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Evaluation of resource recovery from waste incineration residues – The case of zinc

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ABSTRACT

Solid residues generated at European Waste to Energy plants contain altogether about 69,000 t/a of Zn, of which more than 50% accumulates in air pollution control residues, mainly boiler and filter ashes. Intensive research activities aiming at Zn recovery from such residues recently resulted in a technical scale Zn recovery plant at a Swiss waste incinerator. By acidic leaching and subsequent electrolysis this technology (FLUREC) allows generating metallic Zn of purity > 99.9%. In the present paper the economic viability of the FLUREC technology with respect to Zn recovery from different solid residues of waste incineration has been investigated and subsequently been categorised according to the mineral resource classification scheme of McKelvey. The results of the analysis demonstrate that recovery costs for Zn are highly dependent on the costs for current fly ash disposal (e.g. cost for subsurface landfilling). Assuming current disposal practice costs of 220 €/ton fly ash, resulting recovery costs for Zn are generally higher than its current market price of 1.6 €/kg Zn. With respect to the resource classification this outcome indicates that none of the identified Zn resources present in incineration residues can be economically extracted and thus cannot be classified as a reserve. Only for about 4800 t/a of Zn an extraction would be marginally economic, meaning that recovery costs are only slightly (less than 20%) higher than the current market price for Zn. For the remaining Zn resources production costs are between 1.5 and 4 times (7900 t/a Zn) and 10–80 times (55,300 t/a Zn) higher than the current market value. The economic potential for Zn recovery from waste incineration residues is highest for filter ashes generated at grate incinerators equipped with wet air pollution control.

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1. Introduction

In 2011 about 23% of Municipal Solid Waste (MSW) generated within the European Union has been thermally valorised (Eurostat, 2014), which amounts, together with commercial waste, to about 78 million tons of total waste fed to Waste to Energy (WtE) plants (CEWEP, 2011). Besides the production of electricity and heat, MSW incineration (MSWI) goes along with the generation of bottom ash and air pollution control (APC) residues, namely fly ashes (including boiler ash and filter ash) and filter cake. While in many countries bottom ash is already processed in order to recover some of the metals contained (mainly iron scrap, but also aluminium and copper), APC residues (which amount in total to about 2 million tons in the European Union) have been hardly considered for resource recovery so far. In all European countries they are classified as hazardous waste, which results from environmental concerns regarding the leachability of easily soluble salts (such as Cl, Na or K) and heavy metals (such as Cd, Pb, Cu or Zn) on the one hand, as well as the total content of As, Cd, Hg, and dioxins on the other hand.

Due to these characteristics most APC residues are either landfilled at hazardous waste landfills (this includes also the backfilling of former salt mines) or are stabilized with cement or other chemicals in order to comply with regulatory limit values for waste acceptance at non-hazardous landfills. Both practices are associated with significant costs, ranging between € 200 and € 250/t fly ash (Astrup, 2008) and the "loss" of valuable materials (e.g. metals). Contrary to that, only a small portion of APC residues, mainly from fluidized bed incineration, can be landfilled in non-hazardous landfills without prior treatment.

Only in few European countries attempts are made to recycle APC residues (Astrup, 2008) or at least parts of them. In the Netherlands, for instance, fly ashes partly substitute filler material in asphalt

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paved roads. Even though the encapsulation in asphalt may last longer than in cement the dilution and dispersion of pollutants, resulting from this practice has to be criticized from an environmental perspective. In Switzerland several waste incinerators treat their fly ashes by applying acidic washing. Salts/brine (e.g. for the regeneration of ion exchangers or for de-icing roads during winter time) as well as heavy metals are thereby separated from the fly ash, and the processed "almost heavy metal free" fly ash cake is landfilled together with bottom ash at non-hazardous waste landfills. The heavy metals enriched filtrate is neutralized and the hydroxide sludge rich in Zinc (Zn) generated thereby can be sent to specific Zn-oxide recycling facilities (Bühler and Schlumberger, 2010). Over the last few years this so called FLUWA process has been further developed and extended such that zinc can be recovered directly at the incineration plant (Schlumberger, 2010). This new technology, called FLUREC, has recently been introduced on large scale at a Waste-to-Energy (WtE) plant in Switzerland (KEBAG, 2013).

Moreover, the recovery of Zn or other metals out of MSWI fly ashes has gained increasing interest in recent times, also outside of Switzerland. Numerous research activities in different European countries have been dedicated to a recovery of heavy metals contained in MSWI APC residues (e.g. Karlfeldt Fedje et al., 2010a, 2012, 2012; Meylan and Spoerri, 2014). However, most studies conducted so far focused mainly on the technical and environmental evaluation of metal recovery (e.g. Boesch et al., 2014). Economic considerations with respect to metal recovery are rare and limited to residues of certain WtE plants (Karlfeldt Fedje et al., 2014). A comprehensive economic evaluation considering different MSWI fly ashes from plants of various combustion and APC technology has not been carried out so far.

