CHARACTERISTIC OF FINE COAL DENSITY SEGREGATION IN GAS-VIBRO FLUIDIZED BED

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Abstract - Coal is the main energy source of our country, and has made important contribution to the development of national economy, meanwhile brought serious environmental pollution. Coal preparation is the most cost-effective way to clean coal, which can remove harmful substances from coal. More than 2/3 of China's coal is distributed in arid and water-deficient areas. With the increasing shortage of water resources, the traditional wet coal preparation technology cannot meet the needs of large-scale coal processing. There is an urgent need for efficient dry coal preparation technology. With the increase of fine coal content in raw coal, the high-efficiency dry separation technology of fine coal becomes increasingly important. In this paper, the forced vibration energy of pulsating airflow is introduced into a dense fluidized bed. The influence of the frequency of airflow pulsation on the spatial and temporal distribution of the bed density is studied. The density of the bed is gradually increased from the top to the bottom in the middle frequency zone, which is suitable for the classification of fine coal. The effect of gas pulsation frequency and gas velocity on fine coal density segregation was studied by dense pulsating fluidized bed. The experimental results show that the pulsating airflow of appropriate frequency can be strengthened - 6 + 1 mm fine coal in the fluidized bed density separation effect. And a significant desulfurization performance is shown by pulsing air dense medium fluidized bed separator.

Key words: fine coal, pulsating airflow, fluidized bed, density segregation

INTRODUCTION

Coal, which is the main energy source of China, takes accounts for about 67% in China’s energy consumption structure. As the main material of coal-fired power generation, chemical, steel and other industries, coal has made an important contribution to the development of China’s national economy. However, it is contained variety of harmful elements in coal, which the sulfur content of the most. During the combustion process, the sulfur element in the coal will produce sulfur oxides, the most important reason of acid rain. Coal beneficiation is the most cost-effective way to remove harmful elements. In 2016, the “Energy Technology Revolution Innovation Action Plan (2016-2030)” issued by the National Development and Reform Commission and the Energy Bureau proposed that the selection rate will increase to 80% by 2020. More than 2/3 of China’s coal is distributed in dry areas in the west. Wet coal preparation technology, such as heavy medium cyclone, interference bed separation machine and flotation, etc. in the course of work need to use or consume large amounts of water. It cannot meet the requirements of large-scale upgrade processing of coal in dry area. Lignite and other low rank coal, which is easily mud, should not use wet coal preparation technology. Therefore, an efficient dry coal preparation technology is urgent needed.

In recent years, dry coal preparation technology has become one of the research hotspots in mineral processing engineering at home and abroad. Composite dry separation machine (FGX) is mainly used for separation lump and gangue (E. Löffler,2010; B. Zhang et al., 2011). According to reports, FGX separation machine’ separation efficiency is better for the coal of -63.5 +4.75 mm, and the value of possible deviation E is 0.17. Air jig is an air separation equipment, Brazilian scholars use air jig to separate Brazil's high ash high sulfur coal, the ash content decreased from 52.32% to 47.11% after separation, the value of possible deviation E is 0.26 (C.H. Sampaio et al., 2008). The air dense fluid fluidized bed separation technology proposed by China University of Mining and Technology uses the magnetite powder and the coal powder as the binary compound medium. It uses compressed air as fluidizing gas, forming a uniform density and stability of gas-solid two-phase suspension, which can separate coal by density (Y. Zhao et al.,2012). The separation precision of the air-dense medium fluidized bed is higher than that of the FGX separation machine and the air jig, which can reach 0.05, and its effective separation granularity is -100 + 6 mm. However, with the increase of coal content of -6 mm fine coal in the raw coal, efficient dry-separation technology of fine-grained coal becomes increasingly important. The gas-solid pulsating fluidized bed is a kind of fluidized bed which changes the continuous flow in the traditional fluidized bed into the periodic changing flow. The pulsating airflow introduces the forced vibration energy into the gas-solid fluidized bed (Chenlong Duan et al.,2015; Dong. L et al.,2014 and 2015). In this paper, a pulsating airflow is introduced into the air-dense fluidized bed to form a dense gas-solid pulsating fluidized bed. Density distribution of time and space, fine coal density and segregation characteristics by the effect of the pulsating airflow forced vibration energy on the minimum fluidization velocity of the air-dense fluidized bed is studied.

