Chemosphere 212 (2018) 200–208

Contents lists available at ScienceDirect

Chemosphere

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

Reducing polycyclic aromatic hydrocarbon and its mechanism by porous alumina bed material during medical waste incineration

Linbo Qin [a], Futang Xing [a, **], Bo Zhao [a], Wangsheng Chen [a], Jun Han [a, b, *]

[a] Hubei Key Laboratory for Efficient Utilization and Agglomeration of Metallurgic Mineral Resources, Wuhan University of Science and Technology, Wuhan, 430081, PR China
[b] Hubei Provincial Industrial Safety Engineering Technology Research Center, Wuhan University of Science and Technology, Wuhan, 430081, PR China

HIGHLIGHTS

- Porous alumina can effectively reduce PAH and MAH emission during medical waste incineration.
- Heat transmission, catalytic effect, and adsorption effect accounted for the reduction of PAH.
- Heat transmission, catalytic, and adsorption accounted for 22.8, 29.2 and 20.9% of PAH reduction.

ARTICLE INFO

Article history:
Received 12 February 2018
Received in revised form
24 July 2018
Accepted 18 August 2018
Available online 19 August 2018

Handling Editor: Chang-Ping Yu

Keywords:
PAH
Reduction
Porous alumina
Fluidized bed combustor
Combustion
Medical waste

ABSTRACT

In this paper, porous alumina was used as an alternative bed material to reduce polycyclic aromatic hydrocarbon (PAH) and monocyclic aromatic hydrocarbons (MAH) emission during medical waste incineration in a fluidized bed combustor (FBC). In order to understand the reduction mechanisms of MAH and PAH, porous alumina, nonporous alumina, and silica sand (180–250 μm and 250–320 μm) were used as the bed materials. In comparison to the silica sand (180–250 μm) bed material, the reduction efficiencies of ∑MAH, ∑PAH and ∑PAH toxic equivalent (TEQ) by porous alumina bed material were in sequence as 91.57%, 58.90% and 73.23% during medical waste incineration under 800 °C. There were three mechanisms for the reduction of PAH under porous alumina bed materials. Firstly, the evolution rate of hydrocarbon was reduced by porous alumina due to its low heat transfer coefficient. Secondly, porous alumina bed materials could absorb more gaseous hydrocarbon and prolong the residence time of hydrocarbon in the diluted zone of FBC due to its higher BET. Lastly, the oxidization of the gaseous hydrocarbon was accelerated by porous alumina due to its catalytic effect. Thus, less light hydrocarbon, MAH and PAH were formed during medical waste incineration. The experimental results also indicated that the heat transmission, catalytic effect, and adsorption effect of porous alumina bed materials respectively accounted for 22.8%, 29.2% and 20.9% of the ∑PAH reduction.

1. Introduction

Polycyclic aromatic hydrocarbons (PAH) are known as a group of environmental organic pollutants, which has received wide concerns due to their well-recognized carcinogenicity, teratogenicity and mutagenicity (Dat and Chang, 2017). Sixteen PAH, containing two to six carbon rings, have been classified as the priority pollutants by the Environmental Protection Agency in the United States (EPA-PAH) (Li et al., 2017), which can be found in Table S1. It was estimated that the global total annual emission of 16 PAH in 2007 was 530 000 tons. Among them, south Asia (87 000 tons), east Asia (111 000 tons), and southeast Asia (52 000 tons) were the regions with the highest PAH emission densities, contributing half of the global total PAH emissions (Shen et al., 2013). China was considered to contribute approximately 22% of the total global PAH emissions (Wang et al., 2015). PAH are mostly formed from the saturated hydrocarbons under the oxygen-deficient condition (Han et al., 2017a, 2018a, 2018b, 2018c; Qin et al., 2017). Municipal waste incinerators (MWIs) and coal-fired power plants are the major anthropogenic emission sources of PAH (Hsu et al., 2016), which accounts for approximately 62% of the anthropogenic PAH emission

* Corresponding author. Hubei Key Laboratory for Efficient Utilization and Agglomeration of Metallurgic Mineral Resources, Wuhan University of Science and Technology, Wuhan, 430081, PR China.
** Corresponding author.
E-mail addresses: Xingfutang@wust.edu.cn (F. Xing), hanjun@wust.edu.cn (J. Han).

https://doi.org/10.1016/j.chemosphere.2018.08.093
0045-6535/

(Peng et al., 2016). In order to minimize their environmental impact, World Health Organization (WHO) and many countries have prescribed the stringent PAH emission standards (Abdel-Shafy and Mansour, 2016).

At present, the main PAH control methods are plasma (Son, 2017), catalytic decomposition (Kamal et al., 2016), and adsorption (Lamichhane et al., 2016). Li et al. (2016) and Hsu et al. (2016) reported that the PAH removal efficiencies by plasma based on electrostatic precipitator (ESP) and wet electrostatic precipitator (WESP) were 5.45 and 83.5%, respectively. Calléna (Callén et al., 2007) stated that the plasma reduced the low-ring and middle-ring PAH, while increased the BaP_{eq} concentration of PAH due to promoting the high toxicity PAH formation. Catalytic decomposition technology has been successfully used to remove PCDD/Fs from flue gas in Japan, Europe Union and the USA (Kamal et al., 2016). Chen et al. (2018) reported that the removal efficiencies of aromatic hydrocarbons (benzene, o-xylene and chlorobenzene) by the prepared MnO_x-CeO_y catalyst were more than 90% at 240–280 °C. However, the catalytic decomposition was limited because the catalyst was easily poisoned by heavy metals and particulate matter in flue gas (Zhang et al., 2016). Zhou et al. (2005) found that PAH could be removed effectively from flue gas using induct activated carbon injection, and the removal efficiencies of PAH were about 76–91%. However, the activated carbon adsorption just transferred gas phase PAH from the solid phase PAH and increased the concentration of PAH in dust, which would cause the secondary pollution (Lamichhane et al., 2016).

