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Characteristics of fine coal beneficiation using a pulsing air dense medium fluidized bed

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ABSTRACT

Coal is one of the most important primary energy resources worldwide. Because of the shortage of water resources, dry coal beneficiation has become a research hotspot. A pulsating air dense medium fluidized bed (PADMFB) that introduces a pulsating air flow to the air dense medium fluidized bed was proposed for fine coal particles. In order to investigate whether coal particles can be separated by density in PADMFB, as well as size affecting the results under practical condition, the time ratio and the largest distance between two equal-falling particles were used as indexes for analyzing the beneficiation possibility in this paper. The equations of time ratio and the largest distance between two equal-falling particles when sinking from the surface to the bottom of the bed were established. Fine coal was confirmed to be separated theoretically in the PADMFB. Furthermore, the fine coal −6 + 1 mm size fraction was separated using the PADMFB. The ash content of the coal could be reduced from 56.15% to 33.69% when the gas pulsation frequency was 1.82 Hz, and the probable error, *E* value was 0.085 g/cm^3 in experimental setup.

1. Introduction

As the largest coal production and consumption country in the world, China produced 3.68 billion tons of coal in 2013 [1], and coal accounts for approximately 68% of China's primary energy consumption. Coal will continue to dominate the energy sector for quite a long period. In China the proportion of the preparation of raw coal is approximately 59%, particularly only 35% for steam coal which is far lower than that of developed countries. National economy has significantly benefited from coal, while the country suffers from serious environmental pollution such as acid rain and haze. Hazardous materials, particularly pyrite, are supposed to be removed through coal beneficiation, which decreases the sulfur dioxide emission and is recognized as the most economical and effective clean coal utilization technology. With dwindling water resources, the dry coal beneficiation has become one of the research hotspots in the field of coal preparation [2–4]. China University of Mining and Technology has carried out researches on air dense medium fluidized bed (ADMFB) since the 1980s. The coal in fluidized bed was separated under the function of density difference. The upward force controlling the particle motion is greater than gravity for the light particles and less than gravity for heavy particles [5]. After 30 years of research on fundamental theory [6–10], laboratory test [11–16], pilot test and industrial test [17–20], the first industrial modularized dry coal beneficiation system [21] was established in the world. This modularized system with a capacity of 40–60 t/h and a wide-size-range magnetite powder (0.3–0.06 mm) makes the coal with a size fraction of −50 + 6 mm separated efficiently possible.

In recent years, the fine coal content in mines increased significantly because of the advent of mechanized mining. The conventional ADMFB technology for the lower size limit of 6 mm cannot achieve fine coal beneficiation. Domestic and foreign scholars have attached great importance to the efficient dry beneficiation of coal. Z. F. Luo [22,23] developed the application of a continuous-beneficiation dense-medium vibrated fluidized bed for −6 mm coal separation, and the probable error E value was 0.065–0.085. M. M. Fan [24] and Z. F. Luo [25,26] et al. improved the fluidization quality of ADMFB by utilizing a magnetic field, resulting in an effective separation size fraction of −6 + 0.5 mm for a magnetically stabilized fluidized bed, and the probable error E value was 0.066. K.P. Galvin et al. at the Center for Advanced Particle Processing of the University of Newcastle in Australia used a reflux classifier with an air–sand dense medium [27,28] for −8 + 1 mm fine coal separation, and the probable error E value could reach 0.07–0.13, which increased with the decreasing particle size.

When the constant fluidizing gas velocity in a conventional gas–solid fluidized bed was changed to a periodic pulsing airflow, the increased vibrational energy was channeled, and the short circuit in the bed decreased significantly [29,30]. The bubbles in the bed distributed more uniformly and the diameter decreased, thus significantly increasing the efficiency of heat and mass transfer. Furthermore, the material size fraction that can be handled became much broader, and the material that is difficult to fluidize in general became easier to

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fluidize. Therefore, pulsing fluidized bed (PFB) has been applied to drying and burning fields. Based on the former studies [31,32], compared to dense media vibrated fluidized bed, the pulsing air dense medium fluidized bed (PADMFB) has the following advantages: a simple mechanical structure, long using time, high reliability, and the entire equipment does not vibrate. It is of great practical importance to develop PADMFB technology in industrial production.

In this study, PFB and ADMFB were joined into a PADMFB. The formulas that describe the time ratio and distance difference of equal settling particles under the conditions of separating fine coal in PADMFB were established by theoretical analysis. The uniformity and stability of PADMFB density and the separation of fine coal using the PADMFB are discussed.

2. Experimental and material

2.1. Experimental system

The experimental setup as shown in Fig. 1 includes an air-supply system, a pulsing airflow generator, a fluidized bed, a dust removal system, and a data collection system. The fluidized bed vessel consists of a gas distributor and a transparent Plexiglas container with a cross-section of 300 mm × 200 mm and height of 200 mm and its minimum fluidization velocity is 6.0 cm/s. A frequency converter was used for adjusting the frequency of the pulsing airflow. The pulsing airflow was generated by the rotation of a motor-driven ball valve, and the pulsation frequency was controlled by an inverter. Fig. 2 shows the waveform of pulsating air flow. The relationship between the airflow velocity and time can be described using Eq. (1) as follows:

$$v = v_0 + v_c[1-|\cos(2\pi ft)|] \tag{1}$$

Where v is the instantaneous velocity of the pulsing airflow, v_0 is the continuous velocity of air flow, f is the pulsation frequency, and t is the time, and $v_{\max} = v_0 + v_c$.

