Heavy Metal Partitioning in a Municipal Solid Waste Incinerator

Lars Sørum
SINTEF Energy
Department of Thermal Energy and Hydropower
7034 Trondheim
Norway

Morten Fossum
SINTEF Energy
Department of Thermal Energy and Hydropower
7034 Trondheim
Norway

Egil Evensen
Trondheim Energy Company
Sluppenveien 6
7005 Trondheim
Norway

Johan E. Hustad
SINTEF Energy
Department of Thermal Energy and Hydropower
7034 Trondheim
Norway

INTRODUCTION

Waste Management in Norway

Norway has the following priorities for management of municipal solid waste (MSW)[1]:

1) Reduce waste generation and toxic components in waste
2) Encourage re-use, recycling and energy recovery
3) Secure an environmentally safe management of residues

MSW consists of household waste and waste from the service and trade industry delivered to municipal waste treatment plants or recycling schemes. In 1995, a total of 2.7 million tons of MSW (1.26 million tons of household waste and 1.44 million tons of waste from service and trade industry) was handled as follows[2]: 68% was deposited on landfills, 18% was combusted, 13% recycled and 1% composted. Combustion of MSW is handled in five larger plants with energy recovery located in different cities in Norway. In addition, a new incinerator for MSW is planned. This incinerator will have to meet the new emission regulations given by the European Union which are more stringent than the present regulations. Hence, Norway is moving towards more stringent regulations, leading to an increased interest in the environmental aspects of MSW incinerators.

Heimdal Heating Central (HHC)

One of the largest MSW incinerators in Norway is situated in Trondheim and is owned and operated by Trondheim Energy Company (TEV). HHC consists of two lines each with a maximum capacity of 6.5 tonne/hour. The furnaces are moving grate units delivered by VonRoll, Switzerland. The flue gas cleaning system consists of an electrostatic precipitator (ESP) and a wet scrubber. The MSW incinerator is a base load energy production unit in a district heating system. In 1996, a total of 85600 tonne of MSW was incinerated in this plant with a heat production equivalent to 222 GWh. Figure 1 show a sketch of the incinerator. The MSW is delivered by trucks to a bunker for storage and mixing. The waste is collected from the bunker and into the feeding hopper by a waste crane. The waste is fed to the furnace by a dosing pusher. While the waste is transported through the furnace by a moving grate, primary air is supplied for combustion from below the grates and from the side walls. The side walls are cooled and insulated with refractory. Recirculated flue gas is injected into the flame above the grate before the flue gas enters the secondary combustion chamber. The flue gas first flows through a hot water generator and the ESP, which removes dust particles, before it enters the wet scrubber. In the wet scrubber, the flue gas pass through a quencher which reduces the temperature before it enters the wet scrubber where most of the pollutants in gas phase are removed. The water from the scrubber is first treated in a neutralization tank and then in a flocculation tank where particles are separated from the scrubber water. Then the scrubber water passes a sediment reactor where the solid phase is collected in the bottom. The solid phase is transported to a filter press where filter cakes are made. The water from the cleaning process is filtered in a sand filter and a ion exchanger system, before it goes to the drain. The clean flue gas is emitted through the 70 meter high stack. The bottom ash is deposited on a landfill, while the ESP dust and filter cakes are deposited in a landfill as hazardous waste.

Objective of the project

During 1995, TEV carried out an investigation program to examine the residues from the incinerator. Primary attention was on the heavy metals in the bottom ash, fly ash and the landfill leachate. The program was conducted in order to establish more information about characteristics of the residues and thus be able to undertake a sounder evaluation of the environmental aspects of the final treatment of these products. This program was supplementary to the emission analysis done periodically for the flue

gas and drain water. The objective of this work has been to establish knowledge about the partitioning of heavy metals through the incinerator and calculate the concentrations of heavy metal in the input MSW. A comparison of the results obtained from this study with other studies such as the WASTE Program (Burnaby)[3] and Brunner/Mönch[4] is of interest to see equalities and differences in the heavy metal partitioning through the incinerator and also the estimated heavy metal concentrations of the input MSW. All of the three different MSW incinerators (HHC, Burnaby, Brunner/ Mönch) have similar furnaces (moving grate), but different cleaning systems.