EXPERIMENTAL

The experimental system in this study, as shown in Figure 1, mainly contains the air device, pulsating airflow generating device and fluidized bed separator. The pulsating airflow generating device is composed of a butterfly valve, a motor and a frequency converter. The motor drives the butterfly valve to rotate to produce pulsating airflow. The ripple frequency is regulated by the frequency converter controlling the motor speed. The inner diameter of the fluidized bed is 200 mm, and the static bed height is 100 mm. The binary medium in the fluidized bed model machine is composed of magnetite powder and fire coal. The particle properties are shown in Table 1, and the average particle size of the medium particles was 232 μm.

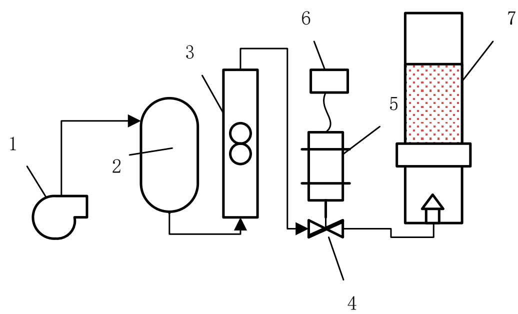

Fig. 1 Schematic of gas-vibro fluidized bed separation system: 1-Blower; 2-Buffer tank; 3-Flowmeter; 4-Butterfly; 5-Electric motor; 6-Inverter; 7- Fluidized bed.

Table 1 Properties of binary heavy medium

	True Density/kg.m^{-3}	Bulk Density/kg.m^{-3}	Particle Size/mm	Mass Ratio/%
Magnetite	4600	2650	-0.3+0.074	95
Coal Powder	2130	1300	-0.15+0.045	5

METHOD

Evaluation of Density Segregation Effect of Fine Coal

The mechanism of the air dense medium separation is shown in Figure 2. The coal particles entered the fluidized bed are density-segregated according to the difference between the coal particle's density and the bed's density. Low-density particles floating in the bed surface become clean coal products, and high-density particles sink in the bottom of the bed become gangue products. In this paper, the density segregation standard deviation is used to evaluate the effect of coal segregation in the fluidized bed, as shown in equations (1) and (2). The greater the standard deviation of the density segregation, the better the effect of coal segregation by density.

$$\sigma_{ash} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}[A(i)-\overline{A}]^2} \tag{1}$$

$$\overline{A} = \sum_{i=1}^{n} A(i)\gamma(i) \tag{2}$$

Where, σ_{ash} is the standard deviation of ash separation, n is the number of stratified sampling, $A(i)$ is the ash content of the i layer,, $\gamma(i)$ is the yield of the i layer. $\overline{A}$ is the weight average of ash content of each layer, which theoretically should be equal to the original coal ash content.

The effect of pulsating airflow on the separation of fluidized beds was characterized by the ratio $(\sigma_{ash})_p/(\sigma_{ash})_c$ of the standard deviation $(\sigma_{ash})_p$ of the dense pulsating fluidized bed to the standard deviation $(\sigma_{ash})_c$ of the conventional air-dense fluidized bed. When $(\sigma_{ash})_p/(\sigma_{ash})_c = 1$, it indicates that pulsating airflow has no effect on the separation efficiency of sorted fluidized bed and the separation performance is the same as that of the traditional air dense medium fluidized bed. When $(\sigma_{ash})_p/(\sigma_{ash})_c <$ 1, it indicates that the pulsating air flow destroys the uniformity of the density of the fluidized bed, reduces the fluidization quality of the sorted fluidized bed, and deteriorates the separation efficiency. When $(\sigma_{ash})_p/(\sigma_{ash})_c > 1$, it indicates that pulsating airflow strengthens the fluidized dry separation process of fine coal and improves the separation efficiency of sorted fluidized bed.

