



Removal of carbon constituents from hospital solid waste incinerator fly ash by column flotation

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ABSTRACT

Hospital solid waste incinerator (HSWI) fly ash contains a large number of carbon constituents including powder activated carbon and unburned carbon, which are the major source of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) in fly ash. Therefore, the removal of carbon constituents could reduce PCDD/Fs in fly ash greatly. In this study, the effects of the main flotation parameters on the removal of carbon constituents were investigated, and the characteristics of the final product were evaluated. The results showed that loss on ignition (LOI) of fly ash increased from 11.1% to 31.6% during conditioning process. By optimizing the flotation parameters at slurry concentration 0.05 kg/l, kerosene dosage 12 kg/t, frother dosage 3 kg/t and air flow rate 0.06 m³/h, 92.7% of the carbon constituents were removed from the raw fly ash. Under these conditions, the froth product has LOI of 56.35% and calorific values of 12.5 MJ/kg, LOI in the tailings was below 5%, and the total toxic equivalent (TEQ) of PCDD/Fs decreased from 5.61 ng-TEQ/g in the raw fly ash to 1.47 ng-TEQ/g in the tailings. The results show that column flotation is a potential technology for simultaneous separation of carbon constituents and PCDD/Fs from HSWI fly ash.

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1. Introduction

Hospital solid waste is considered dangerous because it may possess infectious, radioactive and toxic substances and can cause undesirable effects on human health and environment (Sabiha et al., 2008). Incineration has become the main method for disposal of hospital solid waste in China since the nation-wide outbreak of severe acute respiratory syndrome (SARS) in 2003 (Zhao et al., 2010). It is estimated that currently there are over 300 centralized incinerators and the number is still increasing (Zhao et al., 2008). Although incineration can destroy pathogens and reduce the weight of waste by more than 70%, a large amount of hospital solid waste incinerator (HSWI) fly ash (3% of the original mass) has been generated (Bo et al., 2009). HSWI fly ash contains heavy metals and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), which is classified as hazardous wastes.

Recent reports have shown that the fly ash from HSWI is quite different from that from municipal solid waste incinerator (Bo et al., 2009; Yan et al., 2011). Firstly, hospital solid waste contain more chlorine-containing scrap plastics like polyvinyl chloride compared with municipal solid waste, therefore the HSWI fly ash

usually generally has a higher level of chloride and organic pollutants like PCDD/Fs (Wu et al., 2011). The total toxic equivalent (TEQ) values of PCDD/Fs in some HSWI fly ash exceeded 20 ng I-TEQ/g (Chen et al., 2008). In addition, a lot of powder activated carbon was sprayed into exhaust gas before entering a bag filter for absorption of PCDD/Fs from flue gases to meet much more strictly emission regulations of the hospital solid waste incineration (<0.05 ng I-TEQ/Nm³) (Chen et al., 2009). Yan et al. (2007) found that carbon content in some of HSWI fly ash reached the range of 11.40–91.0% due to activated carbon injection. Both injected powder activated carbon and unburned carbon in solid waste were identified as the main carbon sources of fly ash (Kakuta et al., 2007).

The characteristic of high chloride and carbon content in HSWI fly ash make the tradition processes such as cementation, melting which are effective for municipal solid waste incinerator fly ash be inefficient for HSWI fly ash. Cementation is the most popular and inexpensive method for stabilizing fly ash, but it is difficult to solidify a HSWI fly ash since chlorides and activated carbon hinder the hydration of cement and bring a decrease of compressive strength (Colangelo et al., 2012; Zheng et al., 2011). Melting can also provide an alternative because it can destroy PCDD/Fs at high temperatures and make various heavy metals inert through their incorporation into the glass matrix. This technique is also limited, however, because most chlorides are too volatile at high temperature over 1000 °C to be confined into the vitreous products, which

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causes secondary pollution (Jiang et al., 2009). Meanwhile, high carbon content in fly ash would accelerate the electrode erosion of plasma or arc melting furnace (Liu et al., 2011). Recent reports have found that the water washing pre-treatment for fly ash can reduce undesirable side effect from high chloride in fly ash (Jiang et al., 2009; Zheng et al., 2011; Huang et al., 2011). The appropriate water washing condition is washed twice in distilled water at a liquid-to-solid ratio of 10 or 20 for successful processing (Chiang and Hu, 2010; Liu et al., 2009). However, water washing pre-treatment cannot separate activated carbon from HSWI fly ash.

