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Distribution and leaching characteristics of heavy metals in a hazardous waste incinerator

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ABSTRACT

In this study, distribution and leaching characteristics of heavy metals (As, Cd, Cr, Cu, Pb, Se, Zn, and Hg) along flue gas cleaning systems were investigated in a hazardous waste incinerator located in Zhejiang, China. The particle size distribution, heavy metal loading, and morphological and mineralogical characteristics of solid incineration residues were assessed before and after acetic acid extraction. Results showed that Hg, Cd, As, Pb, and Zn were transmitted into the fly ash mainly by evaporation, condensation, and adsorption, while Se and Cr were mainly by entrainment. High chlorine availability in the industry hazardous waste favored the evaporation of Cu, Pb and Zn. Due to the mass ratio of the bottom slag in the incineration residues being more than 52%, most of Cu, Cr, As, and Zn remained in the bottom slag. Scarcely any Hg and less than 9.6% of Cd were found in the bottom slag. Cd was mainly retained in the fly ash and the absorbent solution of the wet flue gas desulfurization (WFGD) system while most of Pb was found in the fly ash. WFGD system had a high Hg removal efficiency and more than 74.7% of Hg was retained in the absorbent solution of WFGD system. The distinction in the distribution and migration characteristics of heavy metals between two continuous operating conditions was mainly due to the different physicochemical properties of wastes. The studied heavy metals in the bottom slag, with the exception of Zn, showed low leachability, with a leaching ratio below 2%. Cd and Zn presented the highest leachability, and over 56.2% of Cd and more than 39.5% of Zn in the fly ash were transferred into the leachate. For the each studied heavy metal, the leaching ratio in the bag filter ash was the highest.

1. Introduction

According to the statistics of the Ministry of Environmental Protection of China, the amount of industrial hazardous waste (IHW) in China has shown an increasing trend, and 53.47 million tons were produced in 2016 [1]. The impact of IHW on the environment and human health has raised more governmental and public concerns [2]. Incineration has become one of the most preferred disposal technology in China because it can effectively reduce the volume of waste by up to 90 percent and reduce its weight by 60–70 percent [2]. In addition, incineration decomposes hazardous materials such as flammable solvents and infectious hospital wastes [3]. And the energy can be recovered to generate heat or electricity [2]. The secondary pollution would be caused during hazardous waste incineration, such as toxic heavy metals released from hazardous waste incineration for their mobility, bioaccumulation, and bio-refractory properties [4–7]. Hence, the study of their speciation, concentration, distribution, accumulation conditions, and leaching characteristics in incineration byproducts is imperative for the evaluation and control of heavy metal pollution.

During the incineration process, heavy metals are released from IHW and go through the following processes: evaporation, chemical reaction, flue gas entrainment, nucleation and condensation, subsidence of particles on the furnace wall, particle collection in flue gas cleaning systems, and eventually discharged through exhaust gas [8,9]. The distribution of heavy metals during incineration is jointly influenced by the physicochemical properties of wastes and the incineration conditions [10–17]. Luan et al. [11,15] suggested that chlorine and sulfur contributed to the volatilization of heavy metals and metal chlorides and sulfides were prone to volatilize. Belevi et al. [17] conducted research on the factors determining the element behavior in municipal solid waste incinerators and suggested that Cr, Mn, Ni, and Ba were transferred to flue gas mainly by entrainment while Cu, Pb, Zn, As, Cd, and Hg were transferred to flue gas by evaporation. Jung et al. [13] found that a majority of Cd was volatilized into fly ash, while Pb, Zn, Cr, and Cu were mainly retained in bottom ash. Chiang and Terttaliisa et al. [18,19] suggested that As, Cd, Se, and Pb showed high enrichment in fly ash, while almost 90% of Cr was distributed in bottom ash. Previous researchers have also found that flue gas cleaning systems

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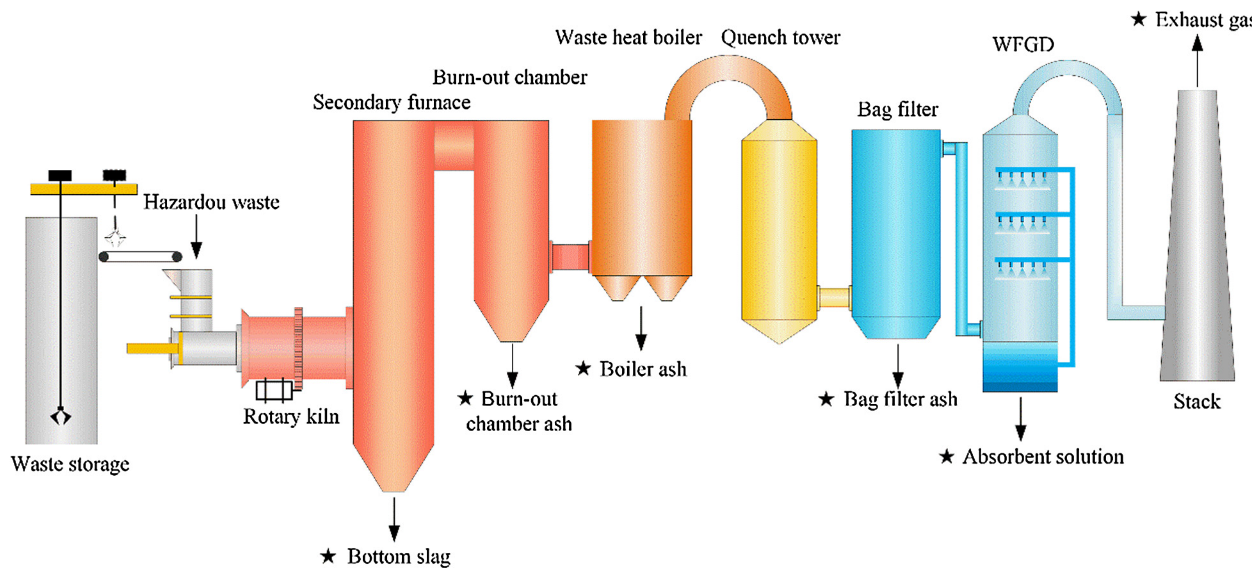

