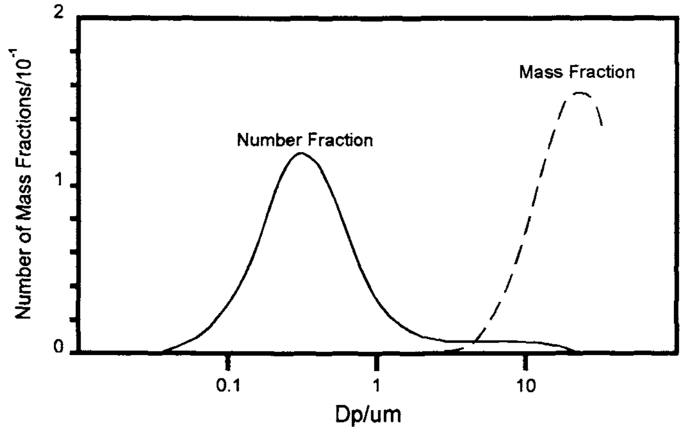
WASTE Program, 1993

The particle size distribution of boiler ashes can be influenced by a number of factors including:

- incinerator type
- operating conditions
- configuration of the boiler
- waste feed composition.

The type of combustion system will influence the range of particle sizes normally carried over to the boiler. Because of the semi-pyrolytic combustion conditions in the primary chamber of a two-stage system, the flue gas velocities in the primary chamber are relatively low and granular sized particles are not likely to be carried over to the boiler. Conversely, because of the semi-suspension combustion of RDF, there is a greater potential for carry-over of a greater proportion of larger sized particles than in a mass burn system.

Figure 10.1 Particle Size Distribution of Boiler Ash from a Mass Burn Incinerator



Glen and Howarth, 1988

Changes in operating conditions can also affect the particle size distribution. For example, in mass burn systems, an increase in the under-fire air pressure and decrease in the depth of the fuel bed due to very wet garbage can increase the potential for carry-over of larger sized particles compared to normal operating conditions. Conversely, a decrease in the under-fire air to control the combustion of relatively dry garbage would result in a smaller proportion of larger sized particles being present in the boiler ash.

The configuration of the boiler will also influence particle size distribution. By increasing the turbulence in the path of the flue gas stream, the potential to increase the proportion of finer sized particles increases due to interception and diffusion (Brownian & eddy) impaction mechanisms.

Finally, the proportion of fine sized or dust-like material (<200 microns) in the waste can influence the ratio of particle sizes carried over in the flue gas stream. For example, higher ratios of fines, soil or construction debris versus organic materials (cellulose) would increase the potential ratio of finer to coarser particles collected in the boiler, since this type of material is readily suspended in the furnace by the turbulence created by primary and secondary air injection.

10.2.2 Particle Morphology

During the WASTE Program, qualitative analysis was conducted on some of the boiler ash samples using scanning electron microscopy (SEM) to determine the morphology of the particles. The particles were categorised into the five types listed in Table 10.4.

Table 10.4
Summary of Morphological Characteristics of Boiler Ashes

CATEGORY	DESCRIPTION
Fused Spheres	spheroids of various colours with particulate or gaseous inclusions
Crystals	irregular in shape, similar to soil-like particles of calcite or quartz
Polycrystallines	dense agglomeration of irregular shaped particles
Opaques	single, large irregular shaped particles (<300 microns)
Char	Black fibrous particles

WASTE Program, 1993

In addition to the identification exercise, the relative percentage of the different particle types was determined optically (Table 10.5). The most common particle types were the polycrystalline and opaque irregular shaped particles, whereas crystals, fused spheres and particles of char were the least common forms. Glen and Howarth (1988) report SEM examination of samples indicated visibly discrete amorphous particles as well as spherical silicate and alumino-silicate particles in the 1 to 30 micron size range. These discrete particles were often encrusted with, or embedded in, a non-silicate matrix, representing much larger agglomerated particle sizes.

Table 10.5
Estimated Relative Percentage of Particle Types in Boiler Ash

MORPHOLOGY	Estimated Relative %	Size Range
Fused Spheres	15	2 - 100
Crystalline	10	5 - 140
Polycrystalline	30	5 - 200
Opaque	30	5 - 300
Char	15	10 - 400

WASTE Program, 1993

10.3 CHEMICAL CHARACTERISTICS

Although there is a relative paucity of data on boiler ash in comparison to other residue streams, there are several sources of data which provide an excellent indication of boiler ash composition. For example, in addition to the data provided in Chapter 8, the NEL study generated a small database differentiating the composition of captured particulate matter versus the composition of fused deposits and dust-like deposits on the heat transfer surfaces. Furthermore, the data from the NITEP Program provide an excellent illustration of how the incinerator type influences boiler ash composition

(Environment Canada, 1985, 1988 & 1992; Bridle and Sawell, 1985; Sawell and Constable 1988, Sawell et al., 1989a & b, 1990a & b, 1991, 1992). The WASTE Program data also provide an indication of how the waste stream can affect ash characteristics (WASTE Program, 1993).