Hence, the aim of the present study is to evaluate the potential for recovery of Zn from incineration residues generated at European WtE plants, focusing on fly ashes but also considering bottom ashes generated. Filter cake resulting from water purification of incinerators using a wet flue gas cleaning system is not considered in this study due to its small mass and low Zn content (Astrup, 2008). The evaluation procedure is based on the framework for evaluating anthropogenic resources recently developed by Lederer et al. (2014) is applied. Their approach foresees a combination of analysing material flows of the resource of interest and a subsequent economic assessment for the recovery of those material flows. The final outcome of the evaluation conducted represents the classification of Zn flows in incineration residues into different categories, which have been chosen in analogy to the classification of natural resource stocks (discriminating between reserves, marginally economic resources, subeconomic resources, and other occurrences of low grade).

2. Material and methods

In general, the applied framework for evaluating anthropogenic resources follows the procedure given in Fig. 1. After an initial phase of prospection (1), which aims at the identification of relevant stocks and flows, a phase of detailed investigation comparable to the exploration (2) of natural deposits follows. Therefore, data for resource flows and stocks of interest are collected and further processed. Thereto the method of material flow analysis MFA as described by Brunner and Rechberger (2004) is applied. MFA allows tracing flows and stocks of materials or chemical substances of interest with a system defined in space and time. Whereas during the prospection macro-level material flow analyses are conducted, the exploration phase is characterized by detailed MFA, which also accounts for uncertainties and if relevant also for associated flows of wanted or unwanted substances. In order to extract the desired material and produce a marketable good, a technology for Zn recovery is required. By choosing the technology, a rough estimate on the associated costs can be given (3). The latter forms the base for the subsequent classification of the different types of flows and stocks of interest (4).

Due to the fact that investigations have a priori been dedicated to the MSWI residues annually generated, the initial step of resource prospection (step 1) has been left out in the frame of the present investigations. Furthermore, contrary to the evaluation of Lederer et al. (2014), only flow resources have been considered. Flow resources are characterized by a continuous availability at different intervals and are in case of natural resources also classified as renewable resources, which are in contrast to non-renewable stock resources. According to Lederer et al. (2014) wastes generated can be considered as anthropogenic flow resources.

As for the present case study these flow resources are partly classified as hazardous waste, costs associated with the conventional disposal of these waste have to be accounted for as revenues when accomplishing the economic analysis of the recovery technology chosen.

2.1. Exploration of Zn flows in MSWI residues

In order to explore residues from waste incineration as potential secondary resource for Zn, a detailed literature analysis focusing on the following issues has been conducted:

- The amounts of waste incinerated in European WtE plants (CEWEP, 2011),
- the technology of incineration applied – distinguishing between grate incineration & rotary kilns on the one hand and fluidized bed incinerators on the other hand (ISWA, 2006a, 2013), as they determine the specific amount of different MSWI residues and their respective content of valuable metals,
- the technology of air pollution control (APC) systems (wet, dry & semi-dry residue systems) used at European Waste-to-Energy plants and the respective amount of APC residues (ISWA, 2013, 2006a), both again influencing the content of valuable metals (e.g. Zn) in APC residues,
- the Zn content in different MSWI residues (e.g., Auer et al., 1995; Hjelmar, 1996; Jakob et al., 1996; Abe et al., 2000; Nagib and Inoue, 2000; Mangialardi, 2003; Aubert et al., 2004; Hallgren and Strömberg, 2004; Ferreira et al., 2005; Aubert et al., 2007; Van Gerven et al., 2007; Chiang et al., 2008; Quina et al., 2008; Bontempi et al., 2010; Karlfeldt Fedje et al., 2010b; Karlsson et al., 2010; Lam et al., 2010; Schlumberger, 2010; De Boom et al., 2011; Nowak et al., 2013; Boesch et al., 2014), and
- transfer coefficients describing the portioning of Zn to the different outputs of incineration plants (e.g., Schachermayer et al., 1996; Brunner and Mönch, 1986; Morf and Brunner, 1998).

In all parameters of interest numerous data sources (as indicated above) have been utilized, which resulted in particular for the Zn content in MSWI residues as well as for the transfer coefficients of Zn rather in ranges of values than in exact figures. The deviations observed between the different sources have been accounted for by using uncertainty ranges for the respective parameters in the frame of the subsequent material flow and economic analyses.

Based on the results of the literature survey a material flow model describing the flows of Zn through European WtE plants has been established.

2.2. Economic Evaluation of Zn flows

The MFA model together with detailed information about the recovery technology, its consumables and costs for alternative

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