

21

ENVIRONMENTAL IMPLICATION OF MSWI BOTTOM ASH UTILISATION

Characteristics and Leaching Behaviour

Peter E. Holm & Ole Hjelmar

*VKI
Denmark*

INTRODUCTION

The development of environmentally sustainable utilisation and disposal strategies for combustion residues such as solid waste products from municipal solid waste incinerators (MSWIs) and coal fired power plants should be based on the best available knowledge of the short and long term leaching characteristics of the residues. The environmental impact may then be evaluated combining the knowledge about the leaching characteristics with information on the mobility and ecological properties of the released contaminants. To a large extent, this knowledge may be obtained through the performance of laboratory leaching experiments that in each case should be adapted to the relevant conditions. The laboratory results may in turn be used as input to a mathematical risk assessment model predicting the emission, transport and fate of the contaminants over a longer period of time. Most laboratory tests are accelerated and cannot take the effects of mineral ageing and weathering processes into account. Therefore, there is a definite need to verify and improve both the techniques and methods employed in laboratory leaching and attenuation studies and the methods of interpretation and modelling by comparing the results to actual field observations.

While the amount of previously reported and ongoing research on laboratory testing, particularly of the leaching properties of waste materials but also on the mobility of leached contaminants, is substantial, less information is available on the behaviour of actually land filled or utilised combustion residues. This is un-

derstandable in the view of the difficulties involved in getting reliable field data that are representative of well-defined conditions.

This paper presents characteristics and leaching behaviour of MSWI residues in general and specifically in relation to utilisation of MSWI bottom ash as a sub-base material at a parking lot.

CHARACTERISTICS OF MSWI RESIDUES

The various types of residues produced by modern MSW mass burn incinerators are bottom ash, grate siftings, boiler ash, economiser ash, fly ash and acid gas scrubbing residues. The specific amounts produced of the different types of MSWI residues may vary and reflect differences in waste composition, technological standards and operation parameters. Figure 1 shows mean data of solid mass stream in MSW incinerators. The data are from modern incinerators and compiled by IAWG (1997).

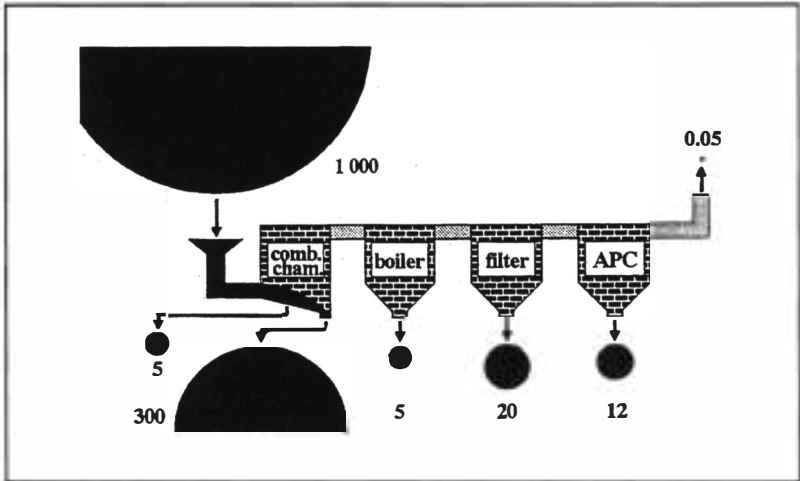


Fig. 1. Typical quantities of MSWI residues produced per tonne solid waste. From IAWG (1997).

The grate siftings and the boiler ash are often directly combined with the bottom ash, and economiser ash is nearly always combined with the fly ash that may be collected separately or as part of the acid gas scrubbing residues. In this paper the term "fly ash" is used exclusively for the fine particles which are carried over from the combustor with the flue gases and subsequently captured in electrostatic precipitators or fabric filters; it does not include acid gas scrubbing residues. As seen in Figure 1, the bottom ash is the main waste stream (in average 300kg/tonne waste) from the incineration process. The bottom (or grate) ash appears after quenching/cooling with water as a coarse, extremely inhomogeneous

granulate, usually containing larger, fused lumps of slag and pieces of scrap metal. The grate siftings may also be relatively coarse whereas the other residues are much finer powders or (from the wet scrubbing process) a wastewater treatment sludge.