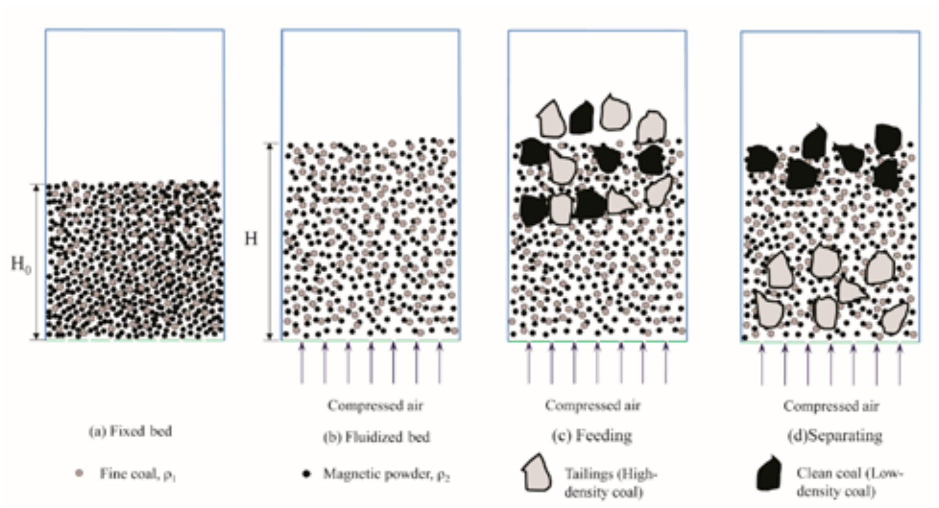

Fig. 2 Mechanism of the air dense medium separation (Y. Zhao et al., 2017)

RESULTS AND DISCUSSION

Temporal and spatial distribution of bed density

Coal particles are separated by density in dense pulsating fluidized bed. Particles smaller than the bed density floats on the surface of the bed and become fine coal, particles larger than the bed density sink in the bottom of the bed and become gangue. Therefore, the uniformity and stability of bed density in dense pulsating fluidized beds is the most important factor to determine the separation efficiency. For the pulsating fluidized bed, the gas pulsation frequency is one of the key factors influencing bed density.

The densities of the upper, middle and bottom beds in the dense pulsating fluidized bed were sampled for 60 s. The image density of the bed is reconstructed after averaging. The spatial distribution of the density is shown in Figure 3 (as an example of f = 5.24 Hz). As shown in Figure 4, the mean value and the standard deviation of the fluctuation frequency were calculated, respectively. According to the characteristics of bed density and density fluctuation, the pulsating frequency of airflow is divided into low frequency ($f \in (0, 2.5]$), intermediate frequency ($f \in (2.5, 4.1]$) and high frequency ($f \in (4.1, +\infty)$) region.

In the low-frequency region, bed density fluctuates greatly, especially in the lower and upper layers of the fluidized bed. For the lower layer of the fluidized bed, the continuous flow of gas for a long time to aggravate the particles, resulting in a large number of bubbles in the bed, resulting in bed density fluctuation. For the upper layer of the fluidized bed, the bubble in the bed moves, merges and grows in the bed, and the breakage of the large-scale bubbles on the free surface of the bed seriously affects the uniformity of bed density. For the middle layer of the fluidized bed, there is an additional motion of the gas in the bed during the pulsating airflow closing stage, so that the particle layer in the middle part of the bed will continue to show a fluidized state in the gas-flow closing stage, the bed density fluctuation is not significant. In the intermediate frequency region, the lowest and highest frequencies are the same frequencies in the middle and lower layers of the fluidized bed. In this frequency range, the density fluctuation of the middle and upper layers in the fluidized bed is very small, and the density fluctuation of the lower layer is still large. Bed density from top to bottom showed an increasing trend, the density of the upper layer of the fluidized bed is the smallest, the density of the lower layer is the largest. This feature is conducive to separation of coal in the separation fluidized bed. In the upper layer of the fluidized bed, the coal particles are sorted at low density. Then the high density particles enter the middle of the bed and are stratified by mid-layer density. At last the higher density particles enter the bottom of the bed. Thereby achieving the coal particles were separated by gradient density.

In the high-frequency region, the density of the upper layer of the fluidized bed is still the lowest in the whole bed, and the density fluctuation is larger than that in the intermediate frequency region. The density fluctuation of the lower layer of the fluidized bed is smaller than that of the intermediate frequency region. With the increasing of the pulsation frequency, the amplitude of fluctuation decreases. In this region, the density of the layer in the fluidized bed is greater than the density of the underlying layer. The density distribution of the whole bed shows a large distribution in the middle and small in the two ends. This distribution of density will result in the deposition of high-density coal particles in the middle of the bed without settling to the bottom of the bed. This situation led to the separation of particles by density is blocked, and separation efficiency and accuracy are decreased.

