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Effect of coal particle swarm properties on the fluidization characteristics and coal beneficiation in a dense-phase gas–solid fluidized bed

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ABSTRACT

This paper analyzes the influence of different coal mass fraction in an air dense medium fluidized bed (ADMFB). The effect of the low density particles layer on heavy sedimentation increased with increasing material layer thickness. The thickness of the low density particles layer also affected the final settling time of the high density particles. Increasing the thickness of the low density particles layer by Δh provoked an increase in the settling of high density particles that was related to their diameter ($\Delta h/D$). The pressure gradient across the bed was lower than that observed for the control experiment, which had only the dense material, owing to a decrease in the pressure gradient in Zones 1 and 5 (at the top and bottom of the bed, respectively). Introducing different coal sizes resulted in different fluidization environments, particle accumulation layers, and changes to the surrounding zone. However, the influence of the coal particles on the local bed characteristics was related to its concentration. The feeding mass fraction of 6–13 mm size and 13–25 mm size coal should be limited to10% and 13%, respectively. The ranges of possible deviation were found to be 0.08–0.15 and 0.07–0.10 for the respective samples.

Introduction

China is the largest coal-producing and coal-consuming country in the world. The country also has some of the world's largest reserves. Coal is the major source of energy in China (Chen & Yang, 2003). Approximately 70% of the raw coal used in China is not cleaned before use (Tao, Luo, Zhao, & Daniel, 2006; Zhou & Liu, 2007), which has resulted in serious pollution problems, such as acid rain and the release of SO_2 and soot particles (Luo et al., 2008). Traditional processes to improve coal quality by separating out impurities, such as coal washing, consume large amounts of water, which may be problematic, especially in drought and cold regions. Furthermore, the coal produced by these traditional processes contains high amounts of water, which is difficult to remove (Luo, Zhao, Chen, Fan, & Tao, 2002; Yang, Zhao, Luo, Song, & Chen, 2013). Therefore, efficient dry separation technologies are urgently needed to address these issues.

Technologies that can avoid the need for product dehydration could be useful for separating fine coal in arid regions. Recent studies of fine coal separation technologies have reported the development of air dense medium fluidized beds (ADMFBs) (Macpherson, Iveson, & Galvin, 2011; Prashant, Xu, Szymanski, Gupta, & Boddez, 2010), vibrating fluidized beds (Yang, Zhao, Luo, Chen, & Song, 2011; Yang, Zhao, Luo, Song, & Chen, 2013; Yang, Zhao, Luo, Song, Duan et al., 2013), magnetically stabilized fluidized beds (MSFBs) (Fan, Chen, Zhao, & Luo, 2001; Fan, Chen, Zhao, Guan, & Li, 2002; Fan, Chen, Zhao, Luo, & Guan, 2003; Song, Zhao, Luo, & Tang, 2012), tribo-electrostatic separation, shallow bed air dense medium fluidized beds (Dwari & Rao, 2009; Kelly & Spottiswood, 1989; Zhang et al., 2014), jigging separators (Breuer, Snoby, Mshra, & Biswal, 2009; Sampaio, Aliaga, Pacheco, Petter, & Wotruba, 2008), and pulsed dense medium fluidized beds (Weinstein & Snoby, 2007).

A number of research groups have shown that dry coal beneficiation using an ADMFB is an efficient way to produce high-quality cleaned coal without using water (Dong et al., 2013; Luo et al., 2003; Wang, He, He, Ge, & Liu, 2013; Zhao, Tang et al., 2010). An ADMFB separator uses a magnetic material as the dense medium and has been used for coal beneficiation yielding a probable error of $E = 0.05\ g/cm^3$. However, uniform density stability remains prob-

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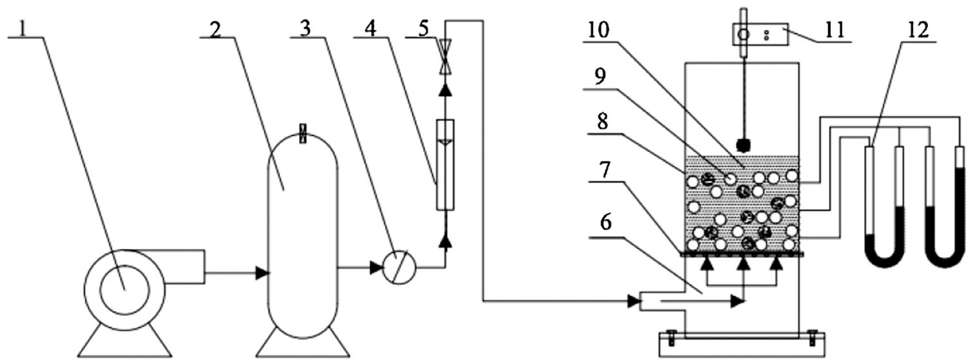

Fig. 1. Preparation system of air dense medium fluidized bed (schematic diagram). (1) Fan; (2) air storage tanks; (3) ball valve; (4) flow meter; (5) butterfly valve; (6) air chamber; (7) cloth wind plate; (8) fluidized bed body; (9) Coal particles; (10) magnetite powder; (11) spark timer; (12) manometer.