Heavy metal characteristics

Heavy metals are environmental toxics which accumulates in the environment. Heavy metals do not break down, but will remain in the environment forever. Cadmium, lead, mercury, vanadium, chromium, nickel, copper, zinc and arsenic are the most important heavy metals found in emissions from combustion of MSW. Cadmium, lead and mercury got most attention due to their relative toxicity[5,6]. Some of the heavy metals, especially cadmium, can deposit in the soil and be absorbed by plants. Mercury can be transformed into methyl mercury in sediments and be accumulated in the food chain, especially through fresh water. Excessive levels of heavy metals can provoke a number of health effects. Excessive amounts of lead and mercury are especially dangerous with regards to damage to the nervous system and fetal life. Lead can also give cardiovascular diseases and anaemia. Excessive amounts of cadmium can damage the kidney after long term exposure and accumulating in the body[6,7]. In order to reduce emissions of heavy metals and other pollutant emissions, the Norwegian government has signed several agreements, both national and international, which have the aim of reducing emissions in the future. For example: the Parliament report on national reduction of 70% of 13 selected environmental toxics, the North Sea Declaration states that the emission of 40 selected substances to both air and water shall be reduced and the Montreal Protocol include reduction of ozone destructive.

EXPERIMENTAL METHODS AND PROCEDURES

The experiments performed during this investigation were mainly conducted in 1995 and 1996. The input MSW has the average composition given in table1[9]. The waste originates from the urban and rural areas in and around Trondheim municipality. The degree of material recovery of different components is estimated to[9]: paper 35%, food waste 22%, plastic/textiles/rubber 11%, glass 25%, metals 63% and other non-combustibles 50%. The total material recovery rate from MSW is estimated to 30%. In the sections below, a description of the sampling and experimental methods and procedures are explained.

Mass Balance

In this study the mass balance has been established for bottom ash, filter ash and filter cake. All of the values are mean values taken over a whole year and are on a dry basis.

All of the MSW delivered to the incinerator is weighed before dumped into the waste bunker. The weight of the waste is continuously recorded every year. The bottom ash, filter ash (ESP dust) and filter cakes are always weighed (on a wet basis) before sent to the landfill. However, the average moisture content has been determined for each of the different residues. All residues were expressed on a dry basis for the mass balance. The amount of flue gas has been calculated by measuring the flow through the stack with a pitot tube and micromanometer according to the Norwegian standard method (NS 4862). All of the moisture from the input waste was considered leaving with the flue gas.

Chemical Analysis

Chemical analysis of the different waste streams have been done according to different standard tests methods. The heavy metals presented in this investigation is mercury (Hg), zinc (Zn), chromium (Cr), cadmium (Cd), lead (Pb) and iron (Fe). Some of the residues and the flue gas has also been analysed for other heavy metals such as arsenic (As), nickel (Ni) and copper (Cu).

Bottom ash. For ten weeks samples were taken every Monday, Wednesday and Friday. The samples were taken from the bottom ash conveyor belt with a spade. Particles larger than 50 mm were sieved out and magnetic metals were removed with a magnet. Other easy visible pieces of metal was also picked out. The samples were air dried for 70 hours at 20°C before shipment to the laboratory, in order to enable crushing of the ash before analysis. Every sampling day six samples, each of approximately 2 kg, were taken with 1-1.5 hours intervals. The samples from one day were mixed and split into two parts and a sample of approximately 4 kg was sent to the laboratory for chemical analysis and another sample was analyzed for grain size distribution. The samples were sent to a certified laboratory in The Netherlands, Tauw Milieu bv, and the chemical analysis was done according to the standard test method ICP NPR 6425 for cadmium, chromium, lead and zinc; mercury was determined by the Cold Vapour-method NEN 5779. Full details of the chemical analysis of bottom ash is given in the report from Kummeneje[10].

The amount of iron in the bottom ash was determined by sieving and magnet separation test in a pilot plant with a capacity of 36 tons/hour[11]. Approximately six tons of bottom ash was handled in the sieving/magnet separation test. The bottom ash was first sieved on 50 mm sieve and this fraction was put through the magnet separator to determine the magnetic fraction. The rest fraction after sieving (<50 mm) was also separated for magnetic materials in the same system. The total amount of magnetic materials from the magnetic separation test was considered as iron.