Table 1 shows the ranges of composition of MSWI bottom ash (excluding the scrap metal portion and the size fraction larger than 45 mm which typically constitutes 10 to 20 % of the total weight), fly ash and acid gas scrubbing residues from the dry and semidry processes.

Table 1. Ranges of composition of MSWI bottom ash and other residues. From Hjelmar (1996)

Parameter	Unit	Bottom ash	Fly ash	Acid gas scrubbing residues from the dry/semidry process (incl. fly ash)	Acid gas scrubbing residues from the wet process (sludge mixed with fly ash)
Si	g/kg	210-290	95-190	57-98	120
Al	g/kg	47-72	49-78	17-46	71-81
Fe	g/kg	27-150	18-35	3.6-18	15-18
Ca	g/kg	65-97	74-130	170-290	03-110
Mg	g/kg	7.7-19	11-19	7.1-12	18-23
K	g/kg	9.2-22	23-47	27-40	35-58
Na	g/kg	22-41	22-57	12-19	28-33
Ti	g/kg	3.2-7.2	7.5-12	1.5-5.1	5.3-8.4
S	g/kg	1.3-8	11-32	8-18	11-26
Cl	g/kg	1.2-3.2	45-101	92-220	48-71
P	g/kg	2.9-13	4.8-9.6	1.7-4.6	6.0-7.4
Mn	g/kg	<0.7-1.7	0.8-1.7	0.3-0.7	1.4-2.4
Ag	mg/kg	4.1-14	31-95	14-60	53
As	mg/kg	19-80	49-320	40-260	130-190
Ba	mg/kg	900-2700	920-1800	310-1400	330-1900
Be	mg/kg	nd	nd	0.5-0.9	1.5-1.9
Cd	mg/kg	1.4-40	250-450	140-300	220-270
Co	mg/kg	<10-40	29-69	4-15	14-22
Cr	mg/kg	230-600	140-530	150-570	390-660
Cu	mg/kg	900-4800	860-1400	450-1100	1000-1400
Hg	mg/kg	<0.01-3	0.8-7	0.3-44	38-390
Mo	mg/kg	2.5-40	15-49	9.3-20	20-38
Ni	mg/kg	60-190	92-240	20-63	67-110
Pb	mg/kg	1300-5400	7400-19000	4000-6500	5900-8300
Se	mg/kg	0.6-8	6.1-31	8.2-16	12
Sn	mg/kg	<100-1300	1400-1900	620-780	1000
Sr	mg/kg	170-350	<80-250	400-500	200
V	mg/kg	36-90	32-150	26-62	62
W	mg/kg	<20-50	nd	nd	nd
Zn	mg/kg	1800-6200	19000-41000	12000-19000	20000-23000
PAH	µg/kg	0.23-2200	30-110	18-5600	nd
CB	µg/kg	6.7-45	50-890	220	nd
PCB	µg/kg	<40	<40	<40	nd
CP	µg/kg	16-34	120-1800	860	nd
PCDD	µg/kg	0.2-10	115-140	0.7-1000	260
PCDF	µg/kg	0.44-4.5	48-69	1.4-370	120
TCDD-eqv ^a	µg/kg	0.02-0.22	1.5-2.5	0.8-2	2.8
TOC	g/kg	4.8-13	4.9-17	6-9	7
LOI	g/kg	5.9-50	11-45	28-49	110

^aTCDD-toxicity equivalents determined according to Eadon's method.

Nd: No data available.
PAH: Polycyclic aromatic hydrocarbons.
CB: Chlorobenzenes.
CP: Chlorophenols.
PCDD: Polychlorinated dibenzo-*p*-dioxins.
PCDF: Polychlorinated dibenzofurans.
TOC: Total organic carbon.
LOI: Loss on ignition (550 °C).