Researchers also reported that carbon constituent including powder activated carbon and unburned carbon is indicated as the major source of organic pollutants in fly ash due to the large adsorptive surface area and the role in denovo synthesis (Huang et al., 2003a). Therefore, it is necessary to explore a physical method to separate carbon constituent in HSWI fly ash. The modern flotation technology was introduced to mineral industries in early 18th centuries. At present, the flotation technique has been applied not only in the mineral industry, but also pulp mills, rubber, waste battery, and environment engineers (Naik et al., 2005). Column flotation is a sophisticated froth flotation technique, which has been developed as an alternative to the conventional, mechanically agitated flotation (Finch et al., 1995; Hasan and Hale, 2007). Column flotation is the most effective method of separating the carbonaceous material from coal ash (Altun et al., 2009). Atsushi et al. (2005) found that column flotation can clean up and reduce the PCDD/Fs-contaminated soil by removing selectively unburned carbon including a high PCDD/Fs concentration of incineration fly ash. Huang et al. (2007) successfully used column flotation to remove 64% of the unburned carbon, 41.9% of total PCDD/Fs and 40.8% of coplanar PCBs from MSW incinerator fly ash. These studies mostly pay attention to the removal of unburned carbon from MSW incinerator fly ash, few concern the fate and disposal of the final product after flotation.

HSWI fly ash contains high amount of soluble salts (NaCl, KCl, calcium compounds) which may influence electrostatic interaction between bubbles and particles, the flotation process and this effect should be taken into account (Chin and Somasundaran, 1993). However, the flotation process for treatment of HSWI fly ash with high chloride and carbon content has not been reported so far. The purpose of this paper is to remove carbon constituents of HSWI fly ash to reduce the organic pollutants like PCDD/Fs, and to determine the optimum flotation conditions by examining effects of some parameters such as slurry concentration, reagent dosage (collector and frother) and the air flow rate on the flotation performance. Furthermore, the characteristics of the final product at the optimum flotation conditions were determined.

2. Materials and methods

2.1. Materials

The fly ash sample used in the study was obtained from a 20 t/d gyration kiln incinerator of a HSW incineration center located in northern China. The air pollution control devices of the incinerator are composed of a water spray tower, a semi-dry scrubber, powder activated carbon sprayer device and a bag filter. The fresh, dry fly ash sample was collected from hopper of bag filter; therefore it

contains activated carbon which was injected into flue gas duct before the particle control process. The ash sample was collected over a 7-day period. It was homogenized and passed through a sieve of 20 meshes, and then being dried at 105 °C for 24 h for further analyses. The loss on ignition (LOI) was determined for the sample as the weight loss when sub-sample was kept at 600 ± 25 °C for 3 h in accordance with the standard for pollution control (GB18485-2001). Table 1 shows the chemical composition and LOI of the raw fly ash. The raw fly ash and powder activated carbon were divided into five size ranges by sieves. The weight distribution, LOI and carbon distribution in each fraction were analyzed. XRD analysis of the sample was conducted with a Rigaku Ultima IV diffractometer.

2.2. Methods

Column flotation experiments were carried out in a glass column of 30 mm in diameter and 950 mm in height, fitted with a fine porous glass sparger at the bottom. Compressed air was introduced into the column through a rotameter. In every run, a quantitative of fly ash and 600 ml of deionized water was stirred in a hybrid mixer for 5 min. After that, a collector (kerosene) and frother (methyl isobutyl carbinol) were added subsequently and conditioned for 5 min. The slurry was then transferred into the column. The required air flow rate was maintained by rotameter. The experiments were carried out by varying different operating parameters such as slurry concentration, kerosene dosage, frother dosage, and the air flow rate. Slurry concentration, collector dosage, frother dosage and air flow rate in the flotation process were set as range of 0.015–0.1 kg/l, 3–15 kg/t, 0.5–4 kg/t, and 0.04–0.08 m³/h separately with reference to preliminary experiments. One variable at a time was varied while keeping other variables at constant.

The two-stage flotation (rougher–scavenger flotation) process was applied in order to fully and efficiently remove the carbon from the HSWI fly ash, that is to say, the rougher tailing from the first flotation stage were re-fed into the column and the cleaning process was continued under the same experimental conditions. The combined froth from the two stages and tailings remaining in the flotation column were vacuum filtered, dried and weighed and then determining LOI of each product. Determination of calorific values of the froth samples was carried out using an IKA-C5000 calorimeter device. The scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) was employed to provide imaging information about the morphology and the composition of the raw fly ash and the final product by a FEI NANOSEM 430 apparatus.

In addition, to evaluate the effect of soluble salts on the ash characteristics during the slurry preparation process, the conditioned fly ash were analyzed and the conditioning process are slurry concentration 0.05 kg/l and conditioned time 10 min.

2.3. PCDD/F analysis

The sample pretreatment was conducted according to a modified version of US EPA Method 23 (2001). The following ¹³C₁₂ isotopically labeled internal standard solution were purchased from Cambridge Isotope Laboratory. A high-resolution gas chromatograph/

Table 1
Chemical composition and LOI of raw fly ash and conditioned fly ash%.

Sample	SiO ₂	CaO	Al ₂ O ₃	Fe ₂ O ₃	MgO	K ₂ O	Na ₂ O	SO ₃	Cl	P ₂ O ₅	TiO ₂	ZnO	F	LOI
Raw fly ash	17.13	24.42	2.85	1.78	1.8	2.8	15.2	6.37	20.43	1.06	1.34	0.63	2.59	11.1
Conditioned fly ash	30.42	38.87	5.16	2.83	3.34	1.39	0.16	5.82	3.56	1.28	2.50	0.98	1.21	31.6

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