CHARACTERISTICS OF PARTICLE BENEFICIATION WITH VARIOUS COMPONENTS USING AN AIR DENSE MEDIUM FLUIDIZED BED

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Abstract - as the one of primary energy resources, coal occupies the highest proportion in china. Due to the shortage of water, it is of great significance for coal beneficiation with an air dense medium fluidized bed (admfb). In this study, the separation behavior of feed particles with various components and densities was analyzed in admfb. The results depicted that the particles of lowest density and highest density have the stable separation behavior due to the density variation. With more particles of middle densities introduced, the phenomenon of particles mixing with various densities would be appeared in fluidized bed. The pressure drop fluctuation also presented the increasing trend with more particles of middle densities introduced. Based on the above analysis, the particles of middle density should be removed from the fluidized bed to avoid mixing of feed particles in the practical production.

KEYWORDS

Fluidized bed; separation behavior; feed particle; coal beneficiation; mismatch rate

INTRODUCTION

As one of the primary energy sources in the world, coal accounted for about 30% of the energy system, especially more than 65% in China (Dong et al., 2015). With the increasing hazards of the fog and haze, more importance should be attached on the burning of coal (Ibrahim et al., 2015). Currently, the desulfurization and deashing before combustion is an effective method for the coal clean utilization. The means of flotation column, water jigging, TBS and other wet technology are traditionally used for the coal separation, based on the difference of density and floating property, the coal could be effectively achieved segregation from other minerals (Xia et al., 2015). However, with the increasingly shortage of the water all over the world, the wet separation would be under restrictions for the water consumption (Zhao et al., 2016, Zhang et al., 2014). In addition, with the complex slime water treatment system and high investment cost, the traditionally means would create the smaller profits due to the low coal prices (Sekito et al., 2004).

In recent years, many scholars have devoted to the research of dry coal preparation (Duan et al., 2015, Oshitani et al., 2012). In particular, different countries was engaged in the research field of n air dense medium fluidized bed (ADMFB). Many studies about the feed particle conditions, bubble behavior, binary mixing and air distributor was carried out for the optimization separation performance (Mohanta et al., 2013). ADMFB researched by China University of Mining and Technology has been successfully used in -50+6mm coal separation

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and the probable error E value was 0.05. Moreover, the first industrial dry coal preparation plant was established in Xinjiang, China (Zhao et al., 2016). Furthermore, However, the recent research mainly focused on the separation for a given minerals lack of representative. The fluidized behavior of medium and bubbles in the bed layer due to various density composition minerals (VDCM) was not studied before.

In the study, the separation performance of VDCM was conducted by the tracer particles and the fluidized behavior of medium and bubbles was analyzed with the theoretical and experiments, including the mismatch ratio and pressure drop fluctuation. The effects on separation performance of various factors, like bed height, gas velocity and particle component, were investigated to optimal the separation the accuracy.

EXPERIMENTAL

Experimental System

As shown in Fig. 1, the experiment system mainly contained blower, buffer tank, flow meter, separation bed, air distributor and air distribution chamber. The separation bed was made by the transparent glass with a diameter of 120mm and height of 300mm. In the separation process, the stable air flow was induced to the buffer tank by the roots and the experimental gas velocity would be adjusted through the flowmeter and DASP-V10 pressure data analysis system. The DASP-V10 pressure data analysis system was composed of pressure sensor, data collector and computer. The data collector was respectively connected with the computer and the pressure sensor. The pressure signal is transmitted to the computer with the analysis of signal processing software with the sampling frequency was 128 Hz and the sampling time was 30 s.