Alumina was successfully used as a bed material to avoid the agglomeration in FBC(Mac an Bhaird et al., 2014; Qin et al., 2016a; Scala, 2018). Shimizu et al.(Winaya et al., 2007, 2008) also discovered that porous alumina could reduce the evolution rate of hydrocarbon and adsorb some hydrocarbons during plastic combustion in FBC, which resulted in the decrease of hydrocarbon emission. According to the PAH formation mechanism, pyrosynthesis and pyrolysis are two major mechanisms of forming PAH (Qin et al., 2015). Hence, hydrocarbons are one of the PAH precursors. Thus, the porous alumina bed material can also suppress PAH and soot formation during combustion process. Our previous studies also proved that the reduction efficiencies of PAH emission and PAH total toxic equivalent (TEQ) by porous alumina bed material during sewage sludge incineration under 850 °C were 52.0 and 97.7%, respectively (Qin et al., 2016b). However, the PAH reduction mechanisms by porous alumina bed materials were still not clearly understood.

In order to discover the mechanism of reducing PAH, the comparisons of PAH emission from medical waste incineration under porous alumina, alumina and silica sand bed material were conducted in a fluidized bed reactor. Moreover, the effects of adsorption, catalysis, and heat transmission of the bed materials on the reduction of PAH were separately investigated.

2. Materials and methods

2.1. Raw materials

2.1.1. Medical waste samples

The typical medical waste is sampled from a hospital in Wuhan city, China. The typical medical waste is composed of plastic infusion bag and infusion set. The mass ratio between plastic infusion bag and infusion set is 1:1. After washing, dry, cutting to 0.5–1.0 mm and mixing, the typical medical waste is prepared. An elemental analyzer (Vario EL III, Elementar Comp., German) is used to determine the carbon, hydrogen, sulfur and nitrogen contents of samples. The chlorine content is analyzed according to the standard CJ/T 96-2013. Proximate analysis is obtained according to standard GB/T212-2008. The ash contents are calculated as the weight loss ratio after combustion at 815 ± 10 °C. The volatile matter content is calculated by the weight loss ratio subtracting the moisture content from the initial weight at 900 ± 10 °C under dry N_2 atmosphere. The fixed carbon content is defined as the difference. The ultimate analysis and proximate analysis of the medical waste is summarized in Table 1.

2.1.2. Bed materials

In order to separately discover the effect of heat transmission, catalysis, and adsorption of porous alumina bed materials on the PAH formation, porous alumina (400–500 μm), nonporous alumina (250–300 μm) and the silica sand with different size (180–250 μm and 250–320 μm) were selected and used as the bed materials. The critical fluidization velocities of the porous alumina, nonporous alumina, silica sand (180–250 μm), and silica sand (250–320 μm) were in the sequence as 0.063, 0.061, 0.062, and 0.096 m/s, as shown in Fig. S1.

The specific surface area and pore size distribution of the bed materials were measured by nitrogen adsorption isotherms at 77 K on an automated adsorption analyzer (Micromeritics ASAP 2020, Norcross, GA) and calculated by the Brunauere Emmette Teller (BET) and Barrette Joinere Halenda (BJH) methods. The true density and apparent density were determined according to GB/T 23561.02-2009 and GB/T 23561.03–2009. The particle diameter distributions of the bed materials were analyzed by a laser particle size analyzer (Winner 2308, China). Meanwhile, the heat-transfer coefficients of the bed materials were also measured according to the method reported by Franke et al. (2001). The density, diameter distribution, BET surface area and heat-transfer coefficients of the bed materials were listed in Table 2.

2.2. Apparatus and procedure

2.2.1. MFBR experiment

In order to obtain the formation rate of the gas species under different bed materials during medical pyrolysis/incineration process, the pyrolysis/incineration experiments were conducted in a micro fluidized bed reactor (MFBR). Fig. S2 showed the diagram of MFBR, which consisted of a fuel sample feeding system, a fluidized bed reactor with 20 mm of inner diameter and an effluent gas cleaning and measuring system. The silica sand, nonporous alumina and porous alumina were separately used as the fluidization medium particles. The fuel sample was injected into MFBR by an electromagnetic valve that released about 10 mL gas per single pulse. The reactor of MFBR was consisted of two stages separated with a porous silica plate, a lower stage was used to receive fuel at the determined temperatures, and an upper stage was used to catch the fine particles escaping from the lower stage. The effluent gas was cleaned by a micro-filter and in turn measured using an online mass spectrometer (MS) (AMETEK, American). A computer was

Table 1
Proximate and Ultimate analysis of medical waste.

Proximate analyses/wt.% (air-dried)				Ultimate analyses/wt.% (dry ash-free)					Lower Heating Value (MJ kg^{-1})
Moisture	Ash	Volatile	Fixed carbon	Carbon	Hydrogen	Nitrogen	Sulphur	Chlorine	
0.32	–	99.13	0.55	81.81	5.684	0.15	0.11	0.076	42.65