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Research Paper

Enhanced combustion efficiency and reduced pollutant emission in a fluidized bed combustor by using porous alumina bed materials

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HIGHLIGHTS

- The fluidization of porous alumina is better than that of nonporous bed materials.
- The porous bed material has a positive effect on suppressing NO formation.
- The porous bed materials can capture parts of hydrocarbon.
- The porous bed materials can promote the combustion efficiency of fuel.

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ABSTRACT

Experimental comparisons of polypropylene combustion in porous and nonporous alumina bed materials were conducted in a semi-pilot scale fluidized bed combustor (FBC). The results indicate that polypropylene can be effectively used as a fuel in both bed materials. The combustion efficiencies of polypropylene in porous alumina (PA) and nonporous alumina (NA) are above 99.3%, and CO concentrations in flue gas are below 343 ppm. During polypropylene combustion, no obvious flame is observed in PA, which implies the combustion temperature is low. Hence, NO formation can be suppressed. Further, PA has the capacitance effect, which can capture or absorb some combustible hydrocarbons or melted polypropylene in the micropore of PA and causes lower CO emission and high temperatures in PA. Thus, the temperature of the freeboard zone is significantly decreased in PA. In the case of NA, the temperature in the freeboard zone seems to be independent of the height. The influence of temperature on polypropylene combustion in PA is also investigated, the experimental results demonstrate that the combustion efficiency is above 99.9% when the temperature is above 750 °C.

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1. Introduction

Plastic is widely used in packaging, numerous automotive applications, and vehicle equipments. The total worldwide consumption of plastics has increased sharply from 1.5 million tons in 1950 to 297.5 million tons in 2015 with the average growth rate of 5–6% [1,2]. With the increase consumption of plastic, there has been an increasing concern about the growing volume of plastic wastes, which results in a series of problems, such as environmental pollution and resource wasting [3]. Thus, the disposal of enormous amounts of plastic waste has received wide attention. At present, the primary disposal methods include landfill, recycled/reused, and incineration [4–6]. Landfill is becoming unfeasible because of the rapid depletion of available sites and the secondary pollution [7]. Recycled/reused is an effective way of treating plastic wastes, which

is considered cleaner and more sustainable, by reducing the quantity of discharges of waste stream and offering a potential way of replacing virgin feedstock in plastic production [8,9]. However, even today only minor amounts of the plastic wastes are recycled [10]. For example, in Europe, including the EU-27 countries, Norway and Switzerland, the collected post-consumer waste reached 25.2 Mt in 2012 but only 6.6 Mt (26.3%) was mechanically recycled [11]. In China, only 20–25% of the plastic waste was recycled in recent years [12]. Incineration has attracted more and more attention because of its energy utilization, reducing the volume and mass of plastic waste [13]. Traditionally, due to the acceptable rate of plastic waste generation, incineration is the optimum approach for post-consumer plastic treatment [7]. However, the emissions of HCl, NO_x, CO, PAHs and dioxin from plastic waste incineration have raised environmental concerns due to the incomplete combustion of plastic waste [14].

A great amount of studies about the incineration behavior of plastics has been reported. Chen et al. [13] and Valavanidis et al. [15] found that the combustion of various plastic materials produced a

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Table 1
Proximate and element analysis of polypropylene.

	Heating value (kJ/kg)	Proximate analysis (Wt%)			Elemental analysis (Wt%, daf)				
		Moisture	V.M.	Ash	C	H	N	S	O*
Polypropylene	47,508	0	100.0	0	84.6	13.8	0	0	1.6

* O content is obtained by difference method.

series of toxic compounds including volatile, semivolatiles, organic PAHs and toxic metals. Wang et al. [16] also reported that the primary pollutants from the batch combustion of three major waste plastics (polyethylene, polystyrene, and polyvinylchloride) were CO, light aliphatic hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), and particulates. To suppress the emission of unburned hydrocarbons, PAHs and CO, Franke et al. [17,18] successfully employed porous alumina sand as the bed materials instead of the conventional silica sand. Shimizu et al. [19] also proved that porous alumina can adsorb some hydrocarbon during plastic combustion in a fluidized bed combustor. However, their studies were carried out in a small-scale fluidized bed combustor without a freeboard region.

In this paper, a semi-pilot scale fluidized bed combustor (FBC) was used to compare combustion of polypropylene in porous alumina (PA) and nonporous alumina (NA) bed materials. In addition, the combustion temperature and CO, CO₂, O₂ and NO_x concentration along the vertical and horizontal directions of the FBC are monitored to understand the mechanisms of suppressing forming pollutants by PA.

2. Experimental techniques and procedure

2.1. Fuel characteristics

In this study, polypropylene was used as the fuel. Granulated polypropylene with an average diameter of about 2 mm was obtained from Idemitsu Kosan Co. Ltd. (Japan). The proximate and elemental analyses of polypropylene were summarized in Table 1.