10.3.1 pH and Acid Neutralisation Capacity

The pH of boiler and economiser ashes from three different types of incinerator systems are presented in Figure 10.2. The box plots have been generated using data from the NITEP and WASTE Programs and are based on the pH of an ash sample mixed in distilled water at a liquid-to-solid ratio of 20:1. The wide variability in the data can be attributed to the difference in incinerator systems. Two-stage systems tend to produce boiler and economiser ash which is neutral to mildly acidic in nature, whereas the RDF and mass burn systems generate ash which is highly alkaline (see Chapter 8). This is a direct result of the degree of enrichment of sorbed SO_2 (sulphation) on the outer layers of particles from the flue gas stream (length of time the ash is retained in the system prior to removal), and the prevailing temperature of the flue gas stream within the individual heat recovery units (see Section 10.3.3). It is also interesting to note the pH of the combined boiler/economiser ash collected during one of the NITEP studies was slightly less alkaline than the ashes from the other mass burn system. This is probably due to the longer retention time of the ash during the eight-hour test runs used during the NITEP study versus the four-hour test runs used in the WASTE Program study.

The degree of sulphation will also greatly influence the acid neutralisation capacity (ANC) of the ash. The ANC curves for heat recovery system ashes from a modern mass burn and semi-suspension combustion system are compared to those of bottom ash and fabric filter residue in Figure 10.3. These naturally alkaline ashes have ANCs similar to that of bottom ashes. In comparison, two-stage system boiler residues have very little buffering capacity [0.95 meq/g to endpoint pH of 4.4 (Sawell et al., 1989)] due to the prolonged retention and subsequent sorption of SO_2.

10.3.2 Solubility in Water

The overall solubilities of boiler and economiser ashes in water from the different types of incinerator systems are given in Figure 10.4. Once again, the data has been gleaned from the NITEP and WASTE Programs. The box plots indicate the ashes from two-stage systems are much more soluble than those from either mass burn or semi-suspension combustion systems. This is directly related to the prolonged retention time of the ash in the two-stage system and is consistent with the discussion on ash deposition in high thermal gradient heat recovery systems. The moderately high solubilisation of the combined boiler/economiser ash from the NITEP mass burn study compared to the WASTE Program study is due to the longer retention time of the ash during the NITEP study (see Section 10.3.1).

Figure 10.2 pH of Boiler and Economiser Ash from Three Different Types of Incinerator Systems