From Table 1 it is seen that the major elements (present in concentrations exceeding 10 g/kg) are nearly the same for all residues shown: Si, Al, Fe, Ca, Mg, Na, K, S (except for bottom ash), Cl (not for bottom ash), Zn (not for bottom ash) and Pb (only for fly ash). Many of these elements are present as oxides. The concentration of the various trace elements varies between the two types of residues; some e.g. Ba and Cr are present at the same concentration level in all residues, some notably Cu are usually enriched in the bottom ash, whereas several trace elements, particularly the more volatile elements (e.g. Cd, Hg, As, Pb and Zn) are enriched in the fly ash and the acid gas scrubbing residues.

LEACHING BEHAVIOUR OF MSWI RESIDUES

The potential leaching and release of components which may adversely affect the environment are obviously important properties in relation to disposal and utilisation of the residues and management of the leachate. Evaluation of the environmental impact related to the leaching of constituents from MSWI residues must ideally be based on information regarding both the short term (months to years) and the long term (several hundreds of years) leaching behaviour of constituents from the residues. Some data on the short term behaviour of most MSWI residues are available, and the evaluation of the short term behaviour may to a large extent be based on the results of laboratory and short term field experiments. Due to the scarcity of long term observations, the long term behaviour of the residues is much less understood. Evaluation of the long term behaviour requires use of different methodologies, e.g. simulation of long term conditions, extrapolation of the results of fundamental laboratory leaching testing, hydro-geochemical modelling and field studies.

Table 2 presents an overview of the maximum levels of concentrations of inorganic salts, trace elements and non-volatile organic carbon (NVOC) observed in initial leachate from the major types of MSWI residues. The concentration levels represent data from a number of laboratory leaching tests (mostly column tests) and a few field investigations (summarised in Hjelmar, 1996).

Table 2. Maximum concentration levels of contaminants in leachates from MSWI residues. Compiled in Hjelmar (1996).

Typical maximum levels of concentration in leachate	Unit	MSWI bottom ash	MSWI fly ash and residues from dry and semi-dry APC processes	Mixture of MSWI fly ash and sludge from wet scrubbing process
>100	g/l		Cl ⁻ , Ca	
10-100	g/l		Na, K, Pb	Cl ⁻ , Na, K
1-10	g/l	SO ₄ ²⁻ , Cl ⁻ , Na, K, Ca	Zn	SO ₄ ²⁻ , Ca
100-1000	mg/l	NVOC, NH ₄ -N	NVOC, SO ₄ ²⁻	
10-100	mg/l			
1-10	mg/l	Cu, Mo, Pb	Cu, Cd, Cr, Mo	NVOC, Mo
100-1000	µg/l	Mn, Zn	As	
10-100	µg/l	As, Cd, Ni, Se		As, Cr, Zn
1-10	µg/l	Cr, Hg, Sn		Pb
<1	µg/l		Hg	Cd, Cu, Hg

For most parameters, the maximum concentrations occur in the initial leachate, and most of the concentrations shown in Table 2 have been observed in fractions of leachate collected at or below L/S = 0.5 l/kg. L/S is the liquid/solid or leachate/waste ratio. For a particular utilised or deposited mass of residue, S will be constant and L will increase as the leachate is formed. An L/S scale may therefore be transformed to a time scale if the rate of percolation or flow through the site is known.

The various MSWI residues differ substantially from each other in terms of water solubility. Only a small fraction, often less than 5 %, of the total mass of the bottom ash is soluble in water whereas 20 to 25 % of the total mass of the fly ash and 30 to 40 % of the total mass of the dry/semi-dry acid gas scrubbing residues consist of salts which are readily soluble in water.

