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Mixing behavior of binary and multi-component mixtures of particles in waste fluidized beds

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ABSTRACT

A transparent waste fluidized bed cold model (cross section of 0.2 m × 0.2 m and height of 2.0 m) was established. 9 kinds of non-spherical particles (NSP) were selected to represent municipal solid wastes, and silica sand was used as fluidization medium (FM). Binary-component (FM and single kind of NSP) and multi-components (FM and two/or more kinds of NSP) particulate systems were formed. Mixing behaviors in these systems were described by a self-defined mixing index M, and assisted with flow patterns. The effects of fluidization number N defined as the ratio between the gas superficial velocity to the minimum fluidization velocity, properties of NSP such as density, shape and size, and mixing time on the mixing behaviors were experimentally studied. It is found that a dynamic stabilization of mixing could be achieved when the fluidization number N > 1 and the mixing time t > 12 s. The density of NSP has a more significant influence on the mixing behavior than particle size and shape. In a multi-components particulate system, well mixing could be found when the density of NSP gets close to that of fluidization medium.

1. Introduction

The world has been undergoing an increase in both economy and population over the past decades, which is also linked to an enormous growth in waste generation [1]. Management of municipal solid waste (MSW) is one of the major issues globally. Generally speaking, MSW is a multi-component mixture including fiber (referred to as paper and biomass), plastics, metals and so on [2]. Pre-treatment processes of MSW usually remove waste with low calorific value (such as food waste, yard trimmings, rubber, leather, textiles and so on) and then shredded for the production of fuels. The resulting waste stream is mainly composed of combustible materials (plastic, fiber, wood and others) and small amounts of non-combustible materials (glass, metals, sand and others) [3].

Fluidized bed technology is widely adopted in fields such as chemical, mineral, petroleum, pharmaceutical, and biochemical industries. However, due to its high specific surface area of the solids and the adjustability of fuels, fluidized bed reactor is also regarded as an effective method for MSW thermo-chemical applications, i.e. gasification, pyrolysis, and direction combustion in the recent years [4–7]. Previous researchers have published a large number of papers on fluidized bed thermo-chemical processing, mainly for coal and biomass. Their studies are mainly focused on process characteristics such as bed pressure drop [8–11], bed height and material property [12–14], minimum fluidization velocity [12–17] and other accompanying aspects related to binary mixtures in this gas–solid system. However, in fluidized beds, the mixing quality of particles influences the rates of heat and mass transfer, and enables to control the final conversion of chemical reactions in the system [18]. Proper mixing of particles is pivotal in ensuring the uniformity of chemical reactions and the distribution of particles, which also prevents the formation of hot spots in a reactor [19].

The studies of mixing/segregation behavior are mainly on binary mixtures formed with ball-sharp particle and bed material, trying to quantify the solids mixing rate for small fluidized beds [19],the time and space distribution of particles of different densities [20], the segregation degree as a function of size ratio between particles and bed material [21]. These studies indicate that particle characteristics such as density, sharp and sizes should be major factors affecting the mixing process [22–25].

The fuels used in waste fluidized beds are usually multi-component mixtures. As mentioned above, Pre-treated municipal solid waste contains various non-spherical particles, mainly composed of plastic, fiber, wood and small amounts of non-combustible materials [3]. Such fuels often have large differences in particle density, shape and size, which makes it difficult to describe the characteristics of gas-solid flow, as well as the mixing behavior, within a waste fluidized bed. Indeed, to

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date, little quantitative information is available about particles mixing in waste fluidized beds. This paper presents an experimental study to overcome this problem. Following the previous studies [1–3], five kinds of wood particles, three kinds of plastic particles were employed to represent common combustible solid waste. Meanwhile, metal particle was also used to represent the small amount of non-combustible materials. A number of well-designed experiments were carried out in a square cold-flow gas solid fluidized bed to investigate the mixing behavior of waste particles and bed material under different operating conditions. The effects of particle characteristics were quantified in order to generate some useful information for the design and control of waste fluidized beds.