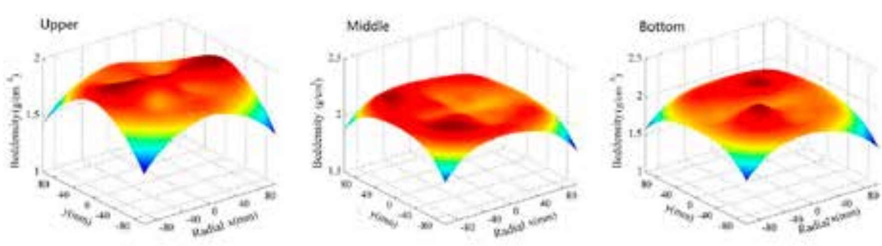

Fig.3 Contour of bed density at high-frequency region (f=5.24 Hz)

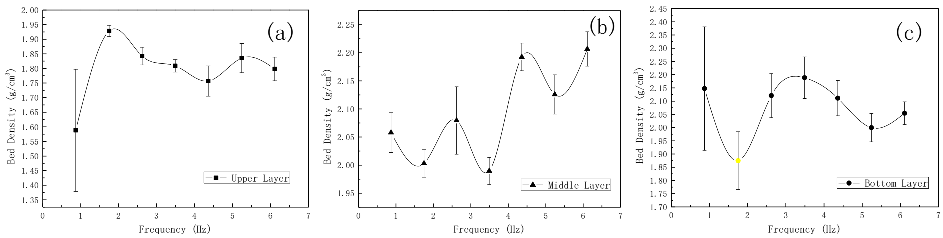

Fig.4 Bed density vs. gas pulsation frequency in pulsed fluidized bed (a)Upper layer; (b)Middle layer; (c)Bottom Layer;

Density Segregation of Fine Coal

The dense pulsating fluidized beds were used to classify -6 + 3 mm and -3 + 1 mm fine-grained coal in order to study the effect of pulsating air flow on the separation efficiency. The effect of pulsating airflow on -6 + 3 mm fine coal separation is shown in Figure 5. In the low frequency region, the separation effect of the dense pulsating fluidized bed is obviously worse than that of the traditional air-dense medium fluidized bed. In the middle frequency region, the separation efficiency was improved significantly, the ash content separation standard deviation increased by 10% or more. In the high frequency region, the separation efficiency of the dense pulsating fluidized bed begins to decrease, even with the conventional ADMFB separation efficiency. From the above studies, it is found that the pulsating fluidized bed has the best separation efficiency when the fluidization number is N = 1.2. However, when the fluidization number is N = 1.3 in the intermediate frequency region and the high frequency region in Fig. 4, the effect of the pulsating airflow on the separation effect is remarkably higher than that of the other operating gas velocities. The main reason is that in the conventional air-dense fluidized bed, the bubble size is large, and with the increase of the operating gas velocity, the bubble diameter increases and the bubble motion is violent. After the introduction of the pulsating gas flow, the size of the bubble under the high operating gas velocity is obviously reduced. Therefore, the improvement of the separation effect is most significant.

For the separation of -3 + 1 mm fine coal, the effect of pulsating air flow is shown in Fig 5. Different from -6 + 3 mm fine coal classification, the effect of pulsating airflow on the separation efficiency is more remarkable when the fluidization number N = 1.1 and 1.2 in the middle and high frequency region. But when N = 1.3, almost no improvement was observed. The reason for this is that the bubble size increases as the operating gas velocity increases. Although the pulsating airflow can reduce the bubble size, the bubble size is still larger than the particle size of the feed particles, and the feed coal cannot be effectively sorted. While at low fluidizing velocity, the bubble size is smaller, and after introducing the pulsating air, the bubble size is further reduced to smaller than the diameter of the feed particles. In addition, the pulsating air flow increases the bed activity at low operating gas velocities, resulting in a significant increase in separation efficiency.

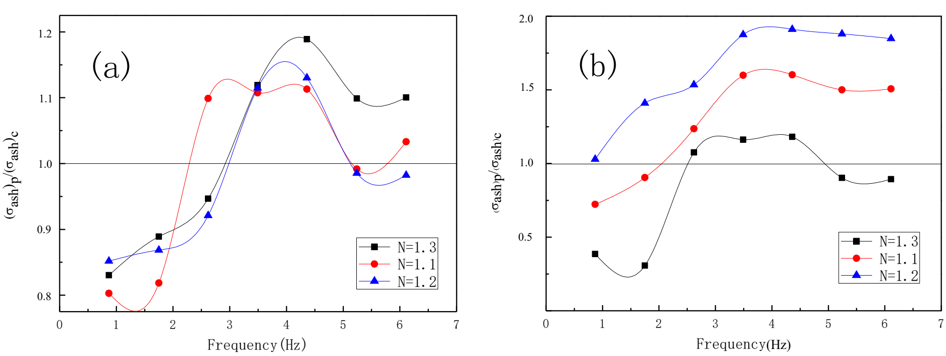

Fig. 5 Efficiency of pulsing gas flow on the separation of fine coal (a)−6+3 mm; (b) −3+1 mm

