



Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Leaching behaviour of incineration bottom ash in a reuse scenario: 12 years-field data vs. lab test results

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ARTICLE INFO

Article history:

Received 24 February 2017

Revised 19 July 2017

Accepted 8 August 2017

Available online xxxx

Keywords:

Leaching behaviour

Laboratory leaching tests

Field tests

Bottom ash

ABSTRACT

Several types of standardized laboratory leaching tests have been developed during the past few decades to evaluate the leaching behaviour of waste materials as a function of different parameters, such as the pH of the eluate and the liquid to solid ratio. However, the link between the results of these tests and leaching data collected from the field (e.g. in disposal or reuse scenarios) is not always straightforward. In this work, we compare data obtained from an on-going large scale field trial, in which municipal solid waste incineration bottom ash is being tested as road sub-base material, with the results obtained from percolation column and pH-dependence laboratory leaching tests carried out on the bottom ash at the beginning of the test. The comparisons reported in this paper show that for soluble substances (e.g. Cl, K and SO₄), percolation column tests can provide a good indication of the release expected in the field with deviations usually within a factor of 3. For metals characterized by a solubility-controlled release, i.e. that depends more on eluate pH than the liquid to solid ratio applied, the results of pH-dependence tests describe more accurately the eluate concentration trends observed in the field with deviations that in most cases (around 80%) are within one order of magnitude (see e.g. Al and Cd). The differences between field and lab-scale data might be in part ascribed to the occurrence in the field of weathering reactions (e.g. carbonation) but also to microbial decomposition of organic matter that modifying leachate pH affect the solubility of several constituents (e.g. Ca, Ba and Cr). Besides, weathering reactions can result in enhanced adsorption of fulvic acids to iron/aluminum (hydr)oxides, leading to a decrease in the leaching of fulvic acids and hence of elements such as Cu, Ni and Pb that strongly depend on DOC leaching. Overall, this comparison shows that percolation column tests and pH-dependence tests can represent a reliable screening tool to derive data that could be employed in risk-based analysis or life cycle assessment (LCA) frameworks for evaluating potential environmental impacts deriving from specific disposal/reuse options for waste materials.

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1. Introduction

The European Commission recently announced the adoption of a new ambitious package of actions to promote circular economy, i.e. the minimization of the consumption of non-renewable raw materials through the increase of recycling and reuse of waste and secondary materials in new production processes and/or applications (EU Commission, 2014). This strategy is also in line with one of the key concepts of the EU Waste Framework Directive: the reduction of the landfilling of waste and of its associated significant environmental impacts, including land use. Within this context, the construction sector is surely one of those presenting

the highest consumption of raw materials (e.g. in road foundations, in embankments or concrete production). In the last decades several studies have focused on the potential utilization of mineral/granular waste streams (e.g. steel slag, bottom ash from waste thermal treatment, construction and demolition waste) as substitutes for raw materials in civil engineering applications (e.g. Forteza et al., 2004; Petkovic et al., 2004; Das et al., 2007; Huang et al., 2007; Keulen et al., 2016) due to their suitable physical (e.g. bulk density, particle size distribution) and mechanical (e.g. compressive strength) properties. However, since such types of waste materials generally contain higher concentrations of potentially harmful substances (e.g. metals and metalloids) compared to natural aggregates, the main concern for their utilization is associated with potential long-term environmental impacts that may be caused by the release of contaminants upon contact with water

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(i.e. leaching behaviour). Thus, to ensure environmentally safe utilization of waste materials such as thermal treatment bottom ash, the release of salts, metals, and metalloids in the foreseen reuse scenario needs to be thoroughly investigated. Standardized laboratory leaching tests are typically employed to assess the potential release of contaminants from solid waste materials. Several experimental methods have been developed for both characterization and regulatory purposes, and many efforts have been made in order to standardize and harmonize leaching test procedures (e.g. Kosson et al., 2002; van der Sloot et al., 2001; van der Sloot and Dijkstra, 2004; van der Sloot and Kosson, 2012; Kosson et al., 2014). Due to the overall complexity of the leaching process, it is generally agreed that one single leaching test cannot provide an adequate description of the phenomena governing the release of contaminants (Kosson et al., 2014). Consequently, to obtain a better assessment of the leaching behaviour of a material in a specific scenario, a combination of different types of leaching tests should be used. The importance of combining different types of leaching tests was stressed by several studies (van der Sloot, 1996; Twardowska and Szczepanska, 2002; Kylefors et al., 2003; Hage and Mulder, 2004; López Meza et al., 2008; Grathwohl and Susset, 2009; Quina et al., 2011; Kosson et al., 2014; Di Gianfilippo et al., 2016). Specifically, pH-dependence tests (e.g. CEN/TS 14429, CEN/TS 14997, EPA Method 1313) in conjunction with percolation column tests (e.g. EN 14405, NEN 7343, EPA Method 1314) are recognized as the most important types of such tests since they provide relevant information on the leaching behaviour of a material, in terms of both progression of leaching, changes in exposure conditions and chemical speciation issues (Hage and Mulder, 2004; van der Sloot and Kosson, 2012; Di Gianfilippo et al., 2016). Indeed, results of pH-dependence tests have been widely used in geochemical speciation modelling to identify and possibly quantify the chemical phases (minerals and sorptive phases) controlling release (van der Sloot, 1996; Astrup et al., 2006; Dijkstra et al., 2006a). Percolation column tests are specifically applied to assess the evolution of the leaching process as a function of the liquid to solid ratio (L/S), i.e. the amount of water in contact with the waste material (Twardowska and Szczepanska, 2002; Kylefors et al., 2003). Although more complicated and time-consuming compared to simple batch tests, these types of tests are considered more reliable for evaluating the release of contaminants from waste materials, since they are expected to better reflect the leaching processes that may occur under field conditions (Kalbe et al., 2008; López Meza et al., 2008; Grathwohl and Susset, 2009). However, the comparison of lab-scale leaching data with field results is not always so straightforward. For instance, Izquierdo et al. (2008) and Butera et al. (2015) found that the leachability of constituents from a waste material predicted through lab-scale tests may differ considerably from the release in field conditions.

