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Thermal co-treatment of combustible hazardous waste and waste incineration fly ash in a rotary kiln

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ABSTRACT

As current disposal practices for municipal solid waste incineration (MSWI) fly ash are either associated with significant costs or negative environmental impacts, an alternative treatment was investigated in a field scale experiment. Thereto, two rotary kilns were fed with hazardous waste, and moistened MSWI fly ash (water content of 23%) was added to the fuel of one kiln with a ratio of 169 kg/Mg hazardous waste for 54 h and 300 kg/Mg hazardous waste for 48 h while the other kiln was used as a reference. It was shown that the vast majority (>90%) of the inserted MSWI fly ash was transferred to the bottom ash of the rotary kiln. This bottom ash complied with the legal limits for non-hazardous waste landfills, thereby demonstrating the potential of the investigated method to transfer hazardous waste (MSWI fly ash) into non-hazardous waste (bottom ash). The results of a simple mixing test (MSWI fly ash and rotary kiln bottom ash have been mixed accordingly without thermal treatment) revealed that the observed transformation of hazardous MSWI fly ash into non-hazardous bottom ash during thermal co-treatment cannot be referred to dilution, as the mixture did not comply with legal limits for non-hazardous waste landfills. For the newly generated fly ash of the kiln, an increase in the concentration of Cd, K and Pb by 54%, 57% and 22%, respectively, was observed. In general, the operation of the rotary kiln was not impaired by the MSWI fly ash addition.

1. Introduction

Municipal solid waste incineration (MSWI) reduces the waste volume by 90%, the mass by 60–90%, and the organic matter by nearly 100% (Brunner and Rechberger, 2015; Chandler et al., 1997; Hjelmar, 1996; Kuo et al., 2007), saving valuable landfill space and avoiding gaseous landfill emissions (CH_4) from organic degradation processes. In Europe, almost 90% of MSWI plants are grate furnace combustors equipped with a grate furnace (Fellner et al., 2015). The solid residues produced in the MSWI grate furnace comprise bottom ash, which can be deposited at non-hazardous waste landfills or used as road construction material, and fly ash, which consists of *"particulate matter carried over from the combustion chamber and removed from the flue gas stream prior to addition of any type of sorbent material"* (Chandler et al., 1997). This MSWI fly ash comprises high contents of easily soluble salts, heavy metals and in some cases also polychlorinated dioxins and furans and is therefore classified as hazardous waste in many countries (Funari et al., 2016; Jiao et al., 2016; Li et al., 2016; Purgar et al., 2016; Ye et al., 2016; Zhan et al., 2016). For this reason, fly ashes from MSWI grate incineration generated in Austria for instance are currently either exported to hazardous waste landfills abroad or stabilised with cement and subsequently disposed of at local non-hazardous waste landfills. Both options involve costs and in the latter case the utilisation of cement requires not only valuable resources but causes significant amounts of CO_2 emissions (up to 500 kg CO_2/Mg fly ash). Hence, in the recent decades numerous studies investigating alternative treatment/disposal options for MSWI fly ash (De Boom and Degrez, 2015; Lindberg et al., 2015; Nowak et al., 2013; Quina et al., 2008; Nowak et al., 2013; Wey et al., 2006; Zacco et al., 2014) have been published.

As the physical, chemical and mineralogical properties of waste incineration fly ashes vary depending on waste composition, type of incinerator and the air pollution control (APC) system installed, it is difficult to compare these results. These facts, as well as the different legislation even in EU member countries, are reflected by various suggestions for alternative treatment and utilisation of fly ashes that can be found in literature.

Several authors propose a wet extraction process (washing) to decrease the content of easily soluble compounds like chloride salts present in MSWI fly ash (Aguiar del Toro et al., 2009;

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Blasenbauer et al., 2015; De Boom and Degrez, 2015; Karlfeldt Fedje et al., 2010; Thomé-Kozmiensky, 2013; Wang et al., 2001; Zhang and Itoh, 2006). These studies show that chloride can effectively be extracted, while the heavy metal content of treated fly ash may still require a stabilisation with cement prior to disposal at a non-hazardous waste landfill. In case that an acidic extraction agent (e.g. acidic scrubber water) is used instead of neutral water (leaching) also some metals (e.g. Zn, Pb) are largely removed.

An extension of the acidic leaching of fly ashes is the so-called FLUREC process that allows extraction and recycling of zinc, cadmium, copper and lead (Boesch et al., 2014; Schlumberger, 2010). However, at current Zn prices, this technique is only economically viable for waste incineration fly ashes showing Zn contents above 50,000 mg/Mg (Fellner et al., 2015).

Another approach is to treat fly ash at temperatures close to or above its melting point with or without additives, thereby transforming it into sintered, melted or vitrified products. These processes decrease the mobility of heavy metals and, as a result, also the heavy metal concentration in the leachate (Li et al., 2015; Sobiecka and Szymanski, 2014; Sobiecka, 2015; Wang et al., 2008; Wunsch et al., 1996; Yang et al., 2009; Zhao et al., 2010; Zupanič et al., 2012) and effectively destroy the polychlorinated dioxins and furans (Miller et al., 1989; Vogg and Stieglitz, 1986; Wu et al., 2011). Sintering trials of MSWI fly ash from grate furnace in a rotary kiln showed that the thermal treatment causes a partial evaporation of lead, thereby rendering the sintered product non-hazardous (Wey et al., 2006). However, in general these high temperature processes require considerable amounts of energy, which calls their cost-effectiveness and sustainability into doubt.