Filter Ash. Samples of approximately 2 kg were taken once a week for three weeks. The samples were taken in the intermediate container below the conveyor belt from the filter ash bin. The samples were stored in plastic bags just above room temperature in order to prevent interaction with the surroundings before shipment to the laboratory. The laboratory, Tauw Milieu bv in The Netherlands, is certified for these chemical analysis. ICP-method NPR 6425 was used to determine the content of cadmium, chromium, iron, lead and zinc. The Cold Vapour-method NEN 5779 was used to determine the content of mercury. Full description of these chemical analysis of the filter ash is given in the report by Kummeneje[12].

Filter Cakes. Some samples of the filter cakes from the washing process were analyzed with Atom Absorption Spectrophotometry (AAS) to determine the content of lead, zinc and chromium [13]. Iron was estimated from values found in the literature. The content of mercury and cadmium was determined by measuring the difference in concentration in the water before and after the water cleaning process. For a whole year one sample was taken every day and all of the samples from one week were put together and analysed. The NS4768 and NS4781 methods were used to determine the content of mercury and cadmium in the samples.

Drain Water. The drain water has been analyzed for mercury, cadmium and lead according to Norwegian standard methods NS4768, NS4781 and NS4781. The amount of iron, zinc and chromium was estimated on the basis of values found in the literature.

Flue Gas. The Norwegian standard method NS 4863 was used to determine the content of lead, cadmium, mercury and chromium in the flue gas. The procedure is described in a SINTEF report[14]. The

content of iron and zinc was estimated on basis of values found in the literature. Four samples of the flue gas were taken for chemical analysis.

Sources of error in mass balances

In addition to the usual measurement inaccuracy's connected to every measurement done in this investigation, the closure of the mass balance also represent a source of error. Since the measurement inaccuracy's are given by the standarized measurement methods, those will not be commented on further. However, the mass balance closure need further explanation. The examination of the bottom ash, filter ash, filter cakes, drain water and flue gas has served different purposes. In addition to the determination of heavy metal balances and concentrations in input MSW, determination of heavy metal concentrations in residues and flue gas with regards to soil, water and air pollution has been one of TEV's objectives with these investigations. All of the measurements used in the mass balances has, therefore not been performed within the same period of time and with different sampling rates. However, this investigation has tried to give relatively long term mass balances and determined the concentrations of heavy metals in input MSW on basis of these findings. Short term investigations within the same time period has both the advantages and disadvantages of stable conditions with regards to operational parameters and composition of input MSW. The closure of the mass balances is therefore more likely to happen in investigations with parallel sampling of the residues and flue gas rather than sampling in series. However, the heavy metal balances and concentrations in input MSW is also a function of the variations in operational conditions and composition of input MSW. More extensive investigations with sampling in parallel would be very interesting and would provide a more complete picture of the mass balances and concentrations of heavy metals in input MSW. The cost of such comprehensive measurements is one of the major problems.

HEAVY METAL PARTITIONING THROUGH THE INCINERATOR

The results of the mass balance, heavy metal partitioning through the incinerator, heavy metal content in the residues and flue gas are presented in the sections below. Further, calculated heavy metal concentrations in the input MSW on the basis of the heavy metal content of the residues and flue gas are presented.

Mass Balance

The result of the mass balance is given in figure 2. The figure show that 83 % of the input MSW is converted to CO_2 and H_2O and is emitted as moist flue gas. The mass flux of bottom ash was found to be 16.5 % and the mass flux of filter ash was 0.37 %. The dust found in the filter cakes was almost negligible (0.02%). Brunner and Mönch[4] found in their investigation a bottom ash portion of 20.5% and a flue gas portion of 77%. The flux of filter ash was the same as this study.

Heavy Metal Balance

Figure 3 and table 2 show the heavy metal balance between the different residues and flue gas for the incinerator.

