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Evaluation of the leaching behavior of incineration bottom ash using seawater: A comparison with standard leaching tests

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ABSTRACT

Batch and column tests were conducted on untreated incineration bottom ash (IBA) samples from two incineration plants in Singapore, using seawater as the leachant. The main objective of this study was to investigate the change in the leaching behavior of certain elements (i.e. As, Cd, Cr, Cu, Ni, Pb, Sb, Se and Zn) when IBA comes into contact with seawater. Such an investigation using seawater as leachant was not commonly carried out when investigating leaching behavior in IBA. The leaching tests were then carried out on the same IBA samples using DI water, as a comparison. Lower level of leaching was observed for Pb and Zn when seawater was used as the leachant. Cr and Sb showed significant cumulative release at Liquid-to-Solids (L/S) ratio 5 in the seawater column leaching. The influence of Dissolved Organic Carbon (DOC) on Cu leaching seems to decrease after L/S 2 when using seawater in the column test. Although the leaching behavior of IBA was affected when seawater was used, for the column test, there was no significant difference during the initial release when compared to DI water. The initial L/S fractions collected were important as the low L/S ratios represent the pore water concentration and the maximum output in an actual application. The results from this study would be useful for the future study on using IBA in marine applications.

1. Introduction

Proper management of municipal solid waste (MSW) incineration bottom ash (IBA) can pose a big challenge to local authorities, in particular if the region lacks land space for long term sanitary disposal. Over the past decades, much emphasis has been placed on the utilization of IBA to ease the dependency on the use of landfills for disposal (Sabbas et al., 2003; Astrup, 2007). In general, utilization of IBA (which accounts for around 80% of incinerated ash) is a common practice in many countries, such as the Netherlands and Denmark, where it is used as a secondary raw material in road construction (van der Sloot, 1996; Leenders, 2000; Astrup, 2007). However, with the concerns on IBA leaching during utilization, strict regulations are being imposed on IBA utilization to ensure environmental safety.

Utilizing IBA depends mainly on its impact to the environment, which is currently determined by conducting a series of appropriate leaching tests. Leaching is defined as the dissolution process whereby a solid gets into contact with a liquid (leachant), after which mass transport occurs between these two phases (Chandler et al., 1997; Todorovic and Ecke, 2006). During this process, the soluble constituents in the solid phase dissolve into the leachant to form leachate. The understanding of this mass transport is important so as to predict the release of constituents that may leach out from IBA into the environment during applications (Todorovic and Ecke, 2006).

Many leaching tests were developed in response to the numerous factors that influence the leaching result. These factors include L/S ratio, particle morphology, contact time, complexing agents and pH. They relate to both physical and chemical reactions that can control the solubility of solids, as well as precipitation and dissolution processes (Chandler et al., 1997). In Europe, countries such as the Netherlands and Denmark based their leaching standards on deionized (DI) water as the leachant (EUR-lex, 2003; Saveyn et al.,

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2014). The use of site-specific leachants, such as seawater, is not common as the results cannot be compared with standardized leaching tests (Chandler et al., 1997). For seawater leaching, column leaching tests have been conducted on marine sediments (Payán et al., 2013) and caliche mineral (Ordóñez et al., 2013). At present, however, seawater leaching on MSW IBA has not been fully investigated in detail. This is crucial in view of possible IBA utilization in marine applications, such as artificial barriers, land reclamation or road constructions along coastlines. Moreover, the leaching behavior of IBA using seawater will be different from DI water due to the high dissolved solid and metals already present in seawater.

This study aims to characterize the leaching behavior of IBA when utilized in marine applications, by using seawater leaching as the main research objective. Two modified European leaching tests based on batch and column tests were conducted, using seawater as the leachant. The same leaching tests were also carried out using DI as a comparison. These two leaching tests were selected because batch leaching serves as a quick compliance test, whereas column leaching simulates the leaching behavior of MSW IBA under percolation. Due to the complexity of leaching phenomena and the fundamental difference between batch and column tests, several papers were written to investigate the relationship between these two tests (Lopez Meza et al., 2008; Grathwohl and Susset, 2009; Quina et al., 2011). In principle, all these papers agreed that column test provides more information than batch test. This study will use the knowledge reported by previous research to explain the leaching behavior exhibited by Singapore's IBA. The results from this study will thus provide a foundation for future study on any possible IBA marine application.

