Process Safety and Environmental Protection 98 (2015) 333–341

Contents lists available at ScienceDirect

Process Safety and Environmental Protection

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

The physiochemical properties and heavy metal pollution of fly ash from municipal solid waste incineration

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ARTICLE INFO

Article history:
Received 28 April 2015
Received in revised form 18 August 2015
Accepted 4 September 2015
Available online 18 September 2015

Keywords:
Fly ash
Characteristics
Heavy metals
Leaching toxicity

ABSTRACT

Fly ash originating from municipal solid waste incineration (MSWI) is potentially hazardous waste and is harmful to the surrounding area once it enters the environment. In this study, we measured the physiochemical properties of fly ash derived from domestic waste incineration as well as the leaching toxicity of heavy metals in fly ash was contained. The results suggested that the porosity of fly ash is relatively high, and the leaching concentration of heavy metals can be greatly reduced through densification strategies in which fly ash is stabilized by chemical agents. The adsorption–desorption curve of fly ash had an obvious hysteresis loop that belongs to the H2-type hysteresis loop. Fly ash was typically mesoporous, and the silicate in fly ash was relatively stable. Its glass phase contents were higher—this allowed it to be used in ceramic tile decoration. In addition, Pb and Cd were the major heavy metals in fly ash. These heavy metals were mainly distributed in the residue. Heavy metals were easily leached out under strong acid or alkaline conditions.

1. Introduction

There were 0.172 billion tons of municipal solid waste generated in China in 2013 (CSY, 2014). The capacity of harmless diposal was 0.154 billion tons. The harmless diposal rate was 50.8% in 2003, and rose to 89.3% in 2013. In the past ten years, the capacity for harmless diposal has increased markedly (Fig. 1) (CSY, 2014). This was most significant since 2006. The main processes for harmless diposal were sanitary landfill, incineration and compost. In recent years, incineration has been favored more than sanitary landfills because of limited land resources in China, especially in the first-tier cities. As shown in Fig. 2 (CSY, 2014), the amount of waste in sanitary landfills is still high, but has been gradually decreasing as incineration becomes more popular. The propotion of incineration was 4.9% in 2003 and 30.1% in 2013. In contrast, the use of sanitary landfill and composting has been decreasing. Hence, the incineration process has a huge space for additional development.

Municipal solid waste incineration (MSWI) is popular because of its superior performance at lowering the volume (~90%) of domestic waste while also generating heat. This can be recycled for electricity (Lin, 2006). However, secondary pollution can accompany incineration. The fly ash generated by the flu-gas cleaning system is a major carrier of secondary pollutants, and the production of fly ash accounts for 3–5% of waste from incineration. Therefore, fly ash is accepted as a hazardous material that has high amounts of heavy metals and dioxin (Quina et al., 2008). Many treatment methods of MSWI fly ash before disposal have been developed: cement solidification (Aubert et al., 2004, 2006; Lin et al., 2003), chemical reagent solidification (Quina et al., 2010; Bontempi et al.,

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http://dx.doi.org/10.1016/j.psep.2015.09.007

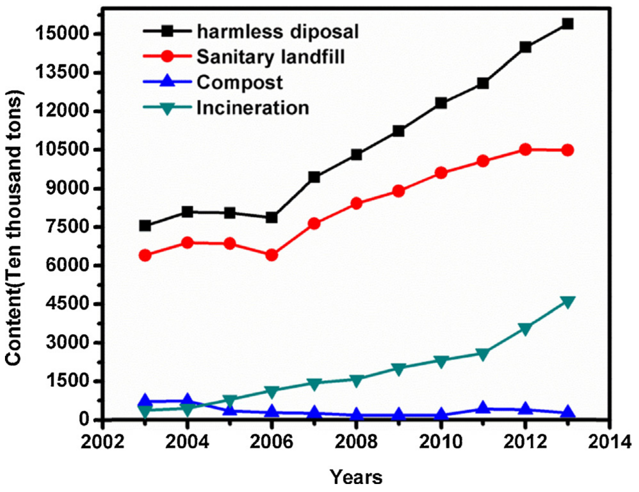

Fig. 1 – diposal capacity of MSW.

2010) and melting solidification (Monteiro et al., 2006; Sakai and Hiraoka, 2000; Ito, 1996).

In Taiwan, the characteristics of three incinerator bottom ash and fly ash was studied (Chang and Wey, 2006). They found that the characteristics and surface structures depend on the difference between the transportation and hybrid systems. The size of the fly ash directly affected its sintering character (Wang et al., 2001). It was found that the larger size fly ash has a lower compressive strength after sintering. The sintered fly ash had sufficient compressive strength to be considered a non-hazardous material when the sintering temperature is 600–800 °C and the grain size is 43–73 μm.