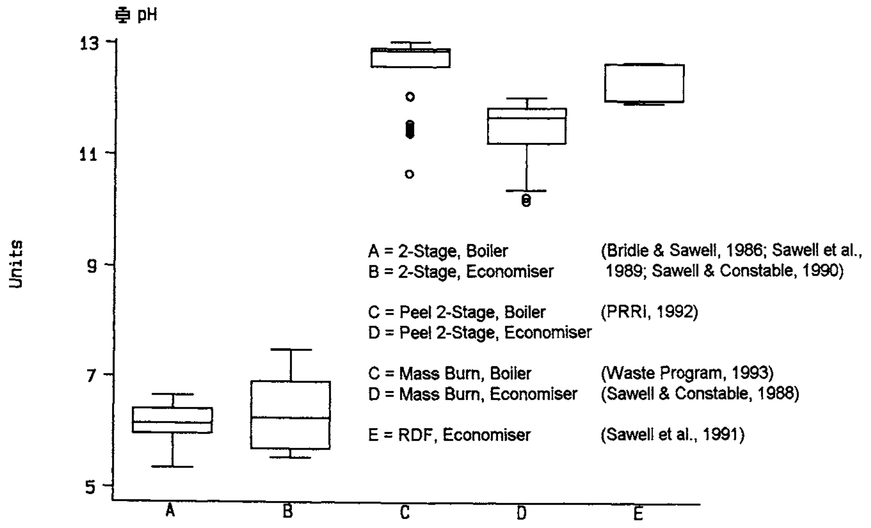
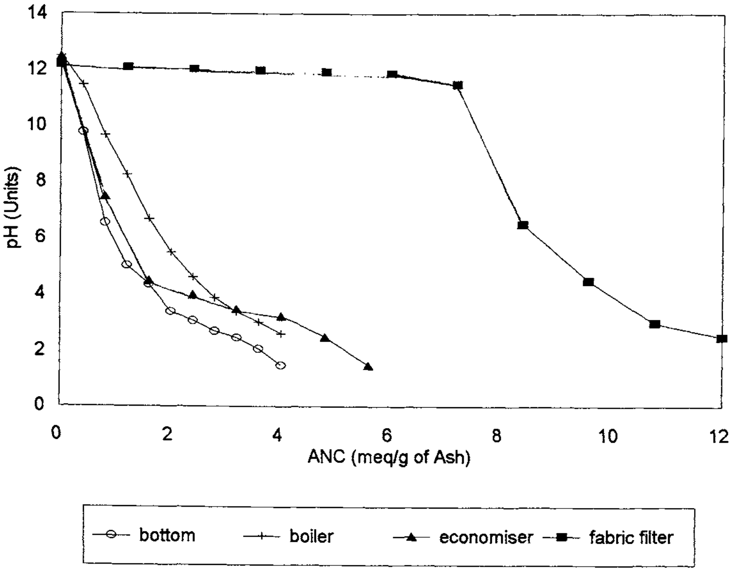
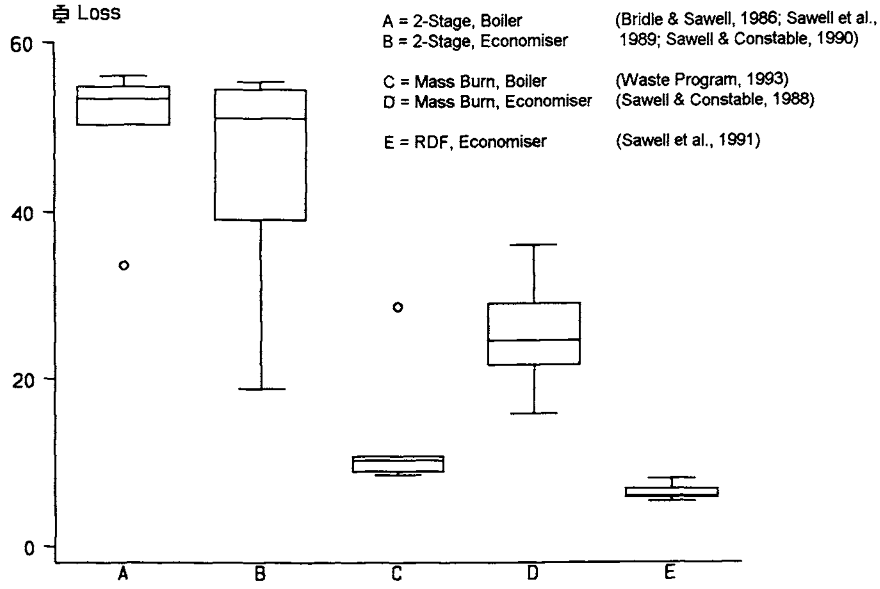


Figure 10.3 Comparison of Ash Stream Acid Neutralisation Capacity Values from Mass Burn and Semi-Suspension Combustion Systems



Adapted from Sawell et al., 1989b; WASTE Program, 1993

Figure 10.4 Water Solubility of Boiler and Economiser Ash from Three Different Types of Incineration Systems



10.3.3 Chemical Composition

Compositional data from the NEL study is summarised in Table 10.6 and indicates the discernable difference between the chemical composition of flue gas particles, the fused upstream layer and the downstream layer collected on the heat transfer surfaces. The particulate matter represents the composition of a raw particle entrained in the flue gas prior to any deposition or condensation mechanism occurring.

In relation to the raw particulate matter, both the upstream and downstream layers become substantially enriched in sulphate, chloride and potassium, and slightly enriched in zinc (bolded in Table 10.6). One of the reasons for the enrichment is the prolonged exposure of the upstream and downstream deposits to the flue gas, which results in sorption of acid gases (SO_2 and HCl) and other volatile compounds. The enrichment of sulphate in downstream deposits is greater than the enrichment in the upstream deposits due to the increased available sorptive surface area of the dust-like deposits. Note the increase in mass of both type of deposits resulted in a corresponding decrease in the aluminum oxide and silicon oxide content, and a slight decrease in the phosphate, calcium oxide and chromium oxide content of the deposits (particulate born).

