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Assessment of mobility and bioavailability of contaminants in MSW incineration ash with aquatic and terrestrial bioassays

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ABSTRACT

Incineration of municipal solid waste (MSW) is a waste treatment method which can be sustainable in terms of waste volume reduction as well as a source of renewable energy. In the process fly and bottom ash is generated as a waste material. The ash residue may vary greatly in composition depending on the type of waste incinerated and it can contain elevated levels of harmful contaminants such as heavy metals. In this study, the ecotoxicity of a weathered, untreated incineration bottom ash was characterized as defined by the H14 criterion of the EU Waste Framework Directive by means of an elemental analysis, leaching tests followed by a chemical analysis and a combination of aquatic and solid-phase bioassays. The experiments were conducted to assess the mobility and bioavailability of ash contaminants. A combination of aquatic and terrestrial bioassays was used to determine potentially adverse acute effects of exposure to the solid ash and aqueous ash leachates. The results from the study showed that the bottom ash from a municipal waste incineration plant in mid-Sweden contained levels of metals such as Cu, Pb and Zn, which exceeded the Swedish EPA limit values for inert wastes. The chemical analysis of the ash leachates showed high concentrations of particularly Cr. The leachate concentration of Cr exceeded the limit value for L/S 10 leaching for inert wastes. Filtration of leachates prior to analysis may have underestimated the leachability of complex-forming metals such as Cu and Pb. The germination test of solid ash and ash leachates using *T. repens* showed a higher inhibition of seedling emergence of seeds exposed to the solid ash than the seeds exposed to ash leachates. This indicated a relatively low mobility of toxicants from the solid ash into the leachates, although some metals exceeded the L/S 10 leaching limit values for inert wastes. The Microtox® toxicity test showed only a very low toxic response to the ash leachate exposure, while the *D. magna* immobility test showed a moderately high toxic effect of the ash leachates. Overall, the results from this study showed an ecotoxic effect of the solid MSW bottom ash and the corresponding ash leachates. The material may therefore pose an environmental risk if used in construction applications. However, as the testing of the solid ash was rather limited and the ash leachate showed an unusually high leaching of Cr, further assessments are required in order to conclusively characterize the bottom ash studied herein as hazardous according to the H14 criterion.

1. Introduction

In today's consumer society the need for efficient and environmentally friendly waste management methods is greater than ever. Incineration of municipal solid waste (MSW) is a waste treatment method which can be sustainable both in terms of waste volume reduction as well as a source of renewable energy. In the incineration process fly and bottom ash is generated as a waste. The bottom ash material may be used as a fill material for road construction (OECD, 1977; Forteza et al., 2004), a stabilizer for liquid wastes such as sewage sludge (Bednarik et al., 2004) or as a landfill cover (Wiles, 1996). The MSW ash residue may vary greatly in composition depending on the type of waste incinerated and it frequently contains elevated levels of environmentally hazardous contaminants such as heavy metals (Hasselriis and Licata, 1996). Potentially adverse environmental effects of MSW bottom ash utilization mainly stems from leaching of heavy metals (Ecke and Aberg, 2004) and organic compounds such as PAH́s (Wheatley and Sadhra, 2004). However, some previous studies have shown that only a small amount of the heavy metal content of the ash is leached (Wiles, 1996).

The EU waste directive 2008/98/EC (EC, 2008) prescribes hazard characterization of waste materials according to 15 assessment criteria. The H14 criterion, which characterizes a waste as "ecotoxic", should preferably be assessed through the use of biotests. A wide range of bioassays are available for ecotoxicity testing, but when selecting an appropriate test method for hazard characterization considerations regarding material properties and exposure conditions need to be made. Several researchers have

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investigated suitable ecotoxicity test batteries for the assessment of the H14 criterion (Pandard et al., 2006; Wilke et al., 2008) and a European ring test, initiated by the German Environmental Protection Agency, UBA, was performed to evaluate available standardized test protocols for the assessment of waste hazard (Moser et al., 2010). Leaching tests are commonly used to assess the mobility of contaminant substances from a solid waste into an aqueous solution (Kosson et al., 2002). There are different types of leaching tests, using leachants such as deionised water, calcium chloride or acidic solutions. The ISO 12457 standard protocol, using deionised water as leachant, is considered a less aggressive leaching method in comparison to the US EPA Toxicity Characterization Leaching Procedure (TCLP) (US EPA, 1992) using an acetic acid/sodium hydroxide solution as leachant (Mantis et al., 2005). The ISO 14735 leaching protocol for the preparation of waste leachates for ecotoxicity testing is analogous to the ISO 12457 protocol but utilizes a weak calcium chloride solution as an artificial rain leachant. If the leachates from a waste can be classified as "ecotoxic" according to the H14 criterion, the material should also be classified as hazardous according to the H15 criterion of the waste directive; i.e. a waste capable by any means, after disposal, of yielding another substance, e.g. a leachate, which possesses any of the previous fourteen hazard properties, H1-H14.