Cadmium (Cd). Cadmium is a quite volatile metal in a combustion context with a boiling point of 767°C. Figure 3 show that 63% of the cadmium remain in the bottom ash, 24% is captured in the filter ash, 8% is emitted with the flue gas, 6% is captured in the scrubber (filter cakes) and virtually nothing is emitted via the drain water. In this study 37% of the cadmium was evaporated from the combustion process and entered the flue gas cleaning system. Several other studies on the evaporation of cadmium

from MSW incinerators have been done and they have shown quite different results. The Brunner and Mönch[4] investigation stated that only 12% of the cadmium remained in the bottom ash, while the Burnaby project[3] could report an even lower content of cadmium in the bottom ash (3.7%). A Swedish investigation[15] of four different MSW incinerators found large variations in cadmium remaining in the bottom ash, varying from 13 to 83%. These large variations can originate from two different important parameters, namely combustion temperature and chlorine content in the waste. Cadmium has a boiling point which is close to the combustion temperature and the content of cadmium in the bottom ash will be dependent on the operating furnace temperature. The operating furnace temperature is a parameter which is strongly dependent on furnace construction, MSW composition and fuel/air ratio. Of these parameters the fuel/air ratio is the easiest to control. Two important factors in the evaporation of cadmium are: chlorine available to form cadmium-chloride and the chemical form of cadmium. With chlorine present, cadmium can form relatively volatile chlorides that will follow the hot flue gases[16]. When the temperature drops, volatile cadmium adsorbs on the relatively small particles which have the largest surface area. The emission of cadmium will therefore be highly dependent on the efficiency of the flue gas cleaning system and it's ability to capture particle emissions.

Table 2 shows the heavy metal balance, the estimated heavy metal content in input MSW and concentrations of heavy metals for the different residues and the flue gas. The total yearly input of cadmium for the incinerator is 434 kg and 33 kg is leaving with the flue gas. The total efficiency of the flue gas cleaning system regarding cadmium is 80% (63% in ESP and 17% in scrubber) in this study. The Burnaby study[3] which had a flue gas cleaning system consisting of a conditioning tower, reactor with lime injection and fabric filter showed an efficiency of 99.8% for cadmium. The Brunner and Mönch[4] study which only had a electrostatic precipitator as flue gas cleaning system had an efficiency factor of 86% for cadmium.

Of the heavy metals in this investigation, cadmium is the one with the highest portion emitted through the stack. The calculated cadmium concentration in MSW was 5 mg/kg. The calculated cadmium concentration in MSW in the Burnaby project[3] was 13.5 mg/kg while Brunner and Mönch[4] reported 8.7 mg/kg. The city of Trondheim is currently implementing a source separation system where environmentally harmful waste such as electrical and electronic waste is separated and sent to a special landfill site for hazardous waste. A study has shown that electrical and electronic waste contributes with a large fraction of cadmium in MSW[17]. The effect of separating this fraction from the input MSW will be followed with great interest.

Chromium (Cr). Chromium with a boiling point of 2672°C can be regarded as a non-volatile heavy metal from a MSW combustion point of view. This is also shown by the results of the heavy metal balance for the combustion plant (table 2). Of the total input of 1829 kg/year to the incinerator, nothing is emitted through the stack. Approximately 2% is captured in the flue gas cleaning system the rest is left in the bottom ash. The Burnaby study reported that 93% of the chromium was left in the bottom ash. Only 0.06% was emitted with the flue gas, the rest was captured in the flue gas cleaning system. Calculated concentration of chromium in MSW is 21.1 mg/kg. The Burnaby project[3] calculated the chromium concentration in MSW to 92.5 mg/kg.

Iron (Fe). Like chromium iron can be regarded as a non-volatile heavy metal in MSW combustion, with a boiling point of 2750°C. From the input of 764954 kg/year virtually nothing is emitted through stack or drain water, 0.4% is captured in the flue gas cleaning system while the rest is found in the bottom ash.

Brunner and Mönch[4] found in their study 99% of the iron in the bottom ash and 1% in the filter ash, while 0.02% were stack emissions. Calculated iron concentration in MSW in this study was 8823 mg/kg.