The focus of this work is to compare the results of laboratory leaching tests with field data for a specific type of waste material, with the aim of assessing the accuracy of the former in predicting field release as a function of pH and the L/S. Specifically, leaching data obtained from a large-scale field test, in which the reuse of municipal solid waste incineration (MSWI) bottom ash (BA) is being tested as road sub-base material (Hjelmar et al., 2007), are compared with the results obtained from percolation column and pH-dependence laboratory leaching tests carried out on the bottom ash as it was being placed into the field application.

2. Materials and methods

2.1. Field test

The field leaching data reported in this study were derived from a large-scale test carried out at Ydernæs near the town of Næstved

in Denmark, where six separate units (named as Unit A-F) were used to investigate the utilisation of MSWI BA as sub-base in roads and parking lots. The full description of the project and the preliminary results are reported in Hjelmar et al. (2007). The units measure approximately 10×10 m (units B-E) or 20×20 m (Units A and F) and contain 50–60 cm thick sub-base layer of MSWI BA. Bottom ashes from three different Danish MSW incinerators (MSWI 1 for Unit A, B, C and F, MSWI 2 for Unit D and MSWI 3 for Unit E) were used; chemical composition data of each sample are reported in Table 1. In this paper, the data regarding the BA type named MSWI 2 and the field test indicated as Unit D were specifically considered.

Test unit D is equipped with a low-density polyethylene (LDPE) bottom liner and a drainage layer as well as pumps and wells for leachate collection. In order to study the release of potential contaminants from the MSWI BA layer as a function of time and the L/S, the unit was covered only with pebbles to facilitate the infiltration of rainwater and the production of leachate. Moreover, to enable the observation of possible edge effects, the liners under the unit were divided into middle and edge sections, each with its own separate leachate collection system. The edge sections constitute approximately the outermost 1.3 m of the bottom liners. The layout and the cross section of the test unit are shown in Fig. 1 (for more details refer to Hjelmar et al., 2007).

The leaching data discussed in this paper belong solely to the middle section, which consists of around 54.2 tons of BA (corresponding to a volume of approximately 30.8 m^3). The field test was started during 2002 and is still running. From the beginning of the test up to September 2014, corresponding to the period for which leaching data are currently available, a cumulative L/S of approximately 3 l/kg was reached.

The leachate collection system is described in detail in Hjelmar et al. (2007). In short, peristaltic sampling pumps, which are triggered by level-controlled leachate pumps placed in pumping wells, collect flow-proportional samples of the leachate from the different liner sections of each unit into closed 10 l polyethylene bottles. The composition of the collected leachate is being monitored at regular intervals. pH and conductivity are measured on all samples, while selected samples are – after filtration ($0.45 \mu\text{m}$) – analysed for Cl, F, SO_4 (ion chromatography), carbonate alkalinity (EN ISO 9963-2), Ca, Mg, Na, K, Al, As, Ba, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Zn (ICP-AES/MS), Hg, Se (AFS) and dissolved organic carbon (DOC).

2.2. Laboratory leaching tests

During the construction of the test site in October 2002, representative samples of the MSWI bottom ash placed in each unit were collected and used for the laboratory leaching tests (carried out in 2002–2003). As described in detail in Hjelmar et al. (2007), prior to arrival at the site, the bottom ash had been stored/weathered in stockpiles for 1–3 months, screened through a 50 mm trommel and subjected to magnetic separation to recover ferrous metals. Hence, the used/tested BA was similar to the BA typically employed in road construction in Denmark. During the construction of the test site, from the dozer grab of BA placed in the unit, two samples were taken randomly with a shovel and placed in a polyethylene drum. Approximately 200 kg of BA were collected. The sample was screened (45 mm) and oversize material that could not be crushed was discarded. The screened material was thoroughly mixed and the sample size was reduced to 25 kg by means of a riffle sample splitter. After air-drying at room temperature, the BA sample was split into sub-samples using the riffle and crushed in a jaw crusher to <4 mm for column leaching testing (EN 14405) and further ground to <0.125 mm for chemical analysis

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