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Characteristics of fluidization and dry-beneficiation of a wide-size-range medium-solids fluidized bed

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A B S T R A C T

Wide-size-range medium-solids are used in a modularized coal beneficiation demonstration system with a gas-solid fluidized bed. The characteristics of fluidization and dry-beneficiation of the medium solids were studied. The numerical simulation results show that 0.15–0.06 mm fine magnetite powder can decrease the disturbances caused by the bubbles. This is beneficial to the uniformity of the gas-solid interactions and thus to the uniformity and stability of the bed density and height. The experimental results show that, with an increase in the fine coal content in medium solids, both the fluidization quality and the beneficiation performance of the bed decreased gradually. When the fine coal content was no more than 13%, a relatively high superficial gas velocity increased the beneficiation efficiency. When the content was more than 13%, part of the fine coal was separated, leading to product layers. The separation efficiency was therefore gradually decreased. The models for predicting the bed density standard deviation and the probable error, *E*, value were both proposed. The *E* value can reach to 0.04–0.07 g/cm^3 under the optimized experimental parameters. This work provides a foundation for the adjustment of the bed density and the separation performance of the modularized 40–60 ton per hour dry coal-beneficiation industrial system.

1. Introduction

Water based wet separation processes are the main methods utilized in the field of coal beneficiation today. These techniques are, however, unsuitable for coals that tend to slime in a wet separation process or for those coals located in arid or cold regions [1,2]. During wet separation processes a lot of coal slime is generated and recovered. This increases the investment and the processing cost. Furthermore, a shortage of water resources inhibits the development of coal beneficiation in some areas, such as northwestern China, South Africa and western United States. Therefore, the advantage and importance of highly efficient dry-beneficiation techniques are recognized, such as without water consumption and without coal slime treatment. A number of scientists and engineers contributed to the development of gas-solid fluidized bed dry coal-separation [3–6]. The theory and technique of dense medium gas-solid fluidized bed beneficiation include the bubbling fluidized bed, the vibrated fluidized bed, and the magnetically fluidized bed [7–17]. The bubbling fluidized bed was utilized to separate 50–6 mm coal by workers at China University of Mining and Technology. The technique undergoes the separation theory study, the laboratory scale beneficiation experiment, the pilot scale beneficiation experiment and the industrial scale beneficiation experiment [18]. The following problem occurred with the medium solids (i.e. magnetite powder) during those studies: it is difficult and costly to prepare a great deal of magnetite powder with a narrow size range of 0.3–0.15 mm; and the activity of the large particle bed is relatively low [19]. To decrease the construction cost a modularized 40–60 ton per hour KZX40 dry coal beneficiation system was constructed by the workers of China University of Mining and Technology and Tangshan Shenzhou Manufacturing, Co. Ltd. Wide size range magnetite powder with a 0.3–0.06 mm particles content of more than 80% was used in the modularized system [20]. It is urgent to perform a study of the fluidization and beneficiation characteristics of wide size range magnetite powder. Based on the study, it is expected that the technic and operational parameters can be optimized, and the modularized system can be adjusted and controlled more quantitatively.

2. Experimental

The laboratory scale experimental apparatus is illustrated in Fig. 1 and is similar to that used in our previous work [19]. The apparatus consists of an air supply, data measurement equipment

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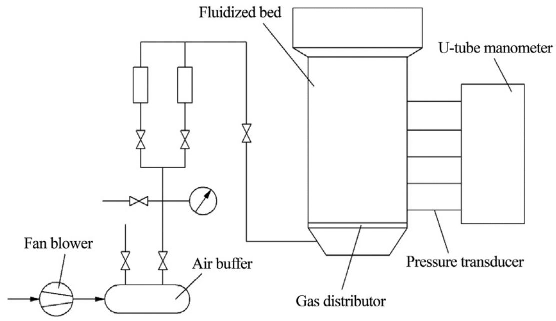

Fig. 1. Schematic of the experimental gas-solid fluidized bed apparatus.

and a plexiglass gas-solid fluidized bed of 278 mm × 160 mm cross-section. Pressure transducers are arrayed vertically along the side wall and the pressure drop data are collected by a monitor. The pressure drop of bed is measured using U-tube manometers fixed on a board. The bed density can be calculated from the bed pressure drop. The bed height can be measured using a ruler fixed on the bed wall.

A mixture of 0.3–0.06 mm magnetic powder and 1.5–0.5 mm fine coal was used as medium solids. 50–6 mm coal with a middle washability was used as a feedstock. To perform an experiment, the fan blower was first turned on. Then, the mixture of the magnetite powder and the fine coal was fed into the bed. A fluidized bed having a certain density and height was formed thereby. The fluidization characteristics and beneficiation performance of the bed were examined under various operating conditions.