2.2. Experimental apparatus and procedures

A schematic diagram of the semi-pilot fluidized bed combustor (FBC) was presented in Fig. 1. The cross section of the FBC was rectangular, with a length of 0.52 m and a width of 0.12 m. The height of FBC was 1.7 m. The FBC was electrically heated. Temperatures of bed materials were measured by thermocouples placed 10 cm above the air distributor. To measure temperatures in the vertical direction of the FBC, thermocouples were also installed in four holes at the upper surface of the combustor. A variable-speed screw feeder was connected to the combustor by a pipe, which was cooled by water to suppress decomposition of PP. The pipe was located at a height of 40 cm above the air distributor. The angle between the pipe and the horizontal direction was about 60°. The falling point of fuel was about 33 cm from the feeder side wall.

An external cyclone located at the exit of the combustor was used to separate particulate matter from flue gas. A gas analyzer (Horiba PG-250, Horiba Corp., Japan) was used to record the concentrations of O₂, CO, CO₂ and NO_x in the exhaust gases. Concentrations of O₂, CO, and CO₂ in the freeboard region were monitored by Shimadzu gas analyzers (Shimadzu Corp., Japan). CH₄, C₂H_x, C₃H_x, and C₆H₆ were monitored by FID detector of GC (Shimadzu Corp., Japan). A U-tube manometer was used to measure the pressure drop.

In the experiments, PA and NA with the similar minimal fluidized velocity were used as bed materials. The detailed properties of NA and PA were listed in Table 2. Before each experiment, bed materials were fed into the chamber to a bed height of about 15 cm. Then electrical heaters heated the chamber to the ignition temper-

ature of polypropylene. After the predetermined temperature was reached, the heaters were turned off. Air was fed to the chamber via four high-precision digital mass flowmeters. Meanwhile, polypropylene pellets were continuously fed to FBC by a screw conveyor. When the temperatures of the bed material and the concentration of O₂ were stable, the temperatures and O₂, CO, CO₂, NO_x, and SO₂ concentrations were recorded. For each test run, the sampling time was about ten minutes.

3. Results and discussion

Fig. 2 showed the bed material temperature as a function of time. The thermocouple was located at 10 cm above the air distributor. In the horizontal direction, one was located at 12 cm from the feeder, another was 38 cm from the feeder. Fig. 2 indicated that, in the NA bed, there was an evident temperature gradient in the horizontal direction. The bed temperatures at 12 and 38 cm from the feeder were 728 °C and 657 °C, respectively. In the PA bed, these temperatures increased to 747 °C and 768 °C. In this run, the temperature of bed material for NA was lower than that of PA. In order to compare polypropylene combustion in the two bed materials, the reaction temperature should be similar. Hence, more fuel should be fed for NA. The fuel feed rates for the NA and PA were 19 and 15 g/min (as

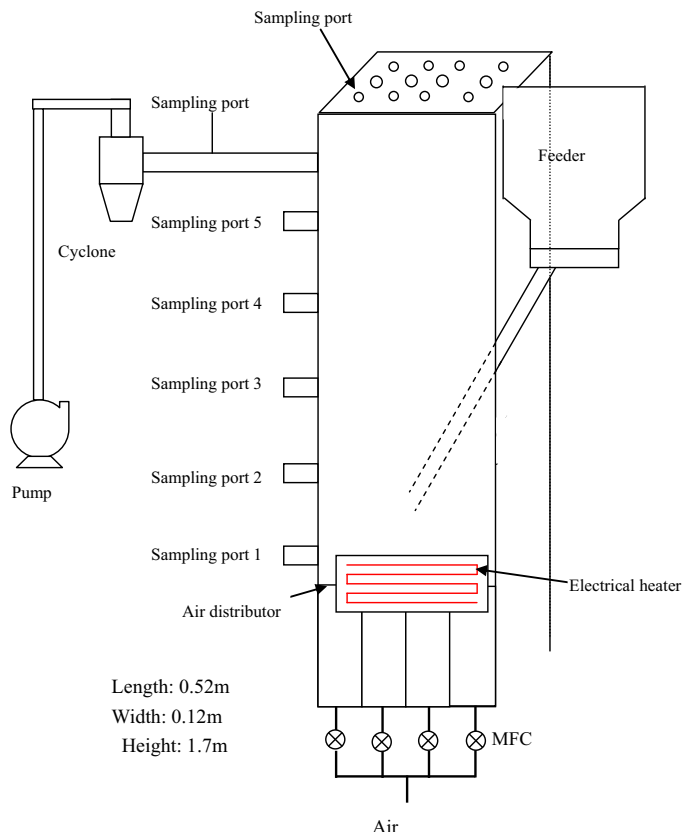


Fig. 1. Schematic diagram of the fluidized bed combustor.

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