Table 10.6
Statistical Summary of Fouling Deposit Chemical Composition Data

	Particulate	Upstream Deposit		Downstream Deposit	
	Mean %	Mean %	Std. Dev.	Mean %	Std. Dev.
Al_2O_3	14.0	6.41	2.59	5.75	1.32
SiO_2	28.1	11.1	4.69	12.9	2.87
PO_3	2.36	1.20	0.73	1.47	0.75
SO_3	7.25	**22.1**	9.24	**26.9**	6.54
Cl	2.51	**11.1**	9.16	**5.44**	5.03
K_2O	3.72	**10.3**	3.66	**11.7**	4.65
CaO	26.7	23.8	5.57	18.2	7.58
Cr_2O_3	0.64	0.57	0.54	0.55	0.75
Fe_2O_3	5.2	3.40	1.56	5.21	2.39
ZnO	2.42	**4.80**	2.32	**6.44**	4.94

Adapted from Glen and Howarth, 1988

As discussed in Chapter 8, the sorption of SO_2 in heat recovery system ashes is a more important reaction than the sorption of chloride since chloride has a lower dew point temperature. This is evident from the order of magnitude difference in the concentrations of chloride in the heat recovery system ash (Figure 10.5) in comparison to the concentrations of sulphate measured in the same ash samples (Figure 10.6).

The concept of sulphate enrichment, or sulphation, of various compounds in boiler ashes which have prolonged exposure to the flue gas stream is supported by the data given in Figure 10.6. The box plots include data gleaned from the NITEP and WASTE programs, and are grouped by incinerator type. These data are compared on the basis of relative sulphate content as indicated by leaching with distilled water.

As mentioned above, sulphate enrichment in boiler ash from two-stage systems is greater than soot blown boiler ash in mass burn and RDF combustion systems due to the greater retention time of the ash in the system. The 390 mg/g of sulphate released per gram of boiler ash from the LVH two-stage facility was the most highly enriched ash due to the fact that all of the boiler ash was held in the heat recovery system for four days prior to soot blowing to accumulate a sufficient sample size, whereas the other samples were collected over four-hour test periods.

The same trend can also be seen in the data in Figure 10.7 in which the releases of sulphate (in µg/g of ash) from boiler ashes in distilled water are compared for the different test runs of the WASTE Program. The data indicate the sample collected during the first test run of the series contained about five times the amount of sulphate

Figure 10.5 Relative Chloride Content of Boiler and Economiser Ashes from Three Different Incineration Systems

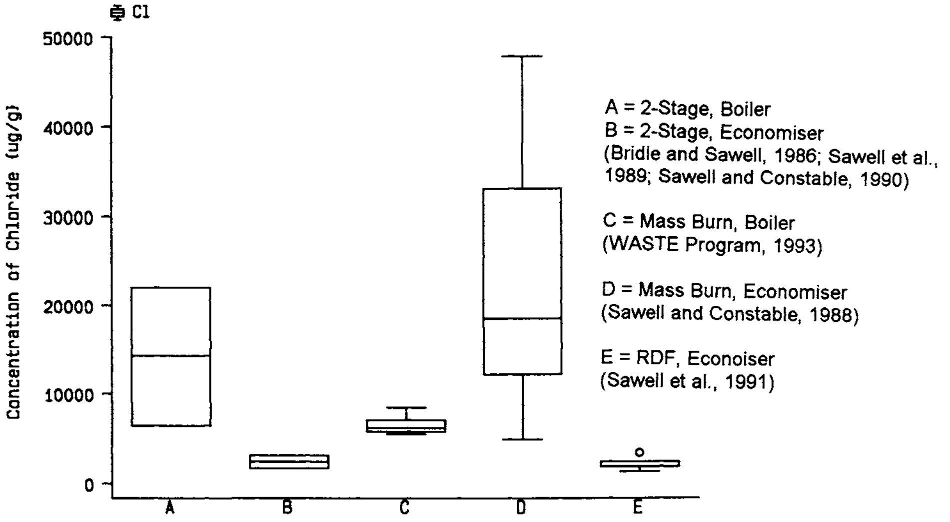


Figure 10.6 Relative Sulphate Content of Boiler and Economiser Ashes from Three Different Incineration Systems

