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De-mixing characteristics of fine coal in an air dense medium fluidized bed

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ABSTRACT

An air dense medium (magnetite) fluidized bed (ADMFB) provides an alternative method for dry coal beneficiation. The de-mixing (segregation) characteristics can significantly affect the quality of the final products. In this study, the segregation characteristics of fine coal (1–3 mm) in an ADMFB were compared to those in an ordinary fluidized bed (FB). Specifically, the pressure drop, density-segregation behaviors, segregation degree, motions of the coal/magnetite mixture, and bubble size were determined with various gas velocities. Density-segregation occurred at a low gas velocity in the ADMFB. However, the particles started to mix when the gas velocity was increased. There was an optimum gas velocity to produce the maximum amount of segregation. The comparative analysis (ash segregation degree and bubble size characteristics) between ADMFB and FB suggested that the bubble-drive flotsam-jetsam mechanism can explain the particle segregation. Furthermore, adding dense medium to a fluidized bed led to a higher amount of segregation because of the reduction in bubble size.

1. Introduction

Coal is one of the most abundant raw materials for electricity generation and industrial production in the world (Jangam et al., 2011). In China, coal consumption has exceeded 3.9 billion tons per year, which accounts for more than half of the total consumption worldwide (Wang et al., 2014). However, direct combustion of coal not only reduces the power generation efficiency but also generates a significant amount of air pollution (Azimi et al., 2013b; Katalambula and Gupta, 2009). According to recent studies (Querol et al., 2008; Swaine, 2000), the emitted particulate materials ($PM_{2.5}$), toxic gases (SO_x and NO_x) and trace elements from coal combustion are most likely the primary reason for the widespread fog and haze, which leads to serious human health problems. Thus, clean coal processes have been introduced to utilize coal. Coal beneficiation is one potential clean coal process because it can economically remove a majority of the harmful minerals prior to combustion (Macpherson et al., 2011; Sampaio et al., 2008; Zhang et al., 2011). Burning pre-treated clean coals also provides additional advantages, such as decreasing the cost of flue gas treatment, enhancing coal use efficiency and reducing environmental pollution (Azimi et al., 2013b).

Due to the lack of water in mining areas, dry coal beneficiation without the use of water is preferred compared to conventional wet beneficiation methods (Noble and Luttrell, 2015; Prusti et al., 2015). For dry beneficiation, air dense medium fluidize beds (ADMFBs) are receiving increasing attention due to their high separation efficiency (Luo et al., 2008; Sahan and Kozanoglu, 1997; Sahu et al., 2011; Zhao et al., 2014; Zhao et al., 2010). The tendency of coal/magnetite mixtures to separate largely determines the overall separation efficiency (Sahu et al., 2015); thus, detailed segregation characterization is one of the key areas of fluidization research.

To characterize the segregation, a numbers of studies have been performed: (I) Various groups observed "size

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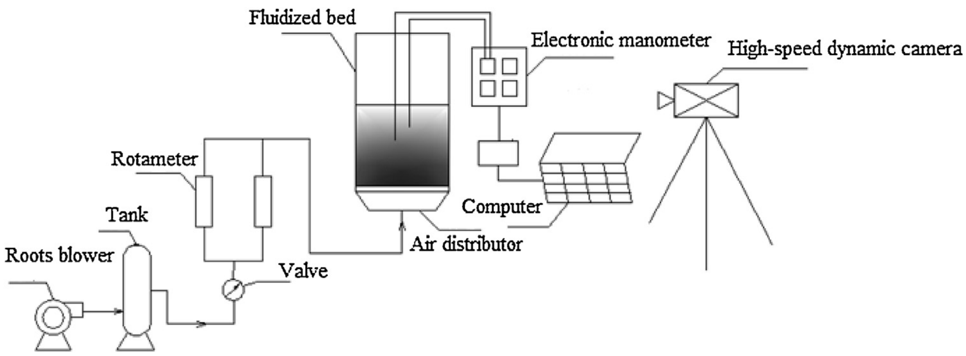

Fig. 1 – Schematic diagram of the experimental apparatus.

