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The segregation behaviors of fine coal particles in a coal beneficiation fluidized bed

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ABSTRACT

The segregation behaviors of fine coal particles in a coal beneficiation fluidized bed (CBFB) were investigated in this work. The size range of 1–8 mm was taken into account and three separate size fractions were studied comparatively in the experiments, e.g. 1–2 mm, 3–5.5 mm and 5.5–8 mm. Both a clean coal sample and a gangue sample were used as the processed material to study the segregation behaviors of both light particles and heavy particles. The dense bed was divided as seven layers from bottom to top and the particle distribution in each layer for each sample was fully demonstrated. The influences of the particle density, particle size and the fluidized air velocity were revealed, the segregation patterns under different conditions were compared and the segregation mechanism was carefully analyzed. The results showed that the flotation and sedimentation of the particles in CBFB were still largely influenced by the particle density for the fine size range particles, and density stratification occurred even within each size fraction sample. The weight fraction in each layer showed a quadratic increase along the bed height for the coal particles. For gangue particles, a large fraction deposited in the bottom while the mass proportions in the middle layers also showed an increased tendency. With a decrease of the particle size, both the particle segregation and the density stratification phenomena deteriorated seriously. It was proved that particle feed size should be above 3 mm as the separation effect was quite inefficient for finer particles. By increasing the fluidized air velocity, the bed density slightly decreased but the bed turbulence was largely strengthened by the increasing bubble boiling effect. The flotation and sedimentation of the particles in 5.5–8 mm were obviously affected while no clear influence occurred to the rest of the two size fractions. Moreover, the results in this work provide a group of data that are quite suitable for CBFB numerical modeling studies.

1. Introduction

Coal beneficiation fluidized bed (CBFB) is a new dry technology for coal separation developed in recent decades for coal upgrading and/or size separation. In operation, a low velocity bubbling fluidization regime is formed in the bed; thus CBFB is one kind of typically dense gas–solid fluidized system characterized by micro-bubbles and high bed densities [1,2]. Under this condition, the feed coal can be segregated as flotsam (refers to the particles sank to the bed bottom) and jetsam (particles rise to the top half of the bed) by its physical properties, such as particle density, size and shapes. The basic concepts, developments as well as separation performances of CBFB have been widely reviewed in literatures [3–8].

The segregation behaviors of the coarse coal particles in CBFB are largely determined by the particle density, and the particle motion is controlled by the balance between the gravity and the effective hydrostatic buoyancy, whereas the Archimedes' principle can be roughly used to explain the separation mechanism [9]. But for the fine particles, interactions between the coal particles and the bed medium as well as the interactions between the coal particles and the bubble phase become relatively significant, thus the separation mechanism is more complicated [10]. At present, the particle size range that can be effectively processed in industrial CBFB technology is reported to be 6–50 mm while finer particles are difficult to deal with [11].Therefore, the influence of coal feed size on the performance of CBFB has gained interest in laboratory researches [12–14]. However, the segregation behaviors and particle distribution patterns in CBFB have not been fully revealed as the bed is traditionally divided as two layers or at most three layers to discuss the overall property of the product stream and the refused stream, which is very useful for the industrial production, but quite not enough to embody the particle behaviors in the academic respect. Besides, the available literatures conform to the fact that the separation efficiency in CBFB decreases with coal feeding size [12,15], but the detailed segregation characteristics for fine particles are not fully demonstrated and a clear proof of the lower feed size limit is not proposed and still remains a challenge.

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More important, the computational fluid dynamics (CFD) has become a useful and promising method to study the gas–solid flow in CBFB technology [16–18]. However, the widely existing experimental data in the references, which are the bases for validating the CFD model, mainly concentrate on the performance of the apparatus and the assessments of separation efficiency by the ècart probable moyen (E_p) value (calculated from the distribution curve/partition curve in which the percent of feed reporting to clean coal is plotted against specific gravity). Those expressions reflect the coal washability and separation quality by the dry CBFB methods, but the detailed particle distributions in CBFB are not fully provided and the information is not appropriate for CFD modeling [19–21]. Besides, confined by the mesh size and accuracy of the numerical modeling, the particle size modeled is only restricted to fine ranges.

Therefore, in this study, the segregation behaviors of fine coal particles of 1–8 mm in CBFB were carefully studied to reveal the particle distribution characteristics, to demonstrate the lower feeding size limit and to provide some available data for numerical modeling. Three size ranges were taken into account separately in the experiments, e.g. 1–2 mm, 3–5.5 mm and 5.5–8 mm. Both a clean coal sample and a gangue sample were used as the processed objects to comparatively study the segregation behaviors of the light particles and the heavy particles. The influences of the particle density, particle size and the fluidized air velocity were mainly concerned. The dense bed was divided as seven layers from bottom to top and the distribution characteristics in each layer for each sample were clearly demonstrated.

2. Experimental setup

The experimental setup of the CBFB used in this study is schematically shown in Fig. 1. The body of the rectangular fluidized bed was made of Plexiglas with a cross-sectional area of 0.5×0.05 m^2, and a height of 1.0 m. The fluidized air was supplied by a fan blower and sent to the bottom of the fluidized bed through an air distributor. The air flow rate was measured with romameters and could be regulated by valves to form the minimum fluidization condition and the designed working conditions for coal beneficiation. Even with a porosity rate of 2% and a thickness of 20 mm, the pressure drop of the air distributor was not enough to ensure the fluidization uniformity in the bed as the length–breadth ratio of the bed cross-section was large. To make compensation, a sand layer of 15 mm with sands of 2–3 mm size naturally packed was set under the air distributor to increase the pressure drop.