lematic and a focus of research in the dry separation field (Zhao, Luo et al., 2010). Many factors affect this process, including the air distributor, geometry of the fluidized bed, characteristics of the dense medium, and air velocity (Grace & Clift, 1974; Luo et al., 2010; Sobolewski & Bandrowski, 1994; Vakhshouri & Grace, 2010). All of these factors influence the bed's fluidization quality, though the air distributor appears to be the most important of these (Lee, Lee, & Kim, 2001; Luo, Zhao, Chen, Tao, & Fan, 2004; Sathiyamoorthy & Horio, 2003;). Despite recent developments, a number of issues continue to hinder the widespread use of gas–solid fluidized beds, such as how the particle swarm's flow and accumulation convection impact the flow characteristics. The current work contributes to clarifying these issues by investigating the influence of different feed mass fraction. The research is based on coal particle swarm properties analysis, and impact of particle swarm accumulation convection on flow characteristics, effect of feed mass fraction on interference subsidence, and different sizes coal beneficiation experiments.

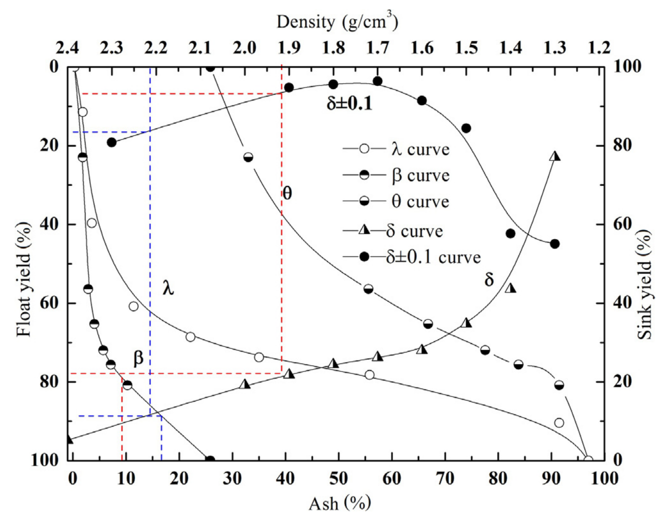

Fig. 2. Washability curves of 6–13 mm coal samples.

Materials and methods

The ADMFB separation system shown in Fig. 1 includes a laboratory-scale fluidized bed, air supplying system, fluidized property measurement system, and determination system of particle sedimentation. Furthermore, 0.15–0.30 mm graded density medium is the leading particle size. The properties of the magnetite powder were as follows: bulk density of 2.44 g/cm^3, true density of 4.19 g/cm^3, and magnetic content of 98.36%, respectively. Because a wide size range density medium can interfere with the test index, therefore to reduce the size range of density medium screening out of 0.15–0.30 mm narrow size range has been undertaken, which has been used as the test density medium.

To compare the impact of different particle sizes in the separation process, 13–25 and 6–13 mm of long flame coal were used as the coal samples. These were taken from the same screened sample and were prepared with the graded density ratio of a tracer material (colored coal according different density), which consisted of density distribution and size distribution of two samples, and was used as the basic sample. Table 1 shows float–sink data for the 6–13 and 13–25 mm coal samples. Furthermore, Fig. 2 shows the two size coal washability curves of the 6–13 mm sample.

Table 1 and Fig. 2 show that there were two grades in the sample: light product (<1.5 g/cm^3) which acts as the largest proportion density level and the cumulative production rate is accounted for around 60%; and product with a medium density (1.5–2.0 g/cm^3), which consists of small and evenly distributed particles. Taking advantage of the fact that the ADMFB was relatively stable, the separation density was controlled at approximately 2.0 g/cm^3.

Light and suspended particles that are close to the apparent fluidization density can be neglected while studying the sedimentation of mineral particles in the fluidized bed. Attention should instead be focused on the sedimentation of high density particles, which have a density that is higher than the apparent fluidization density. In the sedimentation experiment, >2.0 g/cm^3 was used to delimit high density particles, with this level acting as the tracer material. It shows coal sedimentation particle size in Table 2. The settling of high density particles in the fluidized bed is mainly influenced by the particles in the upper layer. Properties of the <1.5 g/cm^3 fraction are shown in Table 3.

Results and discussion

Effect of feed mass fraction on interference subsidence

The data in Table 2 shows that under different thickness of the low density particles (clear coal) layer, four different kinds of particle sizes of the interference of high density particles (coal gangue) subsidence process were obtained, as shown in Fig. 3(a)–(d). These reveal that: compared with free settling, the presence of low density particles led to a hinder and interfere with the settlement process in the material's initial sedimentation period, with this influence more significant for thicker material layers. The thickness of the material layer not only affected the final settlement time of high density particles, but also different size high density particles affected are also different. The impact was smaller for larger particles. The increase in the layer thickness of low density particles led