Mercury (Hg). Mercury is the most volatile of the heavy metals with a boiling point of 357°C. The volatile behaviour of mercury was confirmed in this study with only 6% remaining in the bottom ash. Mercury content in the bottom ash between 0.2-19% has been found in other studies[3,4,15]. Mercury differs from the other heavy metals by the fact that it is in gas-phase in a combustion plant[16]. Mercury is converted to a gaseous metal and gaseous chloride salt in the combustion process. The flue gas cleaning system had an efficiency of 95% for mercury. The wet scrubber captured 92% of the volatile mercury. Brunner/ Mönch[4] had a mercury removal efficiency of 25% with electrostatic precipitator, while the Burnaby study[3] had an efficiency of 40% where practically all captured mercury was found in the fabric filter. The calculated concentration of mercury in MSW in this study was 1.6 mg/kg, which is exactly the same concentration as a similar mercury balance study gave in 1994[18]. Other studies have indicated mercury concentrations in the range of 0.7 - 1.5 mg/kg[3,4,19]. Given the volatile nature of mercury, emphasis should be put into removing mercury containing waste from the input MSW in order to reduce mercury emission to the environment. A study has shown that electrical and electronic waste contributes with a large fraction of mercury in MSW[17]. The potential for reduction of mercury entering the incinerator by removing the electrical and electronic waste fraction should therefore be considerable.

Lead (Pb). Lead, with a boiling point of 1750°C, should in combustion of MSW normally be considered as a non-volatile metal. However, studies have shown that small portions of chlorine in the waste will decrease the volatility temperature with several hundred degrees[20]. From the total of 38061 kg/year input of lead to the incinerator, 94% is captured in the bottom ash, 5% is captured in the flue gas cleaning system and 0.2% is stack emission. Other studies have shown a large variation of lead in the bottom ash ranging from 58 to 89%[3,4,15]. This and other studies have shown that most of the volatile part of lead is captured on ash particles and cleaned in the filter units. The calculated concentration of lead in MSW was 439 mg/kg. Other studies have reported values in the range of 160 to 430 mg/kg[3,4,19]. As for cadmium and mercury, lead is also strongly represented in the older electronic and electrical waste fraction although not relatively as much as mercury and cadmium. The combination lead and PVC (resin PVC contains over 50% of chlorine[21]) is highly possible for the electronic and electrical waste fraction, giving an increase in the volatile release of lead in the combustion process.

Zinc (Zn). Zinc, with a boiling point of 907°C, is one of the more volatile metals in this investigation. Zinc is also the heavy metal with largest yearly stack emissions (76 kg/year). Most of the zinc was found in the bottom ash (86%), while most of the residual 14% is captured in the flue gas cleaning system. Only 0.1% is emitted through the stack. This study differ from other studies with a large portion of the zinc remaining in the bottom ash. Other studies[3,4] have reported 42 and 51% of zinc in the bottom ash, but like this study most of the volatile fraction of zinc is captured in the ESP. The large variation in volatility can be ascribed to differences in combustion temperature due to the relatively low boiling point which is in the area of the combustion temperature. The calculated concentration of zinc in MSW was 1044 mg/kg while others have reported 1873 and 2000 mg/kg[3,4].

CONCLUSIONS

In this study most of the cadmium (63%), zinc (86%), lead (94%), chromium (98%) and iron (100%) was found in the bottom ash. The filter ash captured most of the volatile cadmium (24%), zinc (13%), lead (5%) and chromium (2%). The wet scrubber captured most of the mercury (87%). From these results it is evident that a large portion of the heavy metals are captured in the bottom ash compared to other studies, indicating a relatively low combustion temperature. The calculated concentrations of heavy metal in the input MSW was 1.6 mg/kg for mercury, 5 mg/kg for cadmium, 1044 mg/kg for zinc, 439 mg/kg for lead, 21.1 mg/kg for chromium and 8823 mg/kg of iron. Long term monitoring of the flue gas and residues seem to be a better and easier way to measure the content of heavy metals in MSW rather than sampling the input waste. Reduction in heavy metal emissions is expected after implementation of source separation of environmental harmful waste including electronic and electrical waste in 1997. The potential for reduction of mercury is confirmed by the relatively high concentration in MSW compared to other studies. The continuing work on identifying and separation of MSW fractions with large concentrations of heavy metals seem to be an important method to reduce heavy metal emissions further. Improved flue gas cleaning systems, furnace constructions and combustion control will also contribute to reduced emissions. This work has contributed to a better understanding of the behaviour of heavy metals in MSW combustion and given complementary understanding of the efficiency of various flue gas cleaning systems for different heavy metals.