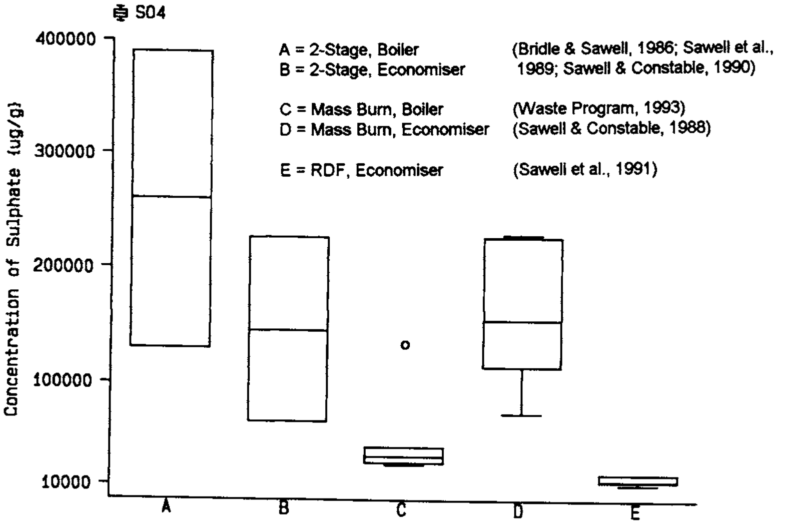
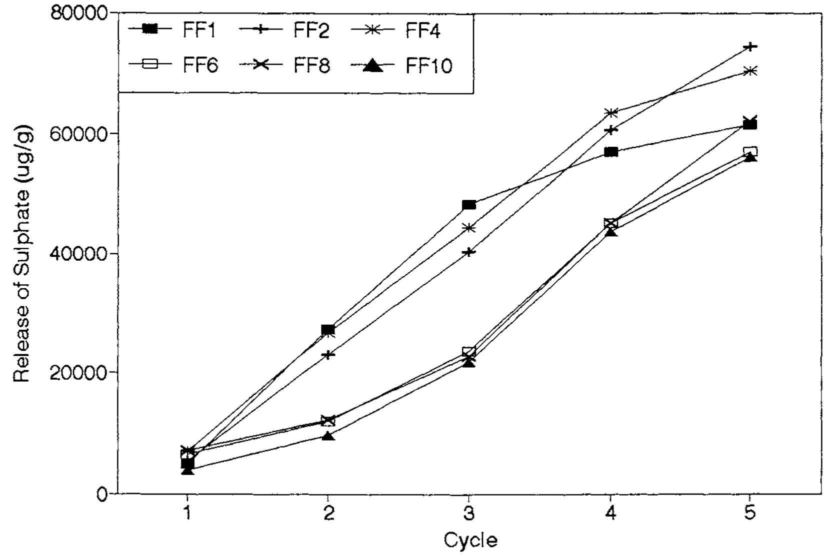


Figure 10.7 Comparison of Sulphate Release from Boiler Ash



WASTE Program, 1993

as the subsequent test run samples. This is because the conditions under which the sulphate enriched sample was taken differed from the other tests. Although a soot blow cycle was initiated prior to starting and finishing a test run, the normal soot blow cycle at the facility was 12 hours. It was hypothesised since the soot blow used to finish the first test run was only four hours after the end of the previous cycle, it dislodged a large quantity of encrusted ash from the boiler tubes which would not have been dislodged in normal operation. In addition, the method of sampling involved manually removing some of the ash from the boiler hopper chute, effectively cleaning out the hopper ducts. The material collected contained ash which had been retained in the boiler for a much longer period of time than the subsequent four hour test runs, and therefore had undergone a much higher degree of sulphation than the other samples.

10.3.4 Heavy Metals

The concentrations of the heavy metals chromium and nickel in boiler and economiser ashes are presented in Figures 10.8 and 10.9. The box plots represent a compilation of data from the NITEP and WASTE programs, as well as data from the regulation compliance testing conducted at the Peel Incinerator Facility near Toronto, Ontario (PRRI, 1992).

Figure 10.8 Comparison of Chromium Content in Heat Recovery System Ashes from Three Different Incineration Systems

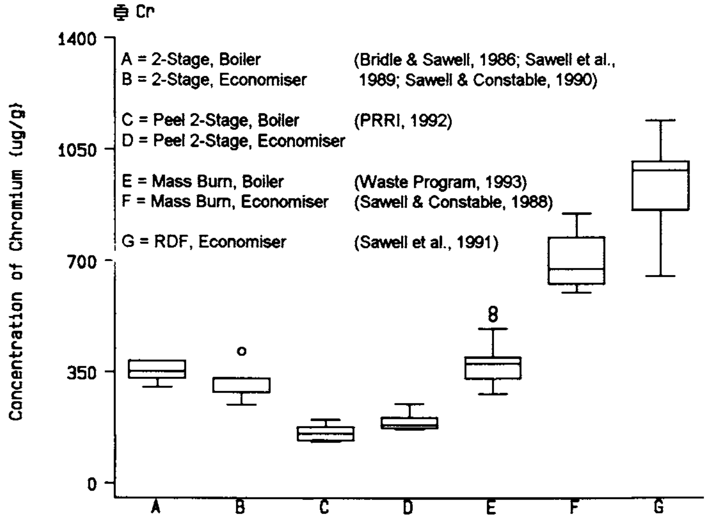
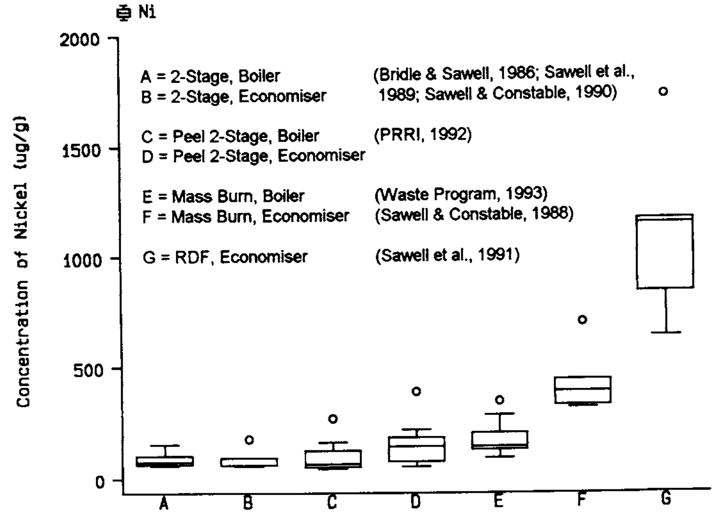


