JOURNAL OF ENVIRONMENTAL SCIENCES 36 (2015) 9–21

Available online at www.sciencedirect.com

ScienceDirect

www.journals.elsevier.com/journal-of-environmental-sciences

JOURNAL OF ENVIRONMENTAL SCIENCES

www.jesc.ac.cn

Distribution and leaching characteristics of trace elements in ashes as a function of different waste fuels and incineration technologies

*Naeem Saqib**, *Mattias Bäckström*

Department of Science and Technology, Man-Technology-Environment Research Centre, Örebro University, SE-701 82 Örebro, Sweden.
E-mail: naeem.saqib@oru.se

ARTICLE INFO

Article history:
Received 23 December 2014
Revised 17 March 2015
Accepted 20 March 2015
Available online 19 June 2015

Keywords:
Incineration residues
Leaching behavior
Biofuel incineration
Metal distribution
Waste incineration

ABSTRACT

Impact of waste fuels (virgin/waste wood, mixed biofuel (peat, bark, wood chips) industrial, household, mixed waste fuel) and incineration technologies on partitioning and leaching behavior of trace elements has been investigated. Study included 4 grate fired and 9 fluidized boilers. Results showed that mixed waste incineration mostly caused increased transfer of trace elements to fly ash; particularly Pb/Zn. Waste wood incineration showed higher transfer of Cr, As and Zn to fly ash as compared to virgin wood. The possible reasons could be high input of trace element in waste fuel/change in volatilization behavior due to addition of certain waste fractions. The concentration of Cd and Zn increased in fly ash with incineration temperature. Total concentration in ashes decreased in order of Zn > Cu > Pb > Cr > Sb > As > Mo. The concentration levels of trace elements were mostly higher in fluidized boilers fly ashes as compared to grate boilers (especially for biofuel incineration). It might be attributed to high combustion efficiency due to pre-treatment of waste in fluidized boilers. Leaching results indicated that water soluble forms of elements in ashes were low with few exceptions. Concentration levels in ash and ash matrix properties (association of elements on ash particles) are crucial parameters affecting leaching. Leached amounts of Pb, Zn and Cr in >50% of fly ashes exceeded regulatory limit for disposal. 87% of chlorine in fly ashes washed out with water at the liquid to solid ratio 10 indicating excessive presence of alkali metal chlorides/alkaline earths.

Introduction

Incineration is a rapidly growing technology for solid waste management in Sweden and all over the world (Swedish Waste Management, 2012). During 2006–2007, there were 2000 waste incineration plants in Asia, 460 in Europe (32 in Sweden) and 100 in North America (Huang et al., 2006; Sora, 2013; Swedish Waste Management, 2011). It is an efficient way to reduce volume and mass of solid waste. Resulting fly and bottom ashes can contain high concentrations of hazardous trace elements such as Cd, Pb, Zn, As, Cr, Cu and other harmful substances (Chang et al., 2009; Chou et al., 2009). If not properly managed, these can pose a serious threat to human health and environment by releasing trace elements into soil and ground water (Ito et al., 2006). The presence of trace elements, alkali metals, Cl and S in the waste is a challenge in waste incineration with respect to operational problems and environmental concerns. Therefore, improved knowledge and understanding about the formation of ashes, distribution of trace elements during incineration, and how

* *Corresponding author*. E-mail: naeem.saqib@oru.se (Naeem Saqib).

http://dx.doi.org/10.1016/j.jes.2015.03.006
1001-0742/

trace element partitioning responds to changes in waste composition, is important with respect to optimization of combustion process and plant efficiency.

It is crucial to understand the influential factors for partitioning of trace elements between bottom and fly ash. During incineration, high volatile elements are mostly found in flue gas or fly ash, partially volatile elements distribute equally or more to fly ash whereas low volatile elements mainly stay in bottom ash (Arena and Gregorio, 2013; Shi et al., 2004). Many studies have investigated the important factors affecting the trace element partitioning during incineration. Zhang et al. (2012) have studied the impact of temperature and moisture content on trace element partitioning to fly ash during municipal solid waste (MSW) incineration. They reported that Zn and Cu compounds transferred from chlorides to oxides with decrease in temperature and increase in moisture content while Pb and Cd distribution was not much affected by temperature. Ménard et al. (2006) studied thermodynamic behavior of trace elements during MSW incineration in grate boiler and reported that Cd volatilize as $CdCl_2$ (g) and that Pb is more volatile than Zn. Astrup et al. (2011) investigated the trace element distribution by adding individual waste fractions such as shoes, salt (NaCl), chromate-copper-arsenate impregnated wood and batteries in MSW and described that added waste materials significantly changed the emissions in fly ash particularly for As, Cd, Cr and Sb. Generally, the focus has been on MSW with varying amounts of industrial/commercial waste in conventional grate boilers (Chang et al., 2009; Morf et al., 2000). Limited work is reported about partitioning of trace elements during biofuel incineration such as virgin wood, waste wood or mixed waste fuels including peat, bark and wood chips (Pedersen et al., 2009; Wiinikka et al., 2013; Saqib and Bäckström, 2014). Since these waste fractions are part of waste fuel being used for heat production especially in Sweden and other European countries, therefore, it is imperative to evaluate the distribution behavior of trace elements during incineration of these materials in both types of combustion systems; grate fired and fluidized bed boilers.

