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Separation performance of fine low-rank coal by vibrated gas–solid fluidized bed for dry coal beneficiation

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ABSTRACT

Vibrational energy was introduced to a dense medium gas–solid fluidized bed to improve the separation performance of 1–6 mm fine low-rank coal. The setup was termed a vibrated gas–solid fluidized bed and could provide a stable fluidization state and uniform density distribution for dry coal beneficiation by the transfer of vibrational energy and the interaction between vibrations and the gas phase. Favorable segregation of the ash content of the 1–6-mm-sized lignite samples is achieved under suitable operating conditions. Higher yields of cleaning coal were acquired when the ash content was reduced. The probable error values were 0.065 and 0.055 at separating densities of 1.68 and 1.75 g/cm^3 for the 1–3- and 3–6-mm-sized lignite samples, respectively. Effective beneficiation of 1–6-mm-sized fine lignite could be achieved using the vibrated gas–solid fluidized bed, which provides an alternative technique for the separation of fine low-rank coal in arid areas.

Introduction

Coal preparation and beneficiation is one of the most efficient techniques for the clean use of coal resources and to ensure environmental protection. Because of a decrease in the number of high-quality coal resources, use of low-rank coal has become increasingly important in the coal industry. Lignite is the most richly reserved low-rank coal. Its reservation of approximately four trillion tons accounts for ∼40% of global coal reservations. Low-rank coal generally contains low ash, low sulfur, and high volatile-matter, and is of strong activity. Lignite, as the major low-rank coal type, has two additional unfavorable properties of high moisture content and low metamorphic grade. These properties make lignite susceptible to water degradation, which excludes potential water-based beneficiation techniques in lignite separation. Available coal resources are distributed mainly in arid regions and countries, such as southeast India, South Africa, and central and western China. Therefore, there is an urgent demand to develop and promote dry coal beneficiation technologies in coal preparation and use.

Dry coal beneficiation technology based on a dense medium gas–solid (DMGS) fluidized bed has become a focused research and application field in recent years. A number of scientists and researchers have studied fluidization separating theory and techniques for coal beneficiation with various equipment and approaches, and acquired notable achievements (Dwari & Rao, 2007; Mohanta, Rao, Daram, Chakraborty, & Meikap, 2013; Sahu, Biswal, & Parida, 2009). Dry coal beneficiation has been carried out successfully in India using air dense medium fluidized bed separators and a number of achievements have been obtained and reported (Sahu, Tripathy, & Biswal, 2013; Sahu, Tripathy, Biswal, & Parida, 2011). China University of Mining and Technology has been devoted to scientific research and industrial applications since the 1980s (Chen & Yang, 2003; He, Zhao, He, Luo, & Duan, 2013a; He, Zhao, Luo, He, & Duan, 2013; Luo & Chen, 2001; Zhao, Luo, & Chen, 2004; Zhao et al., 2010), and has established reliable DMGS fluidized bed beneficiation theories on gas distribution stability, uniformity of density distribution, kinetic behavior of the separating medium, and the formation mechanism of double bed density layers. The main principle of operation is that the feedstock stratifies by bed density, with lighter particles (cleaning coal) floating and denser particles (tailings) sinking based on Archimedes' principle. Researchers at the China University of Mining and Technology have designed and modularized 40–60 t/h beneficiation equipment, which can separate 6–50-mm-sized raw coal with a probable error of 0.05–0.07 g/cm^3 (He, Zhao, He, Luo, & Duan, 2013b; Zhao et al., 2011). However, the high-efficiency separation of 1–6-mm-sized fine coal is difficult to perform with conventional DMGS fluidized beds. New separation techniques have therefore been proposed by introducing vibrational or magnetic energy into conventional fluidized beds (Fan, Chen, Zhao, Guan, & Li, 2002; Fan,

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Chen, Zhao, Luo, & Guan, 2003; Luo et al., 2008; Luo, Zhao, Chen, Fan, & Tao, 2002). The results indicate that the separation efficiency of 1–6-mm-sized fine coal could be improved significantly with novel vibrated or magnetic fluidized bed separators. Vibrated gas–solid fluidized beds (VGFBs) have been recognized as effective separation devices with application potential in the coal beneficiation industry.

In this study, we introduced vibrational energy to investigate the segregation of 1–6-mm-sized lignite under different operating conditions. A theoretical analysis showed that the introduction of vibrational energy could improve the fluidization stability and bed density uniformity. We used a laboratory-scale VGFB to study the separation behavior of 1–3 and 3–6 mm lignite. We were particularly concerned about the effects of external moisture content of lignite and the operating parameters on separation efficiency. Operating conditions were optimized by comparing the segregation efficiency of lignite samples.