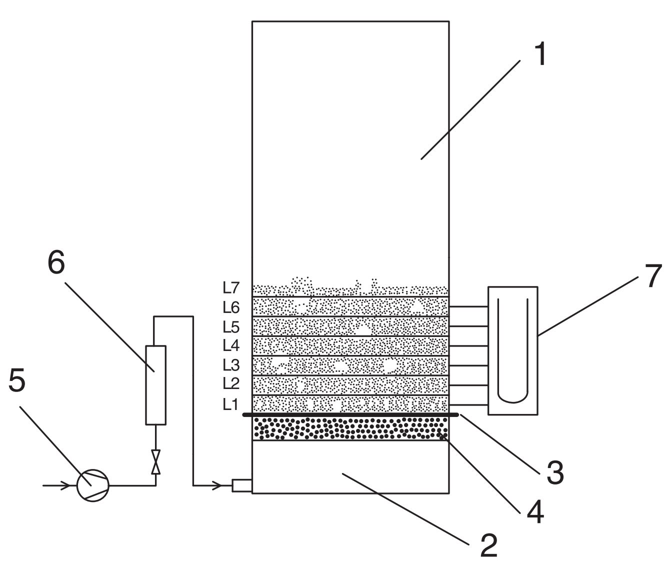

Fig. 1. Schematic drawing of the experimental system of the coal beneficiation fluidized bed. (1) Fluidized bed; (2) air box; (3) air distributor; (4) sand layer; (5) fan blower; (6) rotameter; (7) U-tube water manometer group.

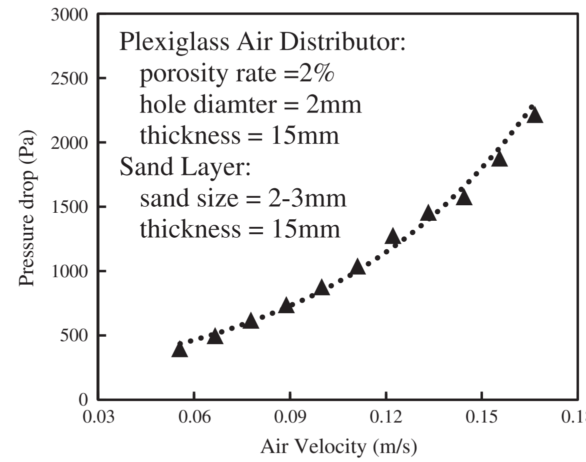

Fig. 2. The pressure drop of the air distribution layers.

By this way, a satisfactorily uniform fluidization state was obtained in the working conditions. The whole pressure drop of the air distribution layers at different air velocity is shown in Fig. 2. To monitor the pressure distribution in the bed, a group of pressure taps were set along two columns both on the front and the back walls as the bed is horizontally wide. The pressure drops were measured by a group of U-tube water manometers. Based on the measured bed pressure drop between two measured points at different heights, the bed porosity at the referred average height was calculated and then the average bed density was obtained.

One kind of Geldart B magnetite powder was used as the bed medium in the measurement. It had a real density of 4181 kg/m^3 and a size distribution of 10–600 μm with a mean particle diameter of 204 μm. The detailed particle size distribution is shown in Fig. 3. The minimum fluidization velocity u_{mf} of the magnetite powder was 0.067 m/s, which was measured according to the pressure drop of the bed with a gradual increase of airflow rate. Both a clean coal sample and a refused gangue sample with apparent density difference were considered in the experiment to reflect particle motion and distributions of both the light product and the heavy product in CBFB beneficiation. Three fine size fractions were selected for each sample, e.g. 1–2 mm, 3–5.5 mm and 5.5–8 mm. The average particle density for each size fraction was tested and reported in Table 1. The gangue sample had a density twice of the coal sample and little difference was observed for different size fractions within the same sample group.

An initial height of 0.3 m was filled with magnetite powder in each operation. The weighted feed coal and/or gangue sample was then

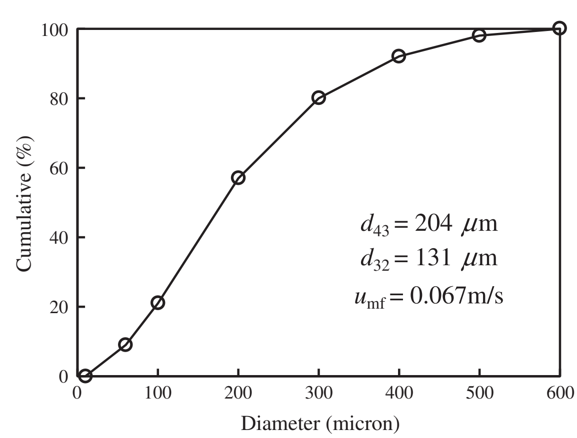

Fig. 3. The particle size distribution of the bed medium (magnetite powder) used in the experiment.