Figure 10.9 Comparison of Nickel Content in Heat Recovery System Ashes from Three Different Incineration Systems



Based on the discussion in Chapter 8, the partitioning of chromium and nickel during incineration indicates these metals will be present mostly in the form of solid particulate matter carried over from the combustion chamber by the flue gas stream. Since the only mechanisms available for deposition of solid particulate are gravitational, inertial or interception impaction deposition, the concentration of these metals in the ash is a function of the carry-over of particulate matter from the combustion chamber and hence is influenced by the composition of the waste feed, the incineration system used and the incinerator operating conditions. Lower concentrations of these metals can be expected if the ash is allowed to remain exposed to the flue gas stream. This is based on the relative increase in mass of the ash due to the enrichment of sorbed volatile compounds onto the boiler ash particles.

The lowest concentrations of chromium and nickel were measured in the samples from the two-stage systems, ranging from 130 to 385 µg/g for chromium and 52 to 387 µg/g for nickel. The next lowest range of concentrations for both metals was the combined boiler/economiser ash from the mass burn system. This is consistent with the low carry-over of particulate from the primary combustion chamber (two-stage systems) and the increase in mass due to enrichment with volatile compounds (both systems).

Although the two-stage chromium and nickel data are closely grouped, the variation would increase slightly if the PEEL data (C & D) had been determined via hydrofluoric acid/aqua regia/peroxide digestion instead of just an aqua regia digestion. These metals are typically associated with silicate matrices, and therefore it is reasonable to expect the "true total" concentrations for both these metals would be higher than expressed (see Chapter 7.2). This is due to the Peel two-stage incinerators being modern units and their operation has been modified so some primary air is injected into the bed of the furnace to enhance burnout. As a result, the particulate loading in the flue gas stream is slightly higher than loadings observed with older two-stage systems.

The highest concentrations of chromium and nickel were measured in the RDF combustion system economiser residues. This is due to the high particulate loading to the flue gas stream caused by the semi-suspension combustion conditions.

10.3.5 "Volatile" Metals

The concentrations of the volatile trace metals cadmium, lead and zinc measured in boiler and economiser ashes are presented in Figures 10.10 to 10.12. The data were taken from the same studies as the heavy metals data.

The partitioning of volatile metals in the incinerator is a function of temperature (see Chapter 8) and hence type of incinerator and operating conditions. Based on the given data, boiler and economiser ashes from two-stage systems contain the highest concentrations of volatile metals which can be attributed to the low particulate loading of the flue gas stream in two-stage systems and a greater degree of enrichment due to prolonged exposure of ash to the flue gas stream.

Figure 10.10 Comparison of Cadmium Content in Heat Recovery System Ashes from Three Different Incineration Systems

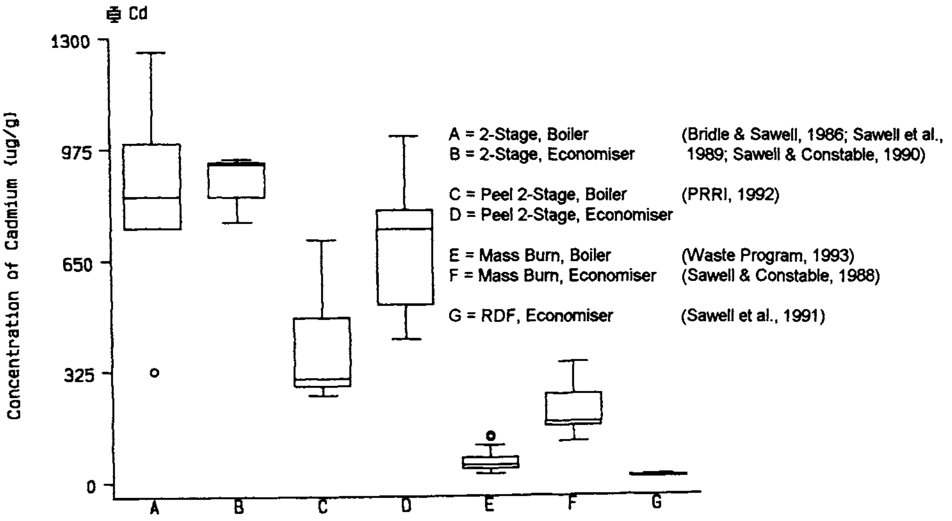


Figure 10.11 Comparison of Lead Content in Heat Recovery System Ashes from Three Different Incineration Systems