EXAMPLE: UTILISATION OF MSWI BOTTOM ASH AS A SUB BASE AT A PARKING LOT

In 1974, approximately 4,000 tonnes of MSWI bottom ash (screened and treated magnetically to remove ferrous material) were used as sub-base under a parking lot in Ballerup near Copenhagen. A 40 cm layer of bottom ash was placed on top of a 100 cm thick layer of gravel (drainage layer). The site was paved with flagstones embedded in 14 cm of gravel which was placed on top of the bottom ash, see figure 2. The entire site which covers an area of 9,300 m² is drained at the bottom of the drainage layer. A 200 m² plastic liner was placed between the ash and drainage layer, and provisions were made to enable collection of drainage

water, leachate (running off the top of the liner) and surface run-off. Samples of each have been collected annually or biannually over periods of a few days (during rain events) since 1975. The rate of infiltration through the bottom ash layer is estimated at 140 mm/year.

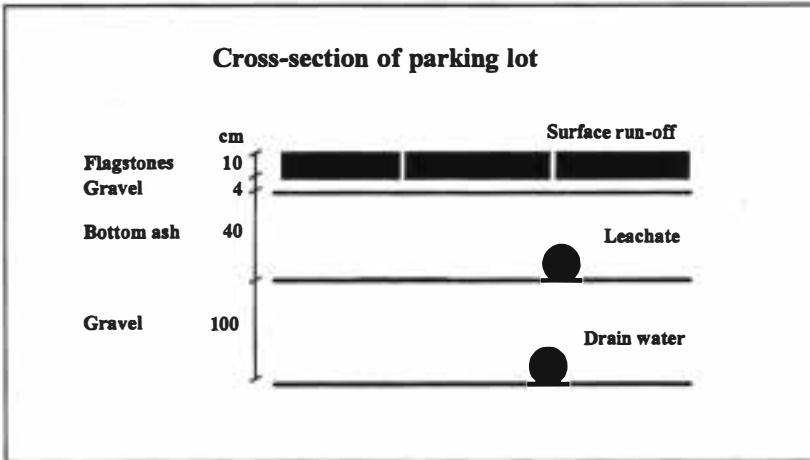


Fig. 2: Cross-section of parking lot in Ballerup with MSWI bottom ash sub-base.

Ranges of the composition of the surface run-off, the leachate and the drainage water (leachate which has passed 100 cm of drainage gravel) collected from 1975 to 1995 are presented in Table 3.

Table 3. Ranges of composition of surface run-off, leachate and drainage water collected during 1975-1995 at a parking lot under which MSWI bottom ash has been used as subbase.

Parameter	Unit	Surface run-off	Leachate	Drainage water
pH		7.2-8.1	7.1-8.6	6.5-8.3
Cl ⁻	mg/l	4-41 (520)	140-2200	230-910
Total-N	mg/l	0.7-6.0 (1100)	4.7-200	2.0-92
Cd	mg/l	<0.0001-0.0006	<0.00005-0.0005	<0.0001-0.001
Cr	mg/l	<0.001	<0.001	<0.001-0.002
Cu	mg/l	0.002-0.05	<0.001-0.002	0.002-0.014
Pb	mg/l	<0.001-0.079	<0.001-0.014	<0.001-0.010
Zn	mg/l	<0.01-0.12	<0.01-0.19	<0.01-0.09

(): extreme values

The total amount of leachate generated is difficult to estimate but corresponds to approximately 0.3 l/kg in 1975 and approximately $L/S = 4$ l/kg in 1995. The leachate is primarily characterised by its inorganic salt content and its relatively low concentrations of heavy metals. The highest concentrations of lead and cadmium were observed in the surface run-off from the parking lot. The relatively high concentrations of chloride and total nitrogen found in one of the surface run-off water samples were probably related to the use of sodium chloride and urea as deicing agents during the winter.

In 1995 samples of the 21 year old bottom ash were obtained and used for solid phase characterisation and leaching behaviour. Table 4 shows the results of the characterisation of the old bottom ash compared with fresh bottom ash sampled in 1993 and 1995 from the same MSW incinerator.

Table 4. Total composition of the MSWI bottom ash sampled under the parking lot and fresh bottom ash from 1993 and 1995.

