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Influence of operational conditions, waste input and ageing on contaminant leaching from waste incinerator bottom ash: A full-scale study

Jiri Hyks *, Thomas Astrup

Technical University of Denmark, Department of Environmental Engineering, Building 115, 2800 Lyngby, Denmark

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ABSTRACT

Leaching of metals and Cl from fresh, naturally aged, and lab-scale aged bottom ashes generated during full-scale incineration experiments with different operational conditions (OC) and waste input (WI) was assessed. Although significant differences in the bulk contents of the generated bottom ashes were observed between the individual experiments, addition of 5.5 wt.% PVC, 11.1 wt.% chromated-copper–arsenate impregnated wood, 14.2 wt.% automotive shredder residue, 1.6 wt.% shoes, and 0.5 wt.% batteries to the normal municipal solid waste received at the incinerator (in six individual experiments) had no significant effect on metal leaching from the bottom ash. Likewise, changes in OC (furnace oxygen level and air distribution) could not be correlated to changes in leaching. The effects on metal leaching from ageing were generally larger than the effects from changes in OC and WI. Ash ageing caused a significant decrease in leaching of Cu, Zn, and Pb while leaching of Sb and particularly Cr increased. For Cl, a clear correlation between the bulk contents and leaching was observed for bottom ash generated in experiments with changes in WI. Comparison of leaching data obtained in this study with leaching from "typical" aged Danish bottom ash revealed no significant differences when the typical variations in leaching data over time and between different Danish incinerators were accounted. Generally, this indicates that metal leaching from bottom ash is not sensitive to limited changes in WI and OC as suggested in this paper, only Cl^- leaching appeared to be affected.

1. Introduction

Municipal solid waste (MSW) incineration is a common waste treatment option which both reduces volume of the waste and also facilitates recovery of the energy in the waste. While environmental impacts related to air emissions can be minimized by modern flue gas cleaning technologies, the major part of the pollution potential is generally associated with the solid residues such as air-pollution-control (APC) residues and bottom ash (Kosson et al., 1996). While APC residues are typically more polluted, the bottom ash is produced in much larger quantities and is often upgraded and used as construction materials (Astrup, 2007). The leaching of contaminants from bottom ash has received significant attention over the years with a considerable focus on leaching mechanism (e.g., Meima and Comans, 1997; Dijkstra et al., 2006; Hyks et al., 2009a).

It is generally anticipated in the literature that no direct correlation exists between the bulk contents of bottom ash and leaching of metals which are controlled by mineral solubilities. Only elements such as Na and Cl, which are rather controlled by their availability in the solid, are generally expected to be affected by changes in the bulk contents (Hjelmar, 1996; Kosson et al., 1996). Although a few studies have shown that both incinerator operational conditions (OC) and composition of the waste input (WI) may affect the solid contents of residues (Morf et al., 2000; Rendek et al., 2007), significantly less attention has been focused on how such changes may affect leaching from bottom ash. Effects on leaching from changes in incinerator OC are relevant for evaluating whether or not a potential for optimization exists. Effects from changes in WI are relevant when assessing environmental consequences of including new waste types at an incinerator (e.g., impregnated wood, plastic waste, etc.) or when discussing whether certain waste materials should rather be avoided. The latter case may be relevant when planning source separation and collection systems for new MSW incinerators.

To assess potential effects on bottom ash leaching from changes in OC and WI at a full-scale MSW incinerator, a range of bottom ash samples was collected during experiments with controlled changes in operational parameters of the furnace (oxygen level and air distribution) as well as experiments with controlled changes to WI composition (various waste materials were added to the normal waste). Based on the observed changes in bottom ash composition, the objectives were to: (i) quantify the consequences for leaching from fresh, naturally aged, and lab-scale aged versions of these ashes, and (ii) compare leaching from these ashes with typical

* Corresponding author. Tel.: +45 4525 1498; fax: +45 4593 2850.
E-mail address: jrh@env.dtu.dk (J. Hyks).

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bottom ash leaching data from a range of Danish MSW incinerators. It should be emphasized that this study focuses solely on the leaching quantification. Changes in partitioning and residue composition as well as the technology-related problems induced by incineration of waste with high calorific value and high concentrations of corrosive agents (e.g., Cl from PVC) are discussed in Pedersen et al. (2009).

2. Experimental

2.1. Full-scale incineration experiments

The incineration experiments were carried out at a full-scale MSW incinerator (I/S FASAN, Denmark) equipped with an air-cooled grate system (Babcock & Wilcox Vølund); the nominal capacity of the furnace was 8 t h^{-1} at 12 GJ t^{-1}. The incinerator primarily received MSW from mainly households (about 80% of which collected directly from the households while about 20% was mixed combustible waste, such as bulky waste, collected at "recycling stations" open for households and small companies) but also to some extent waste from smaller industries. During the experiments, individual truckloads of this industry waste (typically specific waste types such as plastic waste, construction & demolition waste) were diverted from the incinerator in order to minimize potential day-to-day fluctuations in waste composition. The waste received during the experiments therefore consisted exclusively of the MSW also incinerated at the plant outside the experimental period. This waste was comparable to "typical" Danish household waste incinerated at Danish MSW incinerators and is here referred to as "reference waste".