2. Experimental system

2.1. Fluidized bed setup

The main body of the experimental system is a rectangular cube made with transparent Plexiglas (cross section: 0.2 m × 0.2 m, height: 2.0 m), which enables visual observation and helps to record the flow pattern. 66 spout nozzles are well-distributed at the bottom plate of the fluidized bed. A Roots-type blower supplies fluidizing gas into the bed from the bottom. There are also nine pressure taps located on the side wall to measure the pressure drops through the bed space. Besides, a dedicated photography system is set in front of the fluidized bed to record the flow patterns and particle behavior under different operating conditions. A schematic representation of the experimental system is shown in Fig. 1, with further details reported in our previous work [26].

2.2. Particle characteristics

Silica sand is selected as the fluidization medium in this study. Because of its good thermal conductivity and stability, silica sand has been commonly used as the fluidization medium (bed material), especially for those operations involving particles of different densities. Nine kinds of solid particles are adopted as testing materials. The selection of these testing materials (wood, plastic and metal) is on the basis of actual municipal solid waste [3]. The properties of these particles are given in Table 1. The formulae used to determine the particle sphericity is:

$$\phi = \frac{S_v}{S_p} = \frac{\pi(6V_p/\pi)^{2/3}}{S_p}$$

According to the particle characteristics, three groups of experiments are designed, which respectively focus on the density, shape and size differences of waste particles, as shown in Fig. 2.

2.3. Experimental procedure

The experiments were carried out at atmospheric pressure and room temperature. Particles were completely segregated from the bed materials at the initial state. During the experiments, particles/particles mixtures and bed materials with different percentages were laid as laminations into the bed, and the tests were operated and recorded under different technical parameters. Once the fluidization process was well developed and reached dynamic stability at a pre-set superficial gas velocity U, the gas supply was cut, and the bed collapsed and formed a "frozen", packed bed. The bed was divided into four layers and the particles were taken out layer by layer. Different kinds of particles in a layer were then sorted and weighed, as shown in Fig. 1. The data were used to determine the axial distribution of each kind of particles in the bed. Experiments were repeated several times to reduce errors and produce meaningful results.

In this work, the length of particles (wood stick W3) is 3 cm, and the static bed height used is 20 cm. For most of the particles, the probability for a particle to lie between two layers is small. However, long particles such as W2 and W3 may occupy more than one layer, the centre of gravity of such a particle was considered as a key factor. Besides, in our previous study [26], the influence of bed height was carefully studied. The fluidization process was not affected by the change of static bed height.

The minimum fluidization velocity U_{mf} of each of particle mixtures was calculated based on the measured pressure drop, according to the method in our previous work [26]. The fluidization number N ($=U/U_{mf}$) was used in the analysis.

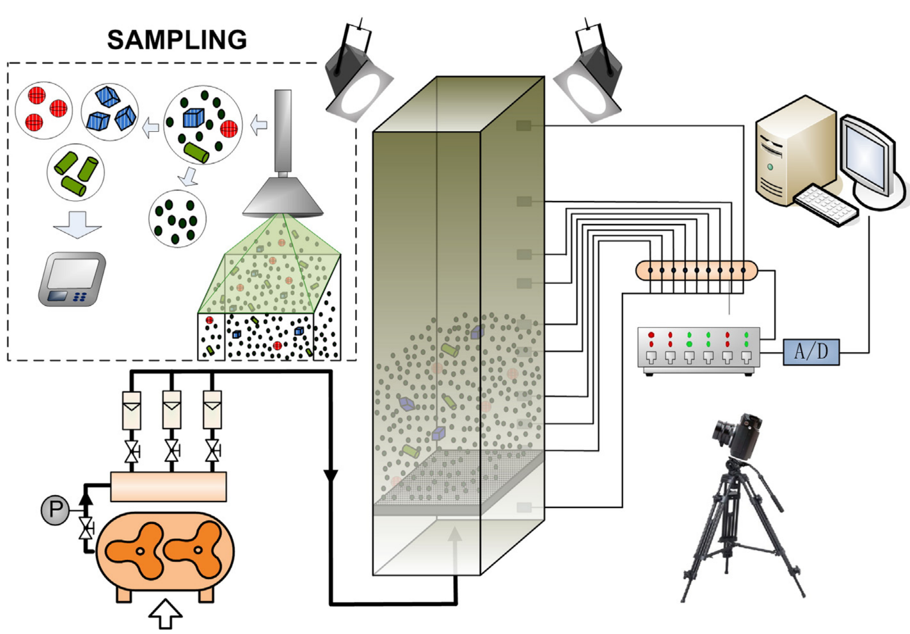

Fig. 1. Experimental setup.