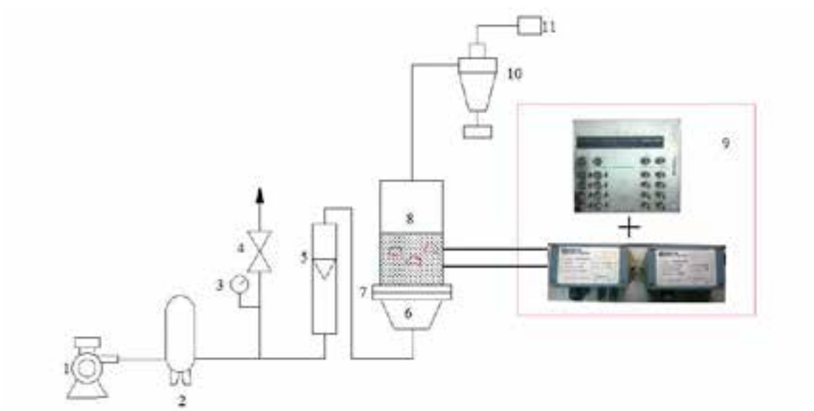


Fig.1.The separation system of gas-solid fluidized bed: (1) blower, (2) buffer tank, (3) pressure gauge, (4) valve, (5) flow meter, (6) an air distributor, (7) air distribution chamber, (8) separation bed, (9) data acquisition system, (10) cyclone dust collector, (11) bag filter.

Material

As shown in the Fig.2, the Geldart B magnetite powder was used as dense medium, which mainly contained the -0.3+0.15mm size fraction particle with 86%. Particularly, the coal powder with -1+0.5mm size fraction was also used as the additional medium in the separation bed to adjust the bed density and broaden the size fraction of the medium. The percent of coal powder used in the study was 10%.

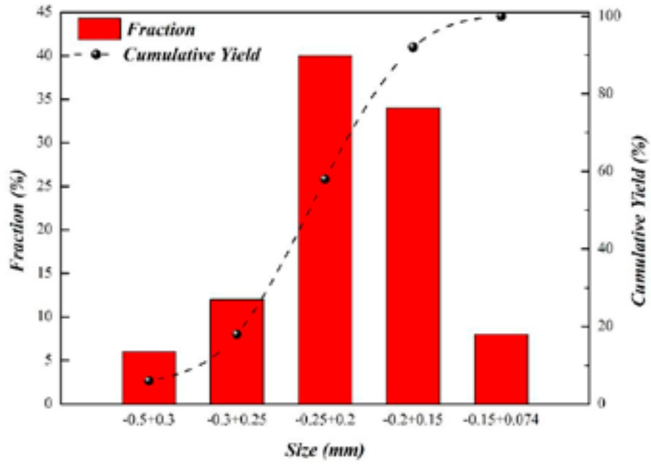


Fig.2 The size distribution of dense medium

As shown in Fig. 3, the particle with density of 1.4g/cm^3 (yellow) was used for simulating the light particle (LP); the particle with density of 1.6g/cm^3 (red) was used for simulating the middle density particle (MDP); the particle with density of 1.8g/cm^3 (blue) was used for simulating the heavy particle (HP). In order to eliminate the negative effect due to the size fraction, the particle of 23mm size fraction was used to investigate the particle separation behavior and the feed particle number was controlled 18 every time. In the experiment, the composition of particles was adjusted by controlling the number of middle density particle ($\boldsymbol{G_{middle}}$), which was respectively feed with the number of 0,2,4,6,8,10 in the separation bed.

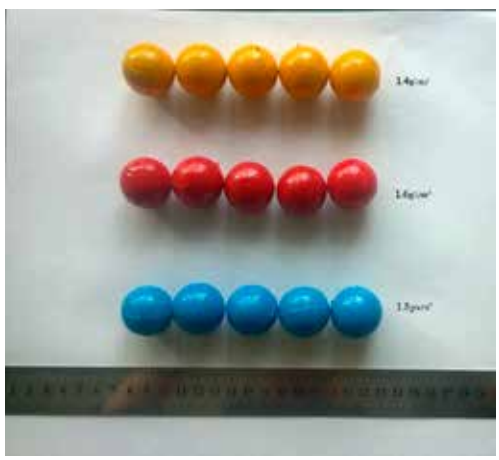
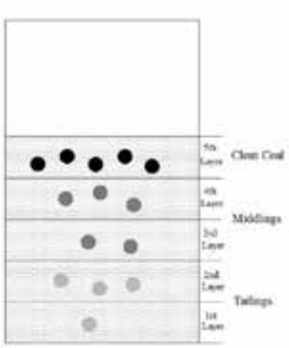


Fig.3.The schematic diagram of simulated particles

Evaluation Index

As shown in Fig.4, the separation bed would be divided into five layers after separation for the composition analysis: 1st and 2nd layers were considered as the tailings area; 3rd and 4th were considered as the middling area; and 5th layer was considered as the concentration area. The mismatch rate ε was used as the evaluation index, as described in equation (1):

$$\varepsilon = \frac{G_{mis}}{G_{total}} \times 100\% \qquad (1)$$



Where ε is the mismatch rate; G_{mis} is the number of mismatch particle; G_{total} is the total particle number. When the particle with the confirmed density was not stay in the correct location, it can be regarded as the occurrence of the mismatch phenomenon, such as the light particles not in the 1st layer. The lower the value of ε the better the segregation performance.