Parameter	Unit	Bottom Ash			
		OldA	Old B	Fresh 1993	Fresh 1995
pH	-	9.3	9.2	-	10.4
Alkalinity	mmol/g	2.2	2.2	-	3.1
Loss on ignition	g/kg	47	43	33	24
NVOC	g/kg	19	20	-	17
Si	g/kg	240	240	180	230
Al	g/kg	45	46	59	65
Fe	g/kg	78	83	120	71
Ca	g/kg	64	65	110	93
Mg	g/kg	8.0	8.1	8.5	11
Mn	g/kg	1.7	2.0	1.7	1.3
Ti	g/kg	2.9	3.0	7.2	7.9
P	g/kg	4.3	4.2	5.6	4.4
K	g/kg	10	10	11	10
Na	g/kg	42	41	21	33
S	g/kg	1.1	1.0	5.1	3.5
Cl	g/kg	0.5	0.5	3.3	3.3
As	mg/kg	41	36	44	27
Ba	mg/kg	1400	1100	1050	1500
Cd	mg/kg	6.9	6.4	11	1.4
Cr	mg/kg	210	230	-	320
Cu	mg/kg	2200	2400	7800	15000
Hg	mg/kg	0.29	0.14	-	<0.2
Ni	mg/kg	130	290	210	320
Pb	mg/kg	2300	2300	2100	2400
Zn	mg/kg	4000	3900	-	4500

The data presented in Table 4 show that the pH of the aged ash is lower than the pH of the fresh ash sampled in 1993 and 1995. The lower pH in the aged bottom ash is probably caused partly by carbonisation (uptake of carbon dioxide) and partly by leaching of alkalinity with percolating water. This was further confirmed by measurements of pH as a function of depth in the bottom ash. pH increased from approximately 8.3 at the top to a pH of 9.3 to 10 at the bottom of the layer.

For an evaluation of the future leaching behaviour of the 21 year old bottom ash, samples of this ash were subjected to different leaching tests, including column leaching tests ($L/S = 0.1, 0.2, 0.5, 1.0$), availability tests ($2 \times L/S = 100$ l/kg, pH = 7 and pH = 4), serial batch leaching tests for granular waste ($L/S = 2, 10, 50$) and pH-static leaching tests at pH = 2, 4, 6, 7, 8, 9, 10, 11 ($L/S = 5$). In Figure 3 examples of the leaching behaviour of chloride and lead are shown in terms of results from the availability test and the serial batch leaching test

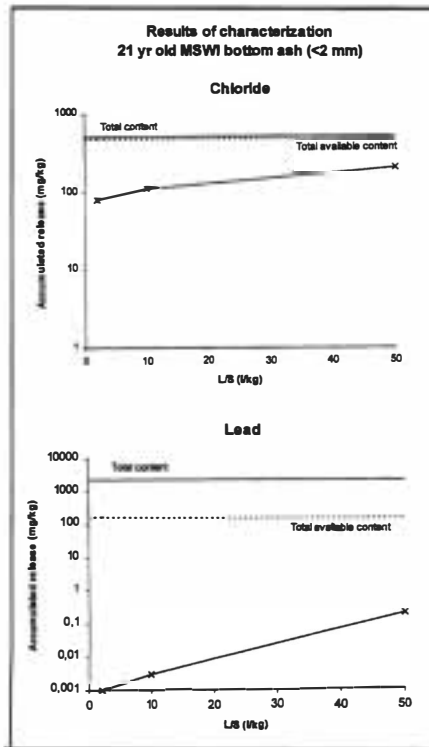


Fig. 3: Accumulated release of lead and chloride from 21 year old MSWI bottom ash shown as function of the L/S-ratio.

The results for chloride shown in Figure 3 show that the amount of chloride characterised as available for leaching approximates the total concentration of chloride found in the ash, and the accumulated release of chloride increases as a function of L/S and has at L/S = 50 l/kg reached approximately 40 % of the total amount of chloride available for leaching. As expected, this behaviour is different from the one observed for the trace elements, here exemplified by lead. A large fraction of the lead found in the ash is not available for leaching as shown by the results of the availability test and the serial batch leaching test. This type of information contributes to a better understanding of the leaching behaviour of these two elements and exemplifies that salts like chloride are relatively easily leached from bottom ash, whereas many trace elements are strongly bound within the solid matrix and only to a limited extent available for leaching.