Beside the specific problems mentioned, a common shortcoming of most of these alternative fly ash treatment processes are the rather high investment costs due to the installation of new treatment plants. For this reason, these processes are not widely applied as plant operators fear making such a risky investment. Using already existing treatment facilities in the vicinity of the point of MSWI fly ash generation like existing hazardous waste incineration plants would reduce this risk. However, such co-treatment of MSWI fly ashes has not been investigated so far.

The objectives of the present work are therefore to assess the feasibility of co-treating MSWI fly ash together with hazardous wastes and to evaluate the fate of the inserted fly ash as well as the quality of the solid residues generated. The particular research questions to be addressed are:

- How do the inserted MSWI fly ash and its components partition among the hazardous waste incineration residues during the co-treatment?
- Does the co-treatment of MSWI fly ash influence the quality of solid residues in general and bottom ash in particular, generated by the rotary kiln?
- In how far is the impact on the quality of bottom ash observed explainable by simply mixing the inserted MSWI fly ash and rotary kiln bottom ash?
- Does the co-treatment of fly ash in the rotary kiln impair its safe and continuous operation?

As the study was carried out in Austria, substance limit values for landfills refer to the legal situation in Austria.

2. Materials and methods

In the present study the co-treatment of moistened MSWI fly ash together with hazardous waste in a rotary kiln was investigated. Thereto two rotary kiln lines (1 and 2) of a hazardous waste incinerator were used. At kiln 1 moistened MSWI fly ash was added to the ordinary hazardous waste fuel at different rates for altogether 102 h; whereas kiln 2 served as reference utilising hazardous waste only. During the experimental time the flows of inserted matter (hazardous waste, moistened MSWI fly ash) were recorded and the outputs via bottom ash, rotary kiln fly ash and scrubber water of both kilns were separately recorded, sampled and subsequently analysed. The results served on the one hand to assess the destination of the inserted MSWI fly ash and its components (determination of transfer coefficients) and on the other hand to evaluate the impact of the MSWI fly ash addition on the quality of solid residues generated at the kiln. Finally, moistened MSWI fly ash was mixed with rotary kiln bottom ash without thermal treatment in order to evaluate if observed changes in bottom ash quality after thermal treatment refer to mixing effects only.

2.1. Inserted MSWI fly ash

The fly ash used for the experiment was collected at a MSWI mass-burning combustor with grate furnace. The APC system at this plant comprises an activated coke injector, fabric filters, a two-stage scrubber and a selective catalytic reduction device. In order to avoid dust emissions during the handling of the MSWI fly ash, it was mixed with water in a mass ratio of approximately 3:1, which lead to a water content of 0.23 kg/kg moistened MSWI fly ash. Then it was transported daily by truck to the hazardous waste rotary kiln incineration plant, where it was stored in the waste bunker. Prior to storage the moistened MSWI fly ash was sampled and analysed (see Table 1). The fly ash from this plant generally exceeds the legal limits for non-hazardous waste landfill for the parameters Hg total content, total dissolved solids in the leachate and Pb in the leachate.

2.2. Rotary kilns

The hazardous waste incinerator utilised for the experiment comprises two rotary kilns with a combined capacity of 100,000 Mg/a. The rotary kilns were built in 1980 and each rotary kiln is 12 m long, has an outer diameter of 4.5 m and rotates at approximately 0.5 min^{-1}. The residence time of waste in the rotary kilns is estimated to be about 1 h. The process scheme is illustrated in Fig. 1. The APC system consists of an electrostatic precipitator, a two-stage scrubber, a selective non-catalytic reduction device for injection of NH_3 and an activated coke filter (Stubenvoll et al., 2002). Gypsum is precipitated from the second scrubber stage and deposited on a non-hazardous waste landfill. The scrubber water is treated in an on-site wastewater treatment plant.

For the investigations conducted, the inputs and outputs of the rotary kiln (cf. Fig. 1) were recorded and analysed in order to assess the flows of substances present in MSWI fly ash added to kiln 1.

2.3. Fly ash treatment

The moistened MSWI fly ash was fed at different rates into rotary kiln 1 of the hazardous waste incinerator for a total period of 102 h. During the first 54 h (phase A) for every Mg of hazardous waste 169 kg (130 kg dry matter) MSWI fly ash were added to rotary kiln 1. Subsequently, the rate of MSWI fly ash addition was increased to 300 kg (231 kg dry matter) fly ash per Mg hazardous waste for a period of 48 h (phase B). During the trial the amount and composition of the hazardous waste inserted into rotary kiln 1 and 2 was, as far as possible, identical so that the only difference between the two kilns was the addition of moistened MSWI fly ash. For all following calculations it was assumed that the composition of hazardous waste inserted into both kilns was

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