In total, 12 experiments were carried out: six with changes in OC and six with changes in WI. In the first six experiments, the reference waste was incinerated with a range of process configurations involving different ratios of primary and secondary air (see Table 1 and Pedersen et al., 2009). The primary focus was to evaluate the importance of the oxygen level and the air distribution in the furnace with respect to the ash quality; incineration of the reference waste with regular OC for the furnace was defined as "Normal" in Table 1.

In the remaining six experiments, different waste materials were added to the reference waste in order to evaluate the effect of these materials on the bottom ash quality. Six waste materials were added one-by-one in six individual experiments in following amounts (expressed as wt.% of the reference waste): 5.5% PVC, 11.1% chromate–copper–arsenate impregnated wood, 14.2% automotive shredder residue (ASR), 1.6% shoes, 0.5% road salt for deicing, and 0.5% batteries. Road salt (NaCl) was added primarily to assess differences between inorganic bound Cl and organic bound Cl (PVC). The lower heating value of the mixture (reference waste plus the added fraction) was kept within the design range of the furnace while OC were maintained as close as possible to the "Normal" situation.

2.2. Bottom ash samples

Bottom ashes from MSW incineration are highly heterogeneous (Chandler et al., 1997) and special attention has to be placed on the sampling. Ashes were sampled using two approaches: (1) by an automated sampler acquiring samples from a falling stream of ashes between two ash conveyers and (2) by collecting, at the end of the ash conveyer, all ashes generated during the course of an experiment. As such, samples obtained by the automated sampler (1) were representative subsamples of the samples obtained in (2). Typically about 40–60 samples were collected by the automated sampler (1) during the course of an experiment amounting to about 200 kg while the samples collected at the end of the ash conveyer (2) typically amounted to about 5–10 t. The first samples (1) are here referred to as "fresh". The latter ashes were subsequently stored outside for 3 months following standard practices at the incinerator thereby allowing the ashes to carbonate. After 3 months, representative subsamples of the 5–10 t were collected from a falling stream at the end of a conveyer belt. These ashes are here referred to as "naturally aged" samples. Both fresh and naturally aged samples were screened to remove metal/inert objects above 20 mm (corresponding to approximately 15 wt.%) and then reduced in size by a riffle splitter until lab samples of about 20 kg were obtained. These samples were further crushed to pass a 4 mm sieve and split to provide the test samples needed for the leaching experiments.

For each experiment, subsamples of the fresh ashes were further subjected to laboratory ageing at 20–25 °C. These ashes were spread in thin layers, regularly moisturized and turned thereby allowing atmospheric CO_2 to react with the solid phase. The entire ageing period lasted up to 6 weeks and was continued until pH was stable for at least a week. The intention was not to reach a theoretical level of carbonation (Meima and Comans, 1997) but rather continue carbonation until pH was semi-stable. These samples are here referred to as "lab-scale aged".

Overall, the three sample types (fresh, naturally aged, and lab-scale aged) represent the typical "range" within which bottom ash from MSW incinerators may appear in. Bottom ash is in most practical situations aged for some time before utilization or landfilling (represented by naturally aged samples) but natural ageing is seldom as complete as what can be achieved in the laboratory (represented by lab-scale aged samples). The fresh samples represent the "starting point" of the ageing process.

Variations in bottom ash composition were addressed during the experiment with PVC by collecting seven individual primary samples using the automated sampler (1). These samples were

Table 1
Conditions during the full-scale incineration experiments as registered by the plant's internal data collection system (refined). Detailed information on measuring techniques is given in Pedersen et al. (2009).

Parameter	OC experiment: reference waste only						WI experiment: reference waste + added fraction					
	Normal	# 1	# 2	# 3	# 4	# 5	PVC	Imp. wood	ASR	Shoes	Road salt	Batteries
O_2 in flue gas (vol.%, wet)[a]	7.3	7.2	9.1	7.9	7.5	8.3	7.9	7.8	7.5	8.0	7.6	7.9
$T_{flue\ gas}$ (°C)[b]	175	176	184	175	175	173	175	176	175	177	175	176
Primary air flow (−)[c]	0.90	1.00	1.15	1.14	0.78	1.08	0.91	0.93	1.01	0.92	1.03	1.14
Secondary air flow (−)[c]	1.09	0.61	1.44	0.73	1.22	0.79	1.12	1.00	1.05	0.99	1.02	0.93
Total air flow (−)[c]	0.96	0.88	1.24	1.01	0.91	1.00	0.98	0.95	1.02	0.94	1.03	1.07
Primary/secondary air distribution (%)	65/35	79/21	65/35	78/22	59/41	76/24	65/35	68/32	69/31	68/32	70/30	74/26

[a] Average concentrations of O_2 in the flue gas downstream of the boiler.
[b] Temperature in flue gas downstream of the boiler sections.
[c] The air flows are given on a normalized basis (to the average values of all experiments).