In this study, the ecotoxicity of a matured, untreated incineration bottom ash was characterized as defined by the EU Waste Framework Directive H14 criterion by means of an elemental analysis, leaching tests and a combination of aquatic and solid-phase bioassays. The aim of the study was to assess the mobility and bioavailability of ash contaminants to determine the ecotoxicity of the ash according to the H14 criterion and to assess whether the material may be used in a construction application. A chemical analysis of the ash leachates was performed to study the extent of metal leachability. Aquatic and terrestrial bioassays were used to determine potentially adverse acute effects of exposure to the solid ash and to aqueous ash leachates.

2. Materials and methods

2.1. Experimental outline

The mobility and bioavailability of contaminants in the solid ash were assessed in leaching and toxicity tests according to the experimental outline of Fig. 1.

2.2. Ash

The bottom ash of the study originated from a municipal waste incineration plant in Sweden. Metal parts were separated from the ash after incineration. The ash was allowed to mature, i.e. weather in order to stabilize the metal content through carbonation reactions with water and carbon dioxide. This reduces future leaching of metals from the ash (ISWA, 2006). Elemental analysis of the whole ash was performed with ICP–MS/IC-AES within one month (Table 1) by a commercial accredited laboratory. Particles with a grain size >4 mm were separated from the ash sample prior to the germination test.

2.3. Control soil for germination test

The control garden soil was a commercial seedling and cactus soil. The soil was a 95% peat and 5% sand mixture, with 0.8 kg/m^3 manure supplied. Nutrients were added at the following concentrations: 112 g/m^3 N; 56 g/m^3 P; and 120 g/m^3 K. The soil pH was 5.5–6.5 and the soil density was 400 kg/m^3.

2.4. Ash leachate

Three sets of two parallel batch leaching tests were performed according to ISO standard protocol 12 457-2 using deionised water as the leachant in a 10:1 L/S ratio. Large particles (>4 mm) were separated from the whole ash sample through sieving. Following centrifugation and filtration over a 0.45 μm membrane filter, the ash leachates were assessed chemically, (see Section 2.4) and with terrestrial and aquatic bioassays (Section 2.5).

2.5. Chemical characterization of leachate

The metal concentrations of the leachate replicates L-A and L-B from the third batch leaching were determined by ICP–MS and ICP-AES at the accredited laboratory Analytica, according to US EPA standard procedures (US EPA, 1994a,b) on filtered leachate samples. No acid digestion was carried out on the leachate samples. pH and conductivity was measured using standard procedures.

2.6. Ecotoxicity assays

The toxicity of sieved ash samples (see Section 2.2 Ash) was assessed in a germination test using *Trifolium repens* (White clover).

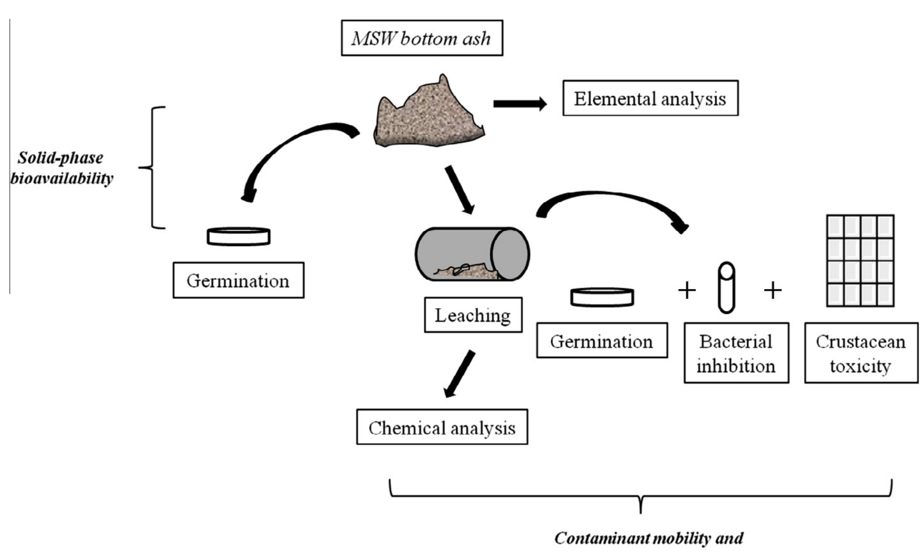

Fig. 1. Experimental outline of the ash contaminant mobility and bioavailability study.