Leaching characteristics of ashes provide useful information for selecting the appropriate management strategy and/or their possible reuse. Fly ash is of particular concern regarding environmental safety, recovery of resources and landfilling. Since trace elements are preferentially deposited on surface of fly ash particles and are readily available for leaching (due to high alkalinity and small ash particle size), it is therefore important to assess their mobility in fly ash (Van der Sloot et al., 2001; Shi et al., 2004).

Leaching tests are common to assess risk and select proper management and disposal strategies for residues (Buchholz and Landsberger, 2012). Leaching characteristics of Korean and Japanese municipal solid waste incinerator (MSWI) fly and bottom ashes indicated that leaching of Pb exceeded regulatory limit in ashes for both countries and leached concentrations of Zn and Cd were pH dependent (Shim et al., 2005). Previous studies have showed that the liquid to solid ratio (L/S), leaching reagents and speciation were the most significant factors affecting the release of Pb and Zn from air pollution control residues (APC), while leaching from fresh bottom ash is also influenced by several factors such as ash matrix, type and concentration of extractant, leachate's pH, L/S and chemical speciation (Kida et al., 1996; Wang et al., 2001; Zhang et al., 2006, 2008; Fedje et al., 2010). Usually MSWI ashes have been discussed with respect to trace element leachability and for reuse purposes (Yao et al., 2011; Quina et al., 2009). However; in many countries waste wood, bark, peat and virgin wood are part of waste fuels for incineration (Krook et al., 2004), therefore it is important to understand leaching behavior of trace elements from these types of ashes.

Today, the major part of fly ash from incinerators in Sweden is transported to Norway where it is used for neutralization of sulphuric acid products from paint production. The resulting slurry is disposed off in an old open pit near Langøya, Holmestrand, Norway (Swedish Waste Management, 2011). But this is not a permanent solution and domestic alternative strategies must be developed for ash management. Therefore, it is important to investigate the leaching behavior of residues as they might have potential to be considered for trace element recovery or any other secondary use.

Reuse of incineration ashes is often limited due to the presence of excessive chlorine content especially in fly ash. Average chloride content is more than 10 and 200 g/kg dry matter weight (dw) in MSWI bottom and fly ash, respectively. For instance, there is a limit of <1 g/kg dw on chloride content in fly ash for use in eco-cement production in Europe (Boghetich et al., 2005; Tokoro et al., 2013). Water washing of ashes prior to any other treatment is a common method for removal of major and trace elements. Wang et al. (2001) reported the removal of 65% Cl and 50% of major elements from MSWI fly ash through water extraction. Similarly, 95% Cl removal was reported with water from hazardous waste incineration fly ash in Finland (Kinnarinen et al., 2013).

Bottom ash, in particular, contains a significant amount of unburned organic matter. Total organic carbon (TOC) and dissolved organic carbon (DOC) contents must be kept low for possible reuse purpose. Belevi et al. (1992) mentioned DOC level of 200–800 mg/L in leachate from MSW bottom ash; while in another study it was reported to be in excess of 2000 mg/L (Brocca et al., 1997). According to European regulations, TOC and DOC must be lower than 5% and 0.5%, respectively, for waste to be landfilled (European Commission, 2003). DOC may also enhance mobility of pollutants from incineration residues when landfilled or used in constructions (Olsson et al., 2007). It has been observed that DOC facilitates the leaching of trace elements through complex formation especially for Cu, which is why it is important to evaluate DOC release from residues (Yao et al., 2011; Zhang et al., 2008).

The present study focuses on trace element partitioning during incineration between fly and bottom ash as a function of waste fuel (virgin wood, waste wood, mixed biofuel, industrial, household, mixed waste), incineration technology and combustion temperature as well as leaching characteristics of bottom and fly ashes.

1. Materials and methods

1.1. *Sampling and storage of ashes*

Fly and bottom ash from 13 Swedish waste incineration facilities, 4 equipped with grate fired, 6 circulating fluidized