The standard deviation of the fluidized bed density, $S\rho$, which is used to evaluate the uniformity and stability of the bed density, is defined as:

$$S_\rho = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\rho_i - \overline{\rho})^2} \tag{1}$$

where N is the number of pressure measuring points in the bed; ρ_i the density at each pressure measuring point; and $\overline{\rho}$ the arithmetic mean density of all the measurements taken at each bed–pressure measuring point.

An experimental design was performed using the Design-Expert software. Three technic and operational parameters included the fluidization number (N), the pressure drop ratio of gas distributor to bed ($\Delta P_d/\Delta P_b$), and the content of 1.5–0.5 mm fine coal in medium solids (ψ). The experimental indexes included the standard deviation of bed density, S_ρ, and the probable error, E, value. A total of 45 experiments were performed. The parameters of the experimental design are shown in Table 1.

3. Results and discussion

3.1. Fluidization characteristics of the magnetite powder bed

The fluidized bed is the environment of coal separation. A bed with a high fluidization quality is crucial to the effective separation of coal. The fluidization characteristic of a bed containing 0.3–0.06 mm magnetite powder was investigated firstly using a numerical method. Fluent 6.2 CFD software was employed to perform the numerical simulations of the bed. The parameters in the simulations are similar to that used in our previous study [19]. The particle density is 4.2 g/cm^3. The mean particle diameters of 0.3–0.15 and 0.15–0.06 mm magnetite powder are 0.18 and 0.12 mm, respectively. An Eulerian two-phase flow model was used throughout the simulations. The drag force was calculated by the Syamlal-O'Brien model. Uniform gas velocity and atmospheric pressure were specified at the inlets and the outlet, respectively. No-slip wall boundary conditions for the gas phase were adopted. It can be seen from Fig. 2 that both the bubble size and bubble number decrease with an increase in the content of the fine particles, i.e. 0.15–0.06 mm magnetite powder. Also, the void fraction of the dense phase decreases gradually. This is beneficial to the bed activity and the bed density. Moreover, the fluctuation in the top surface of bed decreases, indicating a more stable bed height. Therefore, the fine magnetite powder can decrease the disturbances caused by the bubbles, increase the uniformity of the gas-solid interactions, and increase the uniformity and stability of the bed density and height. The magnetite powder bed is suitable for dry separation of coal.

3.2. Uniformity and stability of density of the bed containing magnetite powder and fine coal

The standard deviation of bed density, S_ρ, was experimentally investigated. The effect of various factors on the fluidization quality was shown in Fig. 3. It can be seen from Fig. 3a and b that the surface remains horizontal on the whole along the $\Delta P_d/\Delta P_b$ coordinate axis direction. An obvious fluctuation in S_ρ value is not found when increasing the $\Delta P_d/\Delta P_b$ value. Therefore, for $\Delta P_d/\Delta P_b \geq 1$, the pressure drop ratio is not a significant factor influencing the fluidization quality of the bed. Additionally, for $\psi \leq 13\%$, when the superficial gas velocity is no more than 2.0 U_{mf}, the S_ρ value decreases and then increases gradually. For $\psi > 13\%$, with increasing the fluidization number the S_ρ value decreases and then slightly increases to 0.17 g/cm^3. This is because, for $\psi \leq 13\%$, a higher gas velocity can enhance the uniform mixing of particles and increase the uniformity and stability of the bed density. When increasing the gas velocity enough, the large bubbles across the bed decrease the uniformity of bed voidage. A relatively large disturbance of bed is caused. The fluidization quality of the bed is therefore decreased. It was experimentally observed that for $\psi > 13\%$ a fine coal layer informed at the upper bed. Obviously, the magnetite powder was unevenly mixed with the fine coal. A higher gas velocity is beneficial to the loosing of fine coal layer and thus to the remixing of the coal particles. The uniformity of both the particle distribution and the bed density is therefore enhanced. But the relatively large bubbles decrease the stability of the density distribution and thus cause a high S_ρ value of 0.17 g/cm^3. A similar variation of S_ρ value can also be seen from Fig. 3d. As seen in Fig. 3c, with increasing the fine coal content the S_ρ value increases gradually and then increases rapidly. The fluidization quality of the bed decreases sharply. The reason is that the fine coal particles in the bed are comprised of two parts:

Table 1
Basic parameters for beneficiation experiments design.

Code	Variable	Level				
		Low	Middle low	Middle	Middle high	High
A	Fluidization number	1.5		1.8		2.0
B	Pressure drop ratio	1.2		1.4		1.6
C	Fine coal content (%)	4.0	8	12.0	16	20.0