Further information of the leaching behaviour can be obtained through the performance of pH-static leaching test as shown in Figure 4.

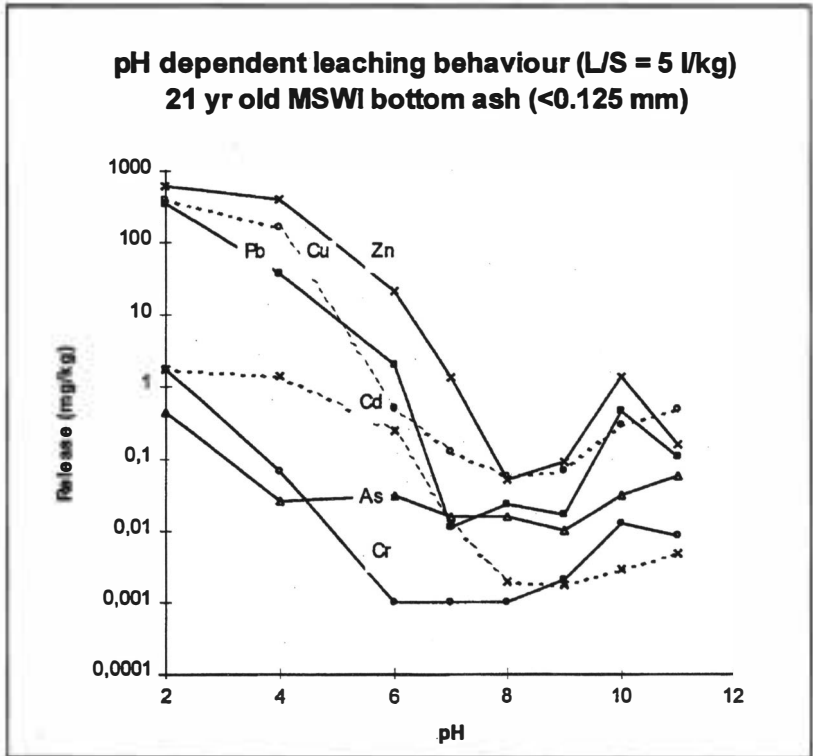


Fig. 4. pH dependent leaching behaviour of a 21 year old MSWI bottom ash.

pH is probably the single most important factor controlling the leaching behaviour of trace elements from incineration residues. The information from this type of testing illustrates the pH-dependent leaching behaviour of the elements found in the slag. The different form of the leaching curves representing the elements reflect the solubility of the different minerals present in the slag.

CONCLUSION AND SUMMARY

This paper presents a number of data on the composition and leachability of MSWI residues. Based on these data it can be concluded that:

The bottom ash contains high concentration of several salts and trace elements.

The leachate from the bottom ash contains high initial salt, ammonia, NVOC concentrations and relatively low concentrations of trace elements.

Results of field and laboratory leaching tests may provide good basis for evaluation of leaching behaviour of contaminant from combustion residues. However, only a few long term studies of actual utilisation of MSWI bottom ash are available and there is a need for further long term field observations and laboratory experiments.

REFERENCES:

IAWG (1997) The International Ash Working Group: Chandler, A.J.; Eighmy, T.T.; Hartlén, J.; Hjelmar, O.; Kosson, D.S.; Sawell, S.E.; van der Sloot, H.A. & J. Vehlow: Municipal solid waste incineration residues. Studies in Environmental Science 67. Elsevier, The Netherlands.

Hjelmar, O. (1996): Disposal strategies for municipal solid waste incineration residues. *Journal of Hazardous Materials* 47: 345-368.

DOI: [https://doi.org/10.1016/0304-3894\(95\)00111-5](https://doi.org/10.1016/0304-3894(95)00111-5)