The separation processing of the heavy medium PADMFB is shown in Fig. 3. Magnetite powder was used as the heavy medium. Under the action of pulsing airflow, the heavy medium forms a gas–solid suspension with fluid properties, as shown in Fig. 3(a); thus, the coal grains in the fluidized bed could be segregated by their densities under the gravity and buoyancy effects. Once the raw coal is fed in the PADMFB, as shown in Fig. 3(b), the coal whose density is less than the bed density would float on the bed layer and become clean coal; the coal whose density is larger than the bed density would sink to the bottom of the bed layer and become gangue. The coal whose density is almost the same as the bed density would suspend in the bed layer and become middling coal, as shown in Fig. 3(c).

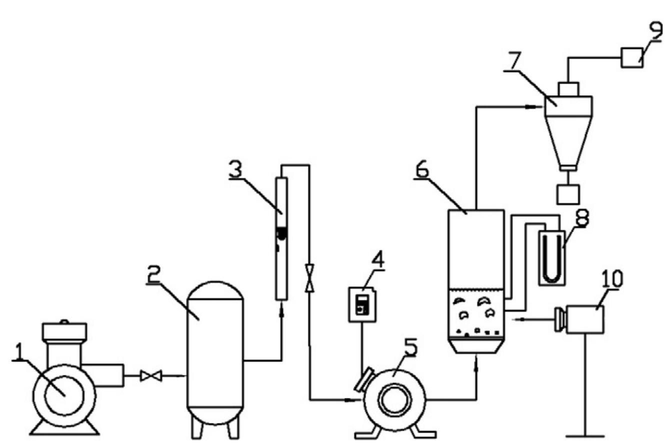

Fig. 1. Schematic of experimental system: 1 — blower, 2 — tank, 3 — flow counter, 4 — inverter, 5 — ball valve, 6 — fluidized bed, 7 — cyclone dust collector, 8 — U-tube manometer, 9 — bag filter, 10 — high-speed camera.

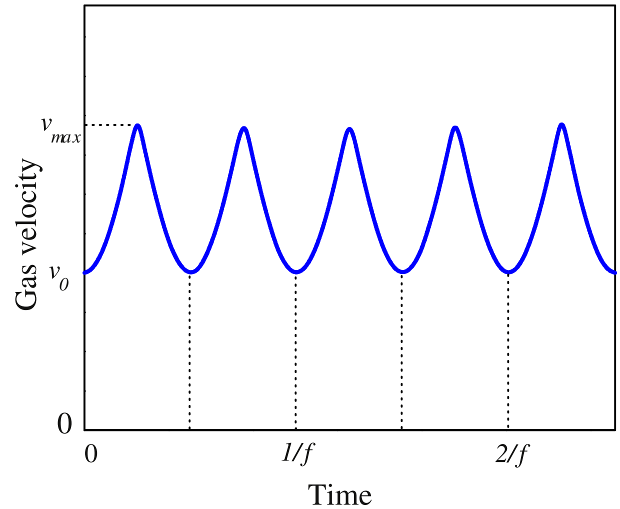

Fig. 2. Waveform of pulsing airflow.

3. Material

Fig. 4 shows grain size cumulative curves of the magnetite powder used as the heavy medium in the experiments. The average size of the magnetite powder was 232 μm, and the true density was 4600 kg/m^3. The −300 + 60 μm size fraction of the heavy medium was confirmed to be the best for separating fluidized bed [21].

Fine coal with a size of −6 + 1 mm was used in the separation experiments. Table 1 shows −6 + 1 mm coal float–sink analysis. The ash content of the raw coal was 56.15%. The washability curve of the raw coal shown in Fig. 5 was drawn after a float-and-sink test. Index β represents the cumulative float curve, which indicates the relationship of cumulative float yield and its average ash content; index λ represents the characteristic ash curve, indicating the relationship between yield of coal which is less than the specified ash content and corresponding ash content; index θ represents the cumulative sink curve, which indicates the relationship between cumulative sink yield and its corresponding density; index δ represents the relative density curve, indicating the relationship between cumulative float yield and its corresponding density; and index ε represents the near-density curve, which indicates the relationship between content of beneficiation density adjacent coal and density. From the washability curves, it can be seen that the raw coal is high ash coal, average ash content is 56.15%, the high density component especially higher than 2.1 g/cm^3 accounts quite much proportion.

4. Theories

4.1. Time ratio of equal-falling particles

During the settling, the particles will generally go through a laminar flow region, transition region, and turbulent flow region [33].

Laminar flow region: According to the Reynolds experiment, if the Reynold's number (Re) is less than the critical value of laminar flow, the flow condition of fluid is a laminar flow, in which the viscous force affects the flow field more than the inertia force. The perturbation of flow velocity in the flow field will decay due to the viscous force; the fluid flows steadily and without an obvious irregular pulse in fluid micells' track.

Transition flow: If the critical value of laminar flow is less than Re, and Re is less than the critical value of turbulent flow. The stream line