Desulfurization

Sulfur is mainly present in the form of pyrite in coal. In order to explore the migration of sulfur in the process of coal separation, the raw coal, clean coal and gangue were detected by XPS, the test results by Dong (2015) is shown in Figure 6. As shown in Figure 6 (a), sulfur mainly in the form of organic sulfur, sulfate and pyrite in raw coal. Quantitative analysis showed that the content of organic sulfur, sulfate and pyrite in raw coal was 1.61%, 0.07% and 2.01% respectively. However, the analysis result of clean coal, as shown in Figure 6(b), shows that sulfur is in the form of organic sulfur in clean coal, with the content of 1.07%. And in the gangue, as shown in Figure 6(c), all three forms of sulfur were found. The contents of organic sulfur, sulfate and pyrite were 1.33%, 4.16% and 7.03%, respectively.

In general, the desulphurization capacity of the gas - solid fluctuating fluidized bed is significant. Due to the difference in density, pyrite sinks to the bottom layer along with gangue. However, due to the strong bond between organic sulfur and coal molecules, organic sulfur cannot be removed by physical methods, clean coal still contains a small part of the sulfur.

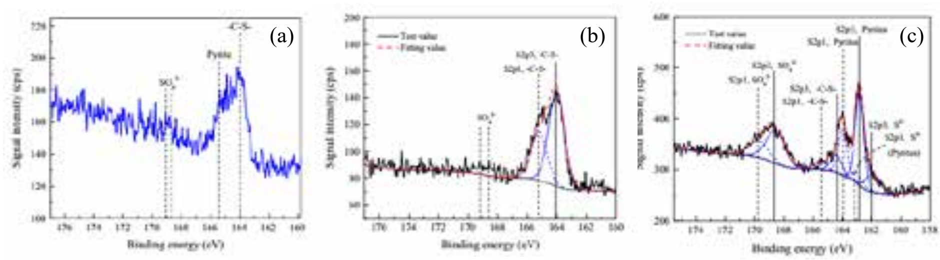

Fig.6 XPS Analysis result of raw coal, clean coal and gangue (a)raw coal (b)clean coal (c)gangue (Dong. L, 2015)

CONCLUSIONS

(1) The fluctuation of pressure and density in a dense pulsating fluidized bed is a stationary random signal of all states, and its statistical properties are deterministic, and the statistical properties of each sample collected by time division can represent the whole bed system features various states experienced.

(2) The effect of pulsating airflow on the bed density of dense pulsating fluidized bed is obvious. When $f \in (2.5, 4.1)$ Hz, the bed density increases from the free surface of the bed to the bed bottom. And it is most dramatic density fluctuation at the bottom of the bed.

(3) The desulphurization capacity of the gas - solid fluctuating fluidized bed is significant. The content of sulfur formed in pyrite and sulfate is greatly reduced in clean coal. A great significance for reducing sulfur emissions is shown by fluctuating fluidization.

REFERENCE

B. Zhang, H. Akbari, F. Yang, M.K. Mohanty, J. Hirschi, Performance Optimization of the FGX Dry Separator for Cleaning High-Sulfur Coal. International Journal of Coal Preparation & Utilization, 2011.(31): 161-186

Chenlong Duan, Wenchao Yuana, Luhui Cai, Keji Lv, Yuemin Zhao, Bo Zhang, Liang Dong, Peng Lv. Characteristics of fine coal beneficiation using a pulsing air dense medium fluidized bed, Powder Technology, 2015,283: 286-293.

C.H. Sampaio, W. Aliaga, E.T. Pacheco, E. Petter, H. Wotruba, Coal beneficiation of Candiota mine by dry jigging. Fuel Processing Technology, 2008.(89):198-202

Dong. L,Zhang.Y ,Zhao.YM ,Wang.HK,et al. Deash and desulfurization of fine coal using a gas