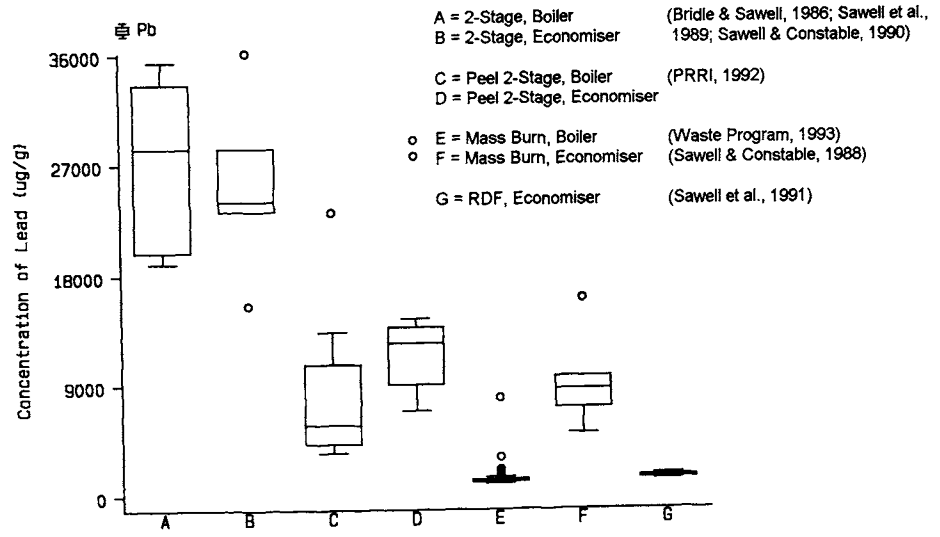
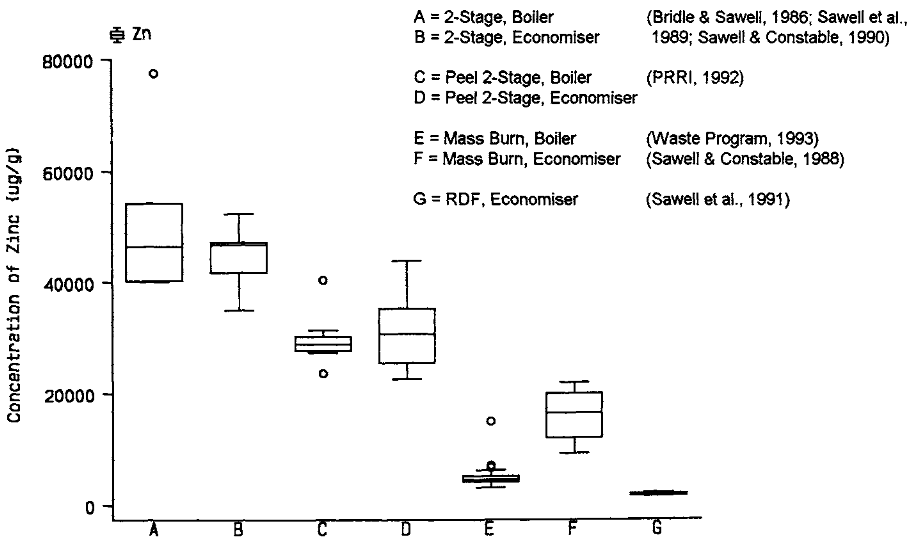


Figure 10.12 Comparison of Zinc Content in Heat Recovery System Ashes from Three Different Incineration Systems



The data indicate both the two-stage and mass burn economiser ashes are more enriched in these metals than the boiler residues. This is a function of the lower temperature regimes in the economiser compared to the boiler, hence greater potential for condensation of these metals onto the surfaces of the impinged ash particles.

10.3.6 Organic Contaminants

As mentioned in Chapter 8, the last sections of the heat recovery system provide potential sites for formation of dioxins and furans. The accepted reactions mechanism is oxychlorination from particulate carbon which occurs at temperatures between 300 and 450°C. Consequently, the ash collected from the hotter sections of the boiler contain very little if any detectable quantities of PCDD/PCDF, whereas the back end of the boiler and the economiser tend to contain higher concentrations.