Fig. 1. The incineration system diagram and sampling points.

Table 1
The operating parameters of the incinerator during the sampling period.

	Outlet temperature of rotary kiln(°C)	Outlet temperature of secondary furnace(°C)	Outlet temperature of quench tower(°C)
C1	767 ± 42	1183 ± 72	166 ± 13
C2	753 ± 34	1168 ± 54	165 ± 11

Table 2
Proximate and ultimate analysis (dry air basis) of raw waste.

	C1	C2
Moisture (wt%)	3.52	3.42
Ash (wt%)	33.97	24.40
Volatile matter (wt%)	39.85	49.86
Fix carbon (wt%)	22.66	22.32
Low heating value (MJ/kg)	13.115	16.848
C (wt%)	38.71	27.87
H (wt%)	3.6	2.61
N (wt%)	5.69	3.31
S (wt%)	2.89	3.04
O (wt%)	11.62	35.35
Cl (wt%)	12.88	3.13
Ca (wt%)	0.74	3.15
Na (wt%)	16.30	4.72
Al (wt%)	0.83	2.49
Si (wt%)	0.57	0.69

influence the distribution of heavy metals in incineration byproducts and change their emission pathways [20–22]. The selective catalytic reduction (SCR) system can promote oxidation of elemental mercury and enhance the removal of oxidized mercury in a WFGD system [20–22]. In addition, an electrostatic precipitator (ESP) combined with bag filter (BF) have a high removal efficiency for particulate matter (PM) and can remove over 99% of particulate mercury [20,21].

Additionally, different extraction procedures that use water and chemical reagents have indicated that heavy metals in the incineration residues are prone to leach under landfill conditions, and thus cause potential harm to the environment [23–27]. Solidification-stabilization of incineration residue is indispensable for reducing the leaching of heavy metals from the incineration residues [28–30]. Previous studies on the distribution and leaching characteristics of heavy metals in flue gas cleaning systems of hazardous waste incinerators are not yet sufficient. Also, few studies investigating the influence of the physical and chemical characteristics of solid incineration byproducts on the distribution and leaching characteristics of heavy metals on the full-scale incinerators are available.

In this study, the distribution and leaching characteristics of heavy metals along flue gas cleaning systems in a hazardous waste incinerator that disposes IHW are investigated. The concentrations and mass distribution of heavy metals in incineration residues, absorbent solutions of the WFGD system, and exhaust gas were obtained under two continuous operating conditions. The morphological and mineralogical characteristics of incineration residues before and after acetic acid extraction using the standard toxicity characteristics leaching procedure (TCLP) [31] were investigated to analyze the relationship between the characteristics of solid incineration byproducts and the leaching characteristics of heavy metals. Information provided by this study on the distribution and leaching characteristics of heavy metals in a hazardous waste incinerator could contribute to a better understanding of the heavy metal abatement capacity of flue gas cleaning systems and the leaching characteristics of heavy metals in solid incineration residues.

2. Experiment

2.1. Plant description

Samples were collected from a hazardous waste incinerator located in Zhejiang, China. The IHW mainly consisted of pharmaceutical waste, waste active carbon, rectification residue, and organic waste liquid. The disposal capability of the incinerator is 100 tons per day. The furnace type of the incinerator is a rotary kiln combined with a secondary furnace and a burn-out chamber. Reducing atmosphere is adopted in the rotary kiln. The incinerator is equipped with selective non-catalytic reduction (SNCR) system to control NO_x. A quench tower (QT) is aimed to fast reduce the flue gas temperature to restrain the de novo synthesis of dioxins and furans. Activated carbon (AC) is added into the upstream flue of the bag filter to adsorb dioxins, furans and heavy metals. A bag filter (BF) was installed to capture the particles in the flue gas. A 20% (w/w) NaOH solution was used in the WFGD system as an absorbent solution and was applied to control acid gas, such as sulfur oxide and hydrogen chloride. The incineration system diagram and sampling points are illustrated in Fig. 1.

2.2. Sampling

Sampling was conducted during two continuous operating