Aubert et al. (2006) analyzed physical, chemical, and mineral properties of two pre-treated MSWI fly ash samples that were applied to the composite concrete. They found that calcium–aluminum borosilicate was the main component of fly ash. This type of ash can is used as an additive for cinders and as a substitute for concrete in cement-based materials. Liu et al. (2009) suggested that the concentration of aluminum borosilicate increased with incineration temperature. Moreover, the leaching behaviors of heavy metals significantly affect the treatment and disposal of fly ash. The heavy metals in the fly ash could be released under acidic conditions, which threaten the quality of groundwater.

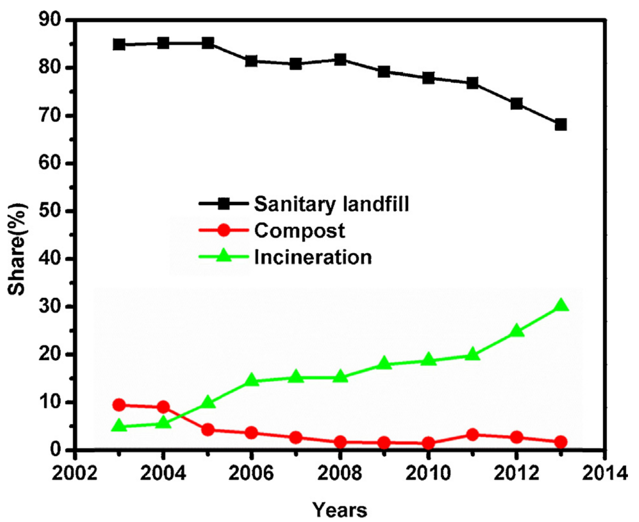

Fig. 2 – change of three treatment method.

TCLP(Toxicity Characteristic Leaching Procedure) (Kim et al., 1998), HVEP (Horizontal Vibration Extraction Procedure) (GB 5086.2-1997) (solid waste-extraction procedure for toxicity of solid waste in China, 1997), ALT (Available Leaching Toxicity), and SEP (Sequential Extraction Procedure) (Jin et al., 2013; Shi and Kan, 2009; Shim et al., 2005; Chou et al., 2009; Van Herck et al., 2000) were used to assess the leaching toxicity of heavy metals in fly ash. Lin and Chang (2006) studied the leaching characteristics of slag ash, and found that the leaching values of Pb and Cd exceeded the standard. Shim et al. (2005) discovered that the neutralizing capacity of fly ash from Japan was four-fold higher than that in South Korea. In addition, the leaching value of both ashes also exceeded the standard. At pH 6–9, the leaching amount of heavy metals was relatively small.

Thus, it is important to understand the leaching behavior of heavy metals on the treatment and disposal of fly ash. Herein, we studied fly ash morphology, specific area, elemental composition, and mineral ingredients. The leaching toxicity, specification, and leaching characteristic of the heavy metals were also determined.

2. Materials and methods

2.1. *Samples*

The fly ash in this study was sampled from a municipal solid waste incinerator in the Jinshan (Shanghai) MSWI plant that handles 800 t of solid waste per day.

2.2. *Physical characterization*

Scanning electron microscope (XL-30ESEM) was used to characterize the

morphology of the fly ash. The size distribution was examined by dynamic light scattering (DLS) on a Malvern Zetasizer (Ms3000h, Britain). Specific surface area was measured by adsorption–desorption of ultrapure N_2 on a Quantachrome Instruments system via Brunauer–Emmett–Teller (BET) method. The X-ray diffraction (XRD) patterns were obtained on an Advanced-D&X diffractometer with Cu-Kα radiation (40 kV, 40 mA). This employed a scan rate of 2°/min in the 2θ range of 0–90° to interpret the mineral composition of fly ash. Elemental composition was analyzed by Energy-dispersive X-ray spectroscopy (EDS, type INCA). The elemental concentrations and chemical ingredients of the fly ash were quantified with X-ray fluorescence (XRF, AXIOSmAX).

2.3. *Leaching toxicity of heavy metals*

Leaching toxicity analysis was performed according to TCLP and ALT standards. And the liquid to solid ratio (L/S) was 20:1 for the former and 100:1 for the later. Leaching results were analyzed by ICP (Inductively Coupled Plasma).

2.4. *Specification analysis of heavy metals and XRD analysis of residue after each step*

Sequential chemical extraction has always been used as a method to study the specification of heavy metals. In this research, the sequential chemical extraction was according to a five-step sequential extraction method (Tessier et al., 1979)