Fig.4.The schematic diagram of product distribution

RESULTS AND DISCUSSION

Interaction effect of various factors on the separation efficiency

Based on the study of the variation in the pressure drop at various velocities, the minimum fluidization velocity $\boldsymbol{U_{mf}}$ was close to 0.082 m/s at various bed height. The fluidization number $N = U/U_{mf}$ was chosen to express the gas energy introduced, where $\boldsymbol{U}$ is the experimental gas velocity and $\boldsymbol{U_{mf}}$ is the minimal fluidization gas velocity. The interaction effect of the gas velocity (N), bed height (H), and various components was further studied by the Design-Expert software. The orthogonal experiment was conducted to analyze the interaction effect of N, H, and $\boldsymbol{G_{middle}}$ and. The experimental scheme and results of interaction effect of various factors are listed in Table 1. The optimum experimental conditions were determined based on the mismatch rate ε.

Table 1 Experimental scheme and results of interaction effect of various factors.

Experimental Number	***N***	***H（mm)***	***G_{middle}***	***ε（%）***
1	1.50	80	10	16.67
2	1.50	100	6	5.56
3	1.60	100	0	0
4	1.50	120	10	27.78
5	1.50	100	6	0
6	1.60	80	6	5.56
7	1.50	120	0	0
8	1.50	100	6	5.56
9	1.50	80	0	0
10	1.40	120	6	16.67
11	1.60	120	6	22.22
12	1.40	80	6	11.11
13	1.40	100	10	27.78
14	1.50	100	6	0
15	1.60	100	10	44.44
16	1.50	100	6	5.56
17	1.40	100	0	0

As listed in Table 2, the fitting precision of different analysis models was obtained. Based on the comparison between Quadratic and 2FI model, the value of F = 8.70 beyond the value of 4 and the Prob >F was lower than 0.05, indicating that the Quadratic model was the optimal model. Moreover, the accuracy analysis depicted that the R^2 were 0.93, indicating an acceptable precision.

Table 2 Variance analysis of various models.

Source	Sum of Squares	df	F Value	Prob > F	
Mean vs Total	2099.23	1			
Linear vs Mean	1684.89	3	7.08	0.0046	
2FI vs Linear	122.51	3	0.45	0.7231	
Quadratic vs 2FI	716.17	3	8.70	0.0093	Suggested
Cubic vs Quadratic	155.06	3	5.57	0.0652	Aliased
Residual	37.1	4			

The mathematical relationship between the mismatch rate ε and the operational factors were established by the regression analysis. The combined formulas of the mathematical model are expressed as Equations (2).

Mathematical model in terms of actual operational factors:

$$\begin{aligned}\varepsilon = &+2241.391 - 2782.8250 * N - 2.94056 * H - 14.80672 * G_{middle} + 1.38750 * N * H \\ &+ 7.35000 * N * G_{middle} + 0.029953 * H * G_{middle} + 874.8250 * N^2 + 4.51437 * H^2 \\ &+ 0.37031 G_{middle}^{\ 2}\end{aligned} \quad (2).$$

Effect of feed particles with various components on the separation efficiency

As shown in Fig. 5, the optimal separation results (when H= 80mm, N = 1.4 and 1.5; When N=1.5, H = 80 and 100 mm) were selected to investigate the effect of feed particles on various components. $\bar{\varepsilon} = \frac{\sum_{i=1} \varepsilon_i}{n}$ was chosen to express the average mismatch rate, where ε_i is the mismatch rate at various $\boldsymbol{G_{middle}}$ conditions. The results show that the beneficiation performance could be divided into stable segregation, unstable segregation. The $\boldsymbol{G_{middle}}$ < 4 and $\bar{\varepsilon}$ = 0 indicate that the segregation of LDP and HDP was almost not affected, and the variation in the separation efficiency was dominated by the gas velocity and bed height as mentioned before. However, with continuously increasing $\boldsymbol{G_{middle}}$, the beneficiation performance was affected by the feed particles with various components in the bed, and the ε has a slightly increasing tendency. When $\boldsymbol{G_{middle}}$ was 6 and the $\bar{\varepsilon}$ was 6.95, unstable segregation behavior was observed. At $\boldsymbol{G_{middle}}$ of 8 and 10, the $\bar{\varepsilon}$ was 12.50 and 20.84, respectively, indicating poor beneficiation performance because of the particle mixing phenomenon.