2. Materials and methods

2.1. IBA sample characterization

Freshly quenched MSW IBA was collected from two incineration plants (denoted as IBA-1 and IBA-2) in Singapore daily for one month. Subsequently, they were collected once a week for four consecutive months. A total of 36 samples were collected over 5 months and combined into IBA-1 and IBA-2 before being analyzed for this study. Approximately 50 kg of wet IBA was collected for each sample. They were oven dried immediately after collection at 40 °C for three days. A portion of the wet IBA were separately tested for the water content by drying at 105 °C for 24 h. The average water content for IBA-1 and IBA-2 were 16.2% and 18.7% respectively. The IBA samples dried at 40 °C were then sieved to four different size fractions: <2 mm, 2–4 mm, 4–20 mm and 20–50 mm. Particles bigger than 50 mm were discarded. Ferrous and non ferrous metals were then removed from size fractions larger than 2 mm, after which size fractions greater than 4 mm were crushed using a jaw crusher to <4 mm for leaching study. After crushing, the four different size fractions were split using a sample splitter, and recombined accordingly to their original percentage into two samples (IBA-1 and IBA-2) for leaching. The detailed sampling and characterization procedures were presented in another parallel study (Sun et al., 2014).

2.2. Total trace element content

Total trace element content was investigated to evaluate the elemental composition of IBA-1 and IBA-2. Both samples were totally acid digested based on US EPA Method 3052. The digested solutions were then analyzed using Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) Thermo X-Series 2, and the final results are tabulated in Table 1. Elements such as Cd, Pb, Sb and Sn were present in higher content (by an order of magnitude) in IBA-2 sample while Mn and Mo were found to be significantly higher in IBA-1 sample.

Table 1
Total trace element content and total organic carbon (TOC) (mg/kg dry weight) of IBA-1 and IBA-2.

Element (mg/kg DM)	IBA-1	IBA-2
Ag	4.80	5.83
As	17.3	16.1
Cd	4.91	12.0
Co	22.5	24.8
Cr	209	197
Cu	1333	1070
Hg	0.63	0.40
Mn	1241	663
Mo	41.4	13.2
Ni	107	106
Pb	442	1385
Sb	92.8	127
Se	0.27	0.98
Sn	71.8	110
V	33.3	28.3
Zn	2668	2218
TOC	7280	6412

2.3. Leaching

Two leaching tests, batch (BS EN 12457-2) and column (CEN/TS 14405) were conducted using DI water and Singapore seawater (labeled as SG-SW with measured pH = 8.1) as the leachants. SG-SW was filtered with 0.45 μm membranes to remove any debris present before using it for leaching. For the batch leaching test, 90 g of IBA was added with 900 ml of leachant into 1 L HDPE leaching bottles to achieve L/S ratio of 10, and the bottles were rotated at 10 rpm for 24 h. For the column leaching test, the dimensions of the columns used were 5 cm in diameter and 30 cm in length. Seven consecutive leachate fractions were collected to cover a cumulative L/S ratio from 0.1 to 10 in accordance with the standard. Peristaltic pumps were used to deliver the leachants in an upflow direction at a rate of 12 ml/h.

After leaching, the leachates were filtered with 0.45 μm membranes using a vacuum pump. The pH was measured using DGi115-SC pH electrode connected to Mettler-Toledo G20 Compact Titrator. The leachates were then separated into two portions: the first portion was tested for DOC using Analytik Jena Multi N/C 2100/2100S (liquid module); the second portion was acidified with a few drops of concentrated nitric acid to pH < 2, and tested for As, Cd, Cr, Cu, Ni, Pb, Sb, Se and Zn using ICP-MS.

3. Results and discussion

3.1. pH profile

The pH profile as a function of L/S ratio for both incineration plants was compared with the pH of batch leaching (Fig. 1). Generally, the pH trend for the column test was similar for both DI water and seawater leachants. The initial pH for both leachants was 12.2 and 12.1 for IBA-1 (DI water) and IBA-2 (DI water) respectively, and 12.1 and 12.0 for IBA-1 (SW) and IBA-2 (SW) respectively. For the column test using seawater, the initial pH of ~12 seemed to be high. This is because based on CEN/TS 14405, the filled columns were saturated with leachants and left undisturbed for three days to equilibrate the system. Theoretically, with the high buffering capacity of the seawater, the initial pH after 3 days of equilibration should be lower than 12. This could indicate that the system using seawater may have oversaturated after three days. However,