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Material analysis of Bottom ash from waste-to-energy plants

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ABSTRACT

Bottom ash (BA) from waste-to-energy (WtE) plants contains valuable components, particularly ferrous (Fe) and non-ferrous (NFe) metals, which can be recovered. To assess the resource recovery potential of BA in the Czech Republic, it was necessary to obtain its detailed material composition. This paper presents the material composition of BA samples from all three Czech WtE plants. It was found that the BA contained 9.2–22.7% glass, 1.8–5.1% ceramics and porcelain, 0.2–1.0% unburnt organic matter, 10.2–16.3% magnetic fraction, 6.1–11.0% Fe scrap, and 1.3–2.8% NFe metals (in dry matter). The contents of individual components were also studied with respect to the BA granulometry and character of the WtE waste collection area.

1. Introduction

Waste-to-energy has recently become a leading technology for municipal solid waste (MSW) treatment in Europe. Annually, waste-to-energy (WtE) plants treat nearly 80 million tons of MSW in Europe and generate about 31 million MWh of electricity and 78 million MWh of heat. Bottom ash (BA) is the most abundant solid residue from WtE. The European annual production of BA is about 20 million tons, i.e. approximately 25% of WtE treated MSW by mass (Lamers, 2015). In recent years, it has been shown that WtE can also contribute towards the recycling process through the recovery of iron scrap, NFe metals and glass, as has been done in some European WtE plants.

Bottom ash is a very heterogeneous material, as its composition corresponds to the composition of incinerated MSW, which varies with respect to the specific country, character of the collection area, season, etc. For example, according to Eurostat data (Eurostat, 2014), annual MSW production per capita in the Czech Republic (307 kg per person in 2013) is half of that in Germany (614 kg per person in 2013), hence the composition should also differ.

The BA composition reported in the literature usually contains 5–13% ferrous metals, 2–5% NFe metals, 15–30% glass and ceramics, 1–5% unburned organics, and 50–70% mineral fraction (Muchová, 2010; Chimenos et al., 1999; Berkhout et al., 2011). Chimenos et al. (1999) reported glass as the main component of two BA samples, constituting 50–60% of particles larger than 1 mm and up to 70% in some size fractions. Fifteen years later, del Valle-Zermeño et al. (2017) found a decrease of approximately 10% in glass content in weathered BA, due to the proliferation of recycling programmes and separate glass collection systems in Spain.

However, attention is mostly paid to the recovery of metals, whether ferrous or NFe, hence their content in BA can more often be found in the literature. The recovery potential and behaviour of aluminium during incineration in WtE plants was studied by Biganzoli et al. (2012), Biganzoli and Grosso (2013), and Biganzoli et al. (2014). According to their studies, more than one-half of metallic Al content in MSW is oxidised and inevitably lost during the combustion process. They also found a strong effect of the Al source (cans, trays, foils, etc.) on recovery efficiency, as the size and thickness of input aluminium waste determines the rate of oxidation during combustion and the size of Al lumps formed in the BA. Hu et al. (2011) and Hu and Rem (2009) confirmed the strong effect of an Al source on overall recovery potential, but stated higher values of recoverable Al (77–93%) in WtE. Al content in BA samples from AEB Amsterdam was about 1.5%. The most abundant of NFe metals was found to comprise 1–2% of BA, according to Biganzoli et al. (2013), Allegrini et al. (2014), and Berkhout et al. (2011).

Allegrini et al. (2014) analysed material flows in a BA treatment plant and determined the average content of NFe metals in Danish BA to be 2.2% (in wet BA). NFe metal content in 2–8, 8–16 and

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16–50 mm BA fractions was nearly the same, i.e. approximately 3.1–3.5%. They also reported that approximately 70% of NFe metals was aluminium. Bottom ash from two Spanish WtE plants analysed by Chimenos et al. (1999) contained 2–4% of NFe metals, of which 90% was aluminium. Muchová (2010) found the average content of NFe metals in BA from an Amsterdam WtE plant as 2.3% and the iron scrap content as 7–13%; more than 80% of metals were in free form, i.e. recoverable without BA crushing. About one-half of NFe metals were in particles >20 mm. Aluminium was dominant in particles of 6–20 mm (60%); in particles <2 mm, Cu was most prevalent (90%). From the aforementioned data, the variability of NFe metal content is obvious. However, clearer and more precise data should be available for possible stakeholders.

In addition, analyses have also recently been performed, focused on precious metals, rare earth elements and EU critical raw commodities. Muchová et al. (2009) analysed the fraction of heavy NFe metals, finding 100 mg/kg Au and 1500–4000 mg/kg Ag in the fraction. This corresponds to an overall BA content of 0.4 mg/kg Au and 10 mg/kg Ag. Both metals were found in all frac tions <20 mm. Morf et al. (2013) stated average Au and Ag content in BA to be 0.4 mg/kg and 5.4 mg/kg, i.e. very similar to the findings by Muchová et al. (2009), and determined them to be recoverable due to their enrichment in specific flows, mainly in the NFe metal fraction. Funari et al. (2015) found nearly the same values, i.e. 5.51 mg/kg Ag and 0.44 mg/kg Au.