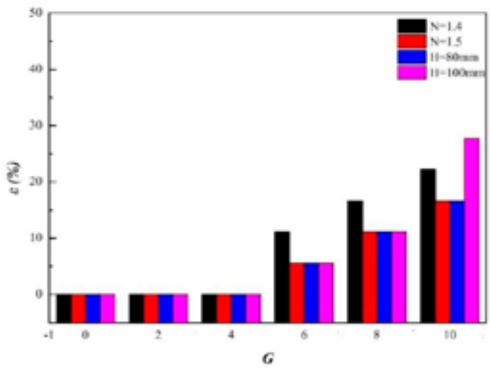


Fig.5. Effect of feed particles with various component on the Separation efficiency.

The results depicted that with increasing number of middle particles, bigger defluidization area would be generated, which would have a negative effect on the air transmission. The gas prefers moving through the minimum energy avoiding the collision with dense medium. Consequently, the gas would merge, generating bigger bubbles, causing the backmixing behavior of dense medium. The local bed expansion ratio was comparatively lower at higher viscosity, which could hinder the settling of heavy particles. In addition, the settling of HDP would be hindered by more MDP causing more frequent mismatch behavior.

Effect of feed particles with various components on the fluidization behavior

By the DASP-V10 data analysis system, the variation in the bed pressure drop of the feed particles with various components was acquired. The $S_{\Delta P}$ was proposed to investigate the variation in the pressure drop fluctuation, as described by Eq. (6):

$$S_{\Delta P}=\sqrt{\frac{1}{n-1}\sum_{i}\left(\Delta P/\overline{\Delta P}-1\right)^{2}} \tag{6}$$

Where ΔP is the pressure at various times, Pa; $\overline{\Delta P}$ is the average pressure drop, Pa; and n is the measurement time. The lower $S_{\Delta P}$ indicates a stable pressure drop. In contrast, higher $S_{\Delta P}$ indicates poor fluidization behavior. As shown in Fig. 6, pressure drop fluctuation presented the increasing trend, further indicating that more middle particles would have the negative effect on the bed fluidization behavior and separation efficiency.

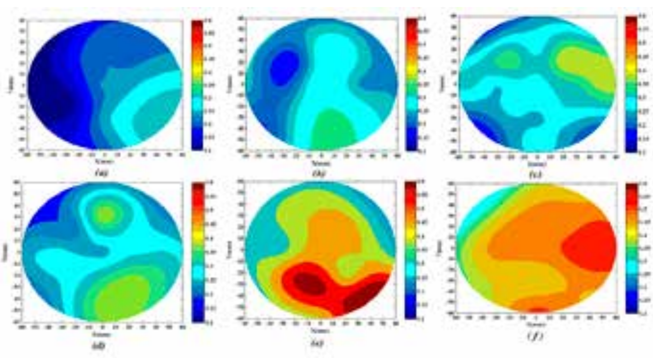


Fig. 6. Pressure drop fluctuations with various ***G**middle*, (a) ***G**middle*=0; (b) ***G**middle*=2; (c) ***G**middle*=4; (d) ***G**middle*=6; (e) ***G**middle*=8; (f) ***G**middle*=10

CONCLUSIONS

In this study, the separation behavior of feed particles with various components and densities was analyzed in ADMFB. The results depicted that the particles of lowest density and highest density have the stable separation behavior due to the density variation. With more particles of middle densities introduced, the phenomenon of particles mixing with various densities would be appeared in fluidized bed. The pressure drop fluctuation also presented the increasing trend with more particles of middle densities introduced. Based on the above analysis, the particles of middle density should be removed from the fluidized bed to avoid mixing of feed particles in the practical production. Based on the above analysis, the MDP could be removed from the fluidized bed as soon as possible by the technical means to avoid the defluidized area generated and keep the separation density stable, which could decrease the mismatch ratio and ensure thorough segregation of particles of various densities.

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