REFERENCES

1. Department of the Environment, Norwegian Parliament Statement No. 44 (1991-1992), Initiative for reduced waste amounts, increased recycling and a secure waste management, Department of the Environment, Oslo, 1992, p. 65 (in Norwegian).

2. Official Statistics of Norway, We are still producing more waste, Weekly Statistics No. 39, Official Statistics of Norway, Kongsvinger, 1996, p. 4 (in Norwegian).

3. The WASTE Program, Waste Analysis, Sampling, Testing and Evaluation (WASTE Program): Effect of Waste Stream Characteristics on MSW Incineration: The Fate and Behaviour of Metals, Final report of the Mass Burn MSW Incineration Study (Burnaby, B.C.), Vol. 1, summary report, 1993, p. 76.

4. Brunner, P. H., Mönch, H., "The Flux of Metals Through Municipal Solid Waste Incinerators", Waste Management & Research, 4(1):105-119 (1986).

5. Scholdager, J., Air Pollution - Emission, Diffusion, Settling and Effects, Lecture Presentation in The Course Energy Technology at Norwegian University of Science and Technology (NTNU), Trondheim, 1990.

6. World Health Organization, Heavy Metal and PAH Compounds from Municipal Incinerators, Report from WHO Meeting Florence 12-16 oct. 1987, Copenhagen, 1988, p. 67.

7. Øverli, J.M., Energy and Environment - Global and International Challenges, Statoil, Environment Project Publication No. 2, Trondheim,1990, p. 31 (in Norwegian).

8. Berntsen, T., Environmental Political Statement - 1995, Department of the Environment, Oslo, 1995, p. 126 (in Norwegian).

9. Trondheim Municipality, Waste Management Plan for Trondheim Municipality 1996-1999, Trondheim, 1996, p. 107 (in Norwegian).

10. Gilde, T., Heimdal Varmesentral - Chemical Analysis of Slag - Results of Chemical Analysis of Slag and Leachate.Kummeneje a.s., Trondheim, 1995, p. 11 (in Norwegian).

11. Skjæveland, R., HVS-Waste Combustion - Characterization of slag with regards to separation of iron, preliminary experiments, Norwegian University of Science and Technology (NTNU) - Department of Geology and Rock and Mineral Engineering, Trondheim, 1996, p. 28 (in Norwegian).

12. Gilde, T., Heimdal Varmesentral - Chemical Analysis of Electrostatic Precipitator Dust - Results of Chemical Analysis of Filterdust and Leachate, Kummeneje a/s, Trondheim, 1995, p. 6 (in Norwegian).

13. Mathillas, F. R., Analysis and Characterization of filtercakes from the flue gas cleaning system of the waste combustion plant, Project work, Norwegian University of Science and Technology (NTNU) - Department of Geology and Rock and mineral Engineering, Trondheim, 1995, p. 36 (in Norwegian).

14. Horrigmo, W., Vassbotn, T., Flatberg, H., Emission Measurements at Heimdal Waste Incinerator 1995, STF84 F96402, SINTEF Energy, Department of Thermal Energy and Hydropower, Trondheim, 1995, p. 34 (in Norwegian).

15. Soma, M. H., What Kind of Emissions Do We Get from Waste Combustion, Technical Winterweek 1986, EG61b, The Association of Norwegian Chartered Engineers, Oslo, 1986, p. 31 (in Norwegian).

16. Benestad, C., Braastad, G., Normann, H. H., et. al., Combustion Plants - Instructions for Officials in Charge, 95:13, The Norwegian Environmental Protection Agency, Oslo, 1995, p. 86 (in Norwegian).

17. Department of the Environment, Collection and Treatment of Waste from Electrical and Electronic Products, T-1135 ISBN 82-457-0100-9, Department of the Environment, Oslo, 1996, p. 64 (in Norwegian).

18. Evensen, E., Assessment of the Mercury-Balance of the Combustion Plant, EE/EB/450, Trondheim Energy Board, Trondheim, 1995, p. 3 (in Norwegian).