segregation", "density segregation", and "combined size/density segregation" (Dahl and Hrenya, 2005; Formisani et al., 2008; Olivieri et al., 2004). Nienow et al. (1978) firstly examined the segregation behavior of nearly 40 binary mixtures. These researchers concluded that for a binary mixture, smaller/denser particles acting as flotsam rise to the upper layer while coarser/denser particles serving as jetsam sink to the bottom layer. However, layer inversion may occur under certain limited conditions involving small, dense particles and coarse particles that are less dense (Di Maio et al., 2013). (II) Several parameters (such as the gas velocity, particle size and density, mass or volume fraction, and bed aspect ratio) that affect the segregation patterns were identified in several binary mixtures (Rao et al., 2011). (III) Based on these parameters and phenomena, Rasul et al. (1999) mapped out a profile that can delineate mixing/segregating regions. Joseph et al. (2007) further obtained an extensive set of concentration profiles for binary mixtures. (IV) Several models were developed to predict mixing/segregating behaviors. Gibilaro and Rowe (1974) proposed a comprehensive 1-D differential model to predict the ultimate mixing/segregating state of binary particles. However, the evaluation of parameters was rather difficult to obtain. Next, Chiba et al. (1980) developed a simple model in which the density and size ratios were combined with the minimum fluidization velocity. Recently, Di Maio et al. (2012) performed a few specific experiments and developed a PSM (Particle Segregation Model) to quantify the mixing/segregating tendency in binary mixtures. (V) Zhang et al. (2009) experimentally studied the mixing/segregation behavior of biomass particles in a fluidized bed. These researchers suggested that several underlying mechanisms (e.g., percolation, buoyancy, and bubbling) cause particle segregation although there was no general consensus on what those mechanisms are.

Compared with conventional binary mixtures, current coal/magnetite mixtures are complicated because the coal is composed of multi-component (i.e. clean coals, middings, and gangues) irregular particles (Liu et al., 2008). It could be reasonable to predict that the segregation behaviors in coal/magnetite mixtures are distinct from those of binary mixtures. To date, knowledge of the detailed segregation characteristics of coal/magnetite mixtures is still lacking.

For this study, the segregation characteristics of ADMFB, including the density-segregation tendency and segregation profiles at various air velocities, were studied. In this study, the segregation characteristics of an ordinary fluidized bed (FB) without magnetite are provided for comparison. In addition, the segregation mechanisms are discussed based on bubble size characterizations.

2. Experimental

2.1. Experimental setup

A schematic of the experimental system is given in Fig. 1. Compressed air from a blower entered the bottom of the column and passed through the distributor plate; the flow rate was regulated by a valve and measured with a rotameter. The fluidizing bed was made of Plexiglas with a diameter of 110 mm and a height of 300 mm. The pressure drops across the column were measured with an electronic manometer. The dynamic bed snapshots were recorded by an Olympus i-speed 3 video camera.

2.2. Experimental procedure

Magnetic powder with a density of 4600 kg/m^3 and an average diameter size of 232 μm was selected as the heavy medium. Coal particles with sizes between 1 and 3 mm were used in this study. Then, the float-sink experiment was conducted according to Chinese standard procedures (GB/T478-2008). The detailed properties are given in Table 1. Based on the results of first two columns, the results of two columns (±0.1 specific gravity distribution) were obtained. As observed, the density fraction of the coals mainly ranged from 1.3 to 2.0 (kg L^{-1}). Among them, the density fraction between 1.3 and 1.4 (kg L^{-1}) was the main float-component (60.64 wt.%) and had the lowest ash content values (8.47%). This result suggests that most of the coals were low-ash samples. Conversely, the density fraction between 1.8 and 2.0 (kg L^{-1}) constituted the major sink-component (3.35 wt.%) and had higher ash contents (50.49%), which indicated that only a few of the coals were gangue. Furthermore, the product of near-density material ($\delta \pm 0.1$) decreased with the mean density (δ), which suggested that this type of coal was easy to separate based on density.

During the separation experiments, the coal to magnetite ratio of the mixture 4:1 by volume based on the aerated bed density. After the mixture was fluidized for a certain length of time, the fluidizing air was cut off suddenly. The static bed with, which had a height of 70 mm, was divided into five layers that were each 14 mm tall measured by a ruler. Then, these particles were discharged layer by layer using a scoop from top to bottom. The top two layers and bottom two layers were considered to be clean coals and gangue, respectively. The other layer was the considered to be the middings. Subsequently, the ash analysis was conducted according to Chinese standard procedures (GB/T1574-2001). Basically, the coal samples were first crushed and ring milled to a size less than 0.2 mm. Next,

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