The efficiency of metal recovery varies according to the technology and is mostly affected by the particle size of the recoverable material. Therefore, the distribution of recoverable materials and overall content are key factors in the selection of appropriate recovery technologies. Current methods of valuable material recovery from BA are based mostly on dry-mechanical separation. WtE plants are often equipped with a magnetic separator for recovering ferrous scrap. Magnetic separation is usually carried out after BA discharge, by means of overhead or drum magnets. The efficiency of such separation without any preparation is limited to large pieces of scrap.

Separation of NFe metals is performed by eddy current separators (ECS). To achieve sufficient separation efficiency, it is necessary to pre-treat the BA, e.g. ageing, sieving, crushing, etc. The separation efficiency of conventional technologies for NFe metals is approximately 30% of their total content in BA, with separation limited to particles larger than 10 mm (Koralewska, 2009) (Grosso et al., 2011). However, in recent years several technologies for increasing separation efficiency have emerged. The Advanced Dry Recovery (ADR) method was developed and installed in a plant in Amsterdam. This method allows the mechanical removal of fine particles smaller than 2 mm, which are associated with high moisture content and cause sticking of the material. Bottom ash processed by ADR can be classified according to particle size and is accessible for conventional dry separation processes without previous drying or water addition. (INASHCO, 2014). Ferrous and NFe metals are recovered from fractions >2 mm, with an overall efficiency of more than 85% for both groups of metals (Koralewska, 2009; Grosso et al., 2011). Dry BA discharge was developed to enable dry BA treatment throughout the whole process. Dry discharge allows more efficient metal recovery due to easier sieving into defined particle size fractions and the possible utilisation of fine particles (less than 2 mm). Furthermore, metals are not agglomerated into clusters by sticky wet fine ash particles and are accessible to technologies such as eddy current separators. Separation efficiency can reach over 90% for both ferrous and NFe metals.

In 2011, a pilot plant for glass recovery was installed in a WtE plant in Bratislava, Slovakia. Multi-step pre-treatment consisting of sieving, drying, dry-washing, and separating ferrous and NFe metals is required. Cleaned glass particles are separated from BA flow by a combination of optical detection methods and pneumatic ejection. Transparent glass particles >7 mm can be separated by this method; efficiency of up to 75% is possible (Makari, 2014).

In this paper, it is presented an overall assessment of BA resource recovery potential for all three Czech waste-to-energy plants. Detailed material characterisation of six samples is presented. Recoverable materials, such as metals and glass are discussed with respect to their particle size distribution and recovery potential. The effects of the waste collection area and the composition of incinerated MSW on BA composition are also presented.

2. Materials and methods

2.1. Bottom ash sampling

Six samples of BA from three WtE plants operated during 2014–2015 in the Czech Republic were obtained and analysed. Details of origins, sampling dates and weights of all samples are shown in Table 1. Bottom ash sampling was carried out by a certified sampling group and sampling was done according to the standardised procedure.

Three samples, P1–P3, were obtained from a WtE plant in Prague, with an annual waste capacity of approximately 320 000 tons and BA production of approximately 75 000 tons. The plant is equipped with a rotating drum grate and wet BA discharge. All samples were taken at the end of the conveyor belt that transported BA from the BA bunker to containers upstream of the magnetic separator.

Samples L1 and L2 originated from a WtE plant in Liberec, with an annual waste capacity of approximately 95 000 tons and BA production of approximately 30 000 tons. More details about the plant were previously published (Šyc et al., 2015). The plant is equipped with a moving grate and wet bottom ash discharge. Both samples were integral and taken from several bottom ash transport containers after magnetic separation. At least six partial samples of approx. 1 kg were taken from different sites in each container with BA, alternately from the top and bottom of the BA layer.

Sample B1 was obtained from the WtE plant in Brno, with a capacity of approximately 235 000 tons of waste and BA production of approximately 60 000 tons. The plant is equipped with a reciprocating grate and wet BA discharge. Bottom ash was taken directly from the conveyor belt that transported BA from the wet discharge to the bunker prior to any treatment. Samples were taken simultaneously from two boiler lines and then mixed together for one integral sample.

All the samples were transported to the lab in closed plastic bags. Before analyses, samples were dried in laboratory conditions for at least five days in a layer approximately 3 cm thick. In the case of sample P3, only one-third of the total sample quantity was used for analysis. All analyses were performed on dry samples.

Table 1
Analysed samples.

WtE plant	Sample	Date of sampling	Weight (kg)
Prague	P1	2–4, 8.7.2014	115
	P2	27–31.10.2014	120
	P3	4–8,11,12.5.2015	272
Liberec	L1	16–20.6.2014	84
	L2	22–24, 27.10.2014	90
Brno	B1	21–24, 27–28.7.2015	150

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