PCDD/PCDF

The formation of PCDD/PCDF was confirmed by two studies. One study was conducted on boiler ashes collected at temperatures above and below 400°C. Ash collected from zones operating at >400°C contained very small quantities of PCDD (1.1 µg/kg for the sum of all congeners), whereas the below 400°C samples contained concentrations of about 600 µg/kg PCDD (Vogg, 1987).

A second, more detailed study was conducted at an Italian incinerator where ash was collected from eight separate sections of the boiler, including the inlet (temperature of 950°C) and outlet (temperature of 270°C). It indicated the concentrations of PCDD and PCDF increased with decreasing temperatures (Mariani, 1990). Detailed data are given in Chapter 8.6.2 along with a more comprehensive description of formation mechanisms.

The range of PCDD/PCDF (total) concentrations in boiler and economiser ashes from the different types of incinerator systems are given in Table 10.7. The results indicate the type of incinerator system is less of an influencing factor on the concentrations of PCDD/PCDF than the following:

- the combustion conditions of the incinerator
- the particulate carbon loading in the flue gas stream
- the ash deposition rates in the back end versus the front end of the boiler
- the particle size distribution of the ashes.

Table 10.7
Summary of Total PCDD/PCDF Concentrations in Heat Recovery System Ashes from Different Types of Incinerator Systems (ng/g)

System	Ash Type	Total PCDD	Total PCDF
Two-stage	Boiler	60 - 150	6 - 20
	Economiser	30 - 170	10 - 40
Mass Burn	Boiler/Economiser	0.09 - 183	0.03 - 120
Semi-suspension	Economiser	BD - 0.433	BD - 1.83

BD = below detection limit of 0.01 ng/g

Environment Canada, 1985, 1988 and 1992; Vogg et al., 1987; Hiraoka et al., 1989; Mariani et al., 1990; Nottrodt et al., 1990; Benfenati et al., 1991

The first two points are interrelated. Modern incinerators, irrespective of type, operate with much greater efficiency and generate less PCDD/PCDF than older incinerator systems. Poor combustion conditions result in less efficient destruction of precursor compounds in the waste and result in greater concentrations of organic precursors in the flue gases, enhancing PCDD/PCDF production.

Incinerator systems which generate a greater proportion of boiler ash in the high temperature area of the boiler will contain a relatively low mean concentration of PCDD/PCDF in the boiler ash, whereas higher mean concentrations will be realised in systems where a greater proportion of ash is collected in the 300 to 450°C area. The particle size distribution acts to influence all of the other factors in that the potential for PCDD/PCDF formation will increase with decreasing particle size due to the greater surface area to volume ratio of the particles.

It is important to note the data ranges given in Tables 10.7 through 10.9 include data from the NITEP program collected under "poor" and "good" operating conditions, and that the maximum levels are typically related to poor conditions.

Other Chlorinated Organics

A summary of the concentrations of chlorobenzenes (CB), chlorophenols (CP) and polychlorinated biphenyls (PCB) in heat recovery system ashes are given in Table 10.8. These compounds are formed in the same manner as PCDD/PCDF compounds. Consequently, measured concentrations are typically influenced by the same factors as listed above.

Table 10.8
Summary of Total Chlorobenzenes, Chlorophenols and PCBs in Heat Recovery System Ashes from Different Types of Incinerators (ng/g)

System	Ash Type	Total CB	Total CP	Total PCB
Two-stage	Boiler	70 - 940	230 - 540	<0.1 - 50
	Economiser	50 - 240	<0.1 - 10	<0.1 - 30
Mass Burn	Boiler/Econ	259 - 1570	59 - 110	<0.1 - 24
Semi-suspension	Economiser	<0.1	<0.1 - 15	<0.1

Environment Canada, 1985, 1988 and 1992

Polycyclic Aromatic Hydrocarbons (PAH)

A summary of PAH concentrations in heat recovery system ash is given in Table 10.9. Since PAH compounds are formed during semi-pyrolytic and pyrolytic processes, their presence in heat recovery system ashes generally provides a good indication of combustion efficiency. These semi-volatile compounds are typically carried over from the combustion chamber and their concentrations are mostly influenced by the particulate loading in the flue gas and the combustion conditions in the furnace.

Table 10.9
Summary of PAH Concentrations in Heat Recovery Systems Ashes from Different Types of Incinerator Systems (ng/g)

System	Ash Type	Total PAH
Two-stage	Boiler	110 - 780
	Economiser	12 - 160
Mass Burn	Boiler/Economiser	21 - 70
Semi-suspension	Economiser	16 - 6,430

Environment Canada, 1985, 1988 and 1992

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