Experimental

Setup

The experimental VGFB system is shown in Fig. 1. It contains an air supply and controlling system, VGFB, measurement devices for bed stability, and adjusting and controlling device for the vibration parameters. A 120-mm-diameter cylindrical plexiglass fluidized bed of 300 mm height was made and installed on the vibration platform. Compressed air was pushed into the air chamber of the fluidized bed. Then, it was transported into the bed through a self-designed gas distributor located at the base of the bed. The gas distributor was made up of a micro-perforated plate with double-layer filtration fabric, which shows good air distribution characteristics. The ratio of open to total gas distributor area is approximately 28.26%. Uniform gas import for coal separation in the bed is of great benefit. The air flowrate was monitored using a gas rotameter and adjusted using an air valve. Pressure drops in different bed heights were measured using a group of pressure transducers (*U*-type, Wuqiang Hongxing Factory, China). Bed densities at different locations were measured by electronic transmission densimeter. The vibrational amplitude and frequency of the bed were controlled by the vibration-controlling and adjusting system (DC-600-6, Sushi Co., Ltd., China). Two fine lignite samples, 1–3 and 3–6 mm, were selected to investigate segregation performance. Lignite was fed into the bed after the bed fluidization had stabilized. Lignite was stratified because of the mechanism of bed density-based separation. All layers, sorted as cleaning coal, middling, and gangue, were analyzed to evaluate the separation efficiency, from which the operating parameters were optimized.

Materials

Separating media need to have a stable density, which is critical to the formation of a steady bed, and is an important factor in efficient coal separation. Easy recycling and reuse is an additional requirement for separating media. To ensure the fluidization quality of fluidized beds and to decrease the preparation cost of the separating medium, a 0.074–0.3 mm magnetic powder was used as the major separating medium in the investigation. It has a real density of 4.2 g/cm^3 and a bulk density of 2.56 g/cm^3. Its magnetic material content and magnetization intensity are 99.79% and 77.86 A m^2/kg, respectively. Physical properties of the magnetic powder indicate a suitable density distribution and high magnetic material content, which is favorable to form stable fluidization states in the bed and provide a uniform separating density for coal beneficiation.

Table 1
Detailed properties of different-sized lignite samples.

Size fraction (mm)	1–3	3–6
Ash content, A_{ad} (%)	28.79	23.52
Moisture content, M_{ar} (%)	23.36	27.85
Volatile content, V_{daf} (%)	49.51	48.90
Calorific value, $Q_{net,ar}$ (MJ/kg)	17.82	18.93
Sulfur content, $S_{t,d}$ (%)	2.33	2.19

Lignite from Inner Mongolia, China was used as the low-rank coal sample. The sample was crushed and sieved into 1–3 and 3–6 mm fractions. Detailed properties of the different-sized lignite samples are summarized in Table 1.

Methods

In the segregation experiments, the separating medium was fluidized by introducing compressed air into the bed uniformly through a gas distributor. After achieving stable fluidization, the lignite sample was fed into the bed and separated for a period of time. The fluidization index was used to examine the stability of the fluidized bed, which is a ratio of minimum bubbling velocity to minimum fluidization velocity (U_{mb}/U_{mf}) (Sahu et al., 2011, 2013; Singh & Roy, 2005). Normally, a larger value of U_{mb}/U_{mf} indicates a better fluidization stability in the bed. When the air supply was shut down suddenly, the bed became static immediately. The static bed was divided into five layers (*L*1–*L*5) from the top to the bottom in the axial direction, as shown in Fig. 1. The sample in each layer was collected and the lignite feed sample was sieved out to determine the mass fractions and average ash content. A segregation index was proposed to evaluate the separation performance of lignite samples, as defined in Eq. (1):

$$S = \sum_{i=1}^{n} \left[\gamma_i \left| \frac{A_i}{A_0} - 1 \right| \right], \quad (1)$$

where A_i refers to the ash content of the coal sample in layer i, A_0 refers to the initial ash content of the feeding coal, n is the number of total layers, and γ_i refers to the mass fraction of the coal sample in layer i. A larger S value indicates a better segregation efficiency of the coal sample.

The vibrational amplitude (A) and frequency (f) of the fluidized bed are two crucial parameters to improve the segregation performance of the 1–6-mm-sized fine coal. Based on an overall consideration of the above two parameters, the vibrational intensity was proposed to determine the combined effects of A and f on lignite segregation index and could be calculated from Eq. (2):

$$K = \frac{A(2\pi f)^2}{g}, \quad (2)$$

where K represents the vibrational intensity and g is the gravitational acceleration.

Results and discussion

Coal separation analysis in VGFB

Lignite can be more effectively classified by bed density after vibrational energy has been introduced to the bed. Two factors that play significant roles are the vibrational energy that is transferred from the entire bed and the interaction between the vibration and the gas phase, which improves the bubbling fluidization stability and the bed activity.