19. Halmø, T., Solid Waste, Tapir, Trondheim, 1984, p. 316 (in Norwegian).

20. Federal Register, US EPA, Guidance on Metals and Hydrogen Chloride Controls for Hazardous Waste Incinerators, 1989.

21. C-H. Wu, C-Y. Chang, J-L. Hor, S-M. Shih, L-W. Chen, F-W. Chang, "On the Thermal Treatment of Plastic Mixtures of MSW: Pyrolysis Kinetics", Waste Management, 13:15 (1993).

Table 1. Average composition of MSW delivered to HHC[9].

COMPONENT	FRACTION [wt%]
Paper	30
Food wastes	17
Plastic, textiles,rubber, leather	6
Wood	8
Glass	7
Metal	12
Other combustibles	6
Other non-combustibles	14
Total	**100**

Table 2. Concentrations in residues, flue gas and waste and heavy metal balance.

	Cd	Cr	Fe	Hg	Pb	Zn
Concentration in residues, flue gas and waste						
Flue gas [mg/Nm^3 dry]@11%O_2	0.057	0.00075	0	0.013	0.162	0.159
Bottom ash [mg/kg dry]	19	125	53250	0.62	2513	5464
Filter ash [mg/kg dry]	323	127	9833	8	5833	37667
Filtercake [mg/kg dry]	1331	10	2600	5805	7027	8567
Drain water [Tg/m^3]	1.3	0.9	0	3.6	48.1	100
Input MSW [mg/kg]	5	21.1	8823	1.6	439	1044
Heavy metal balance for the combustion plant						
Flue gas [kg/year]	32.7	0.44	0	7.2	91.8	76.3
Bottom ash [kg/year]	272	1788	761768	9	35950	78165
Filter ash [kg/year]	104	41	3154	3	1871	12083
Filtercakes [kg/year]	27.7	0.2	54.1	120.8	146.2	178.3
Drain water [kg/year]	0.02	0.02	0	0.06	0.83	1.7
Input MSW [kg/year]	434	1829	764954	139	38061	90515

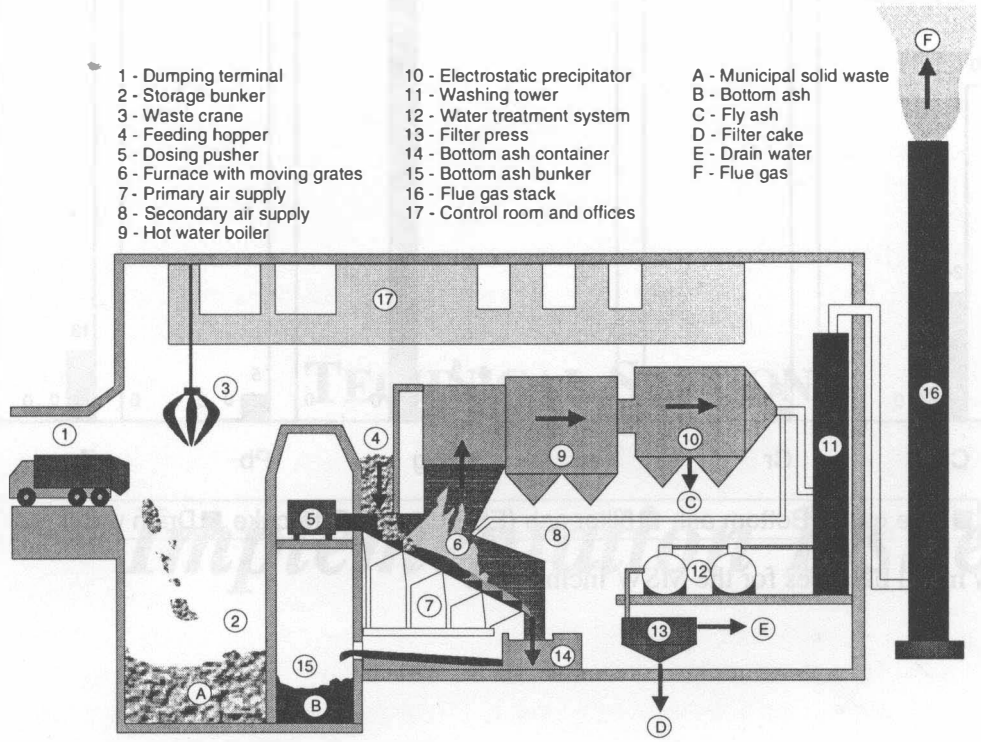

Figure 1. Sketch of the waste incinerator with major parts and mass fluxes indicated.

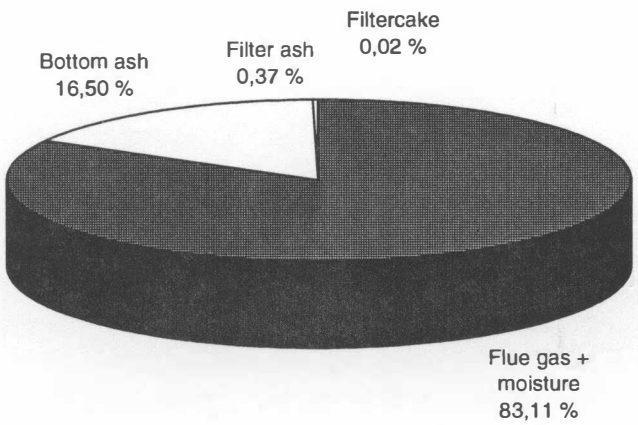

Figure 2. Overall mass balance for the MSW incinerator (dry basis).

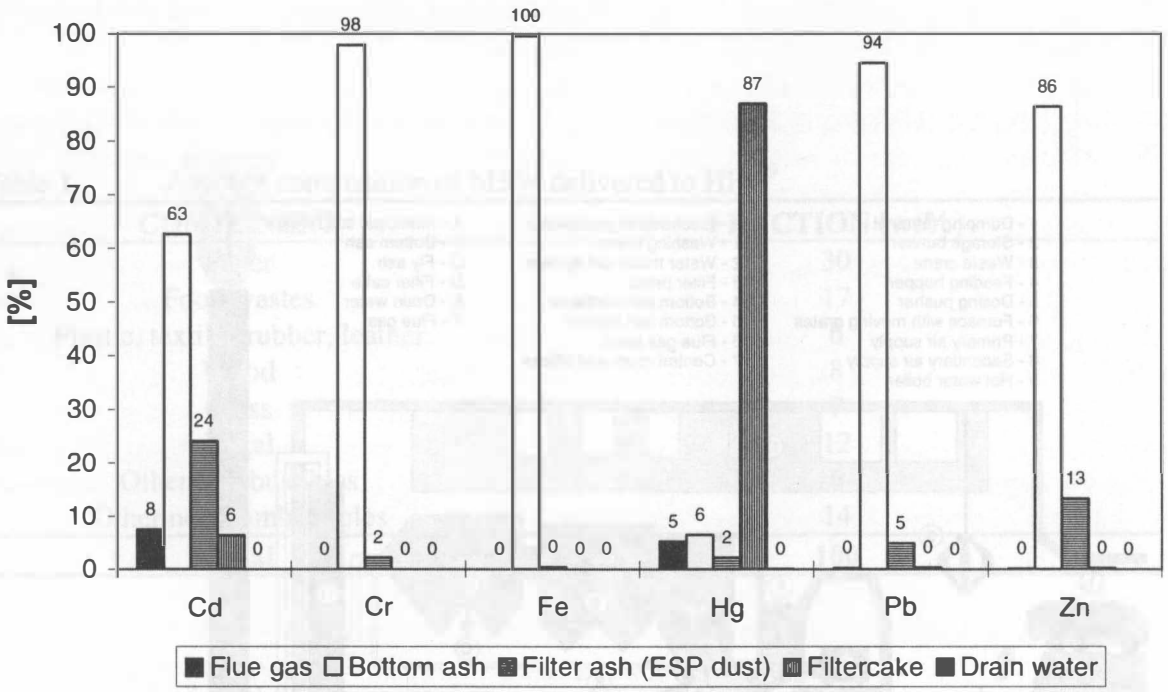

Figure 3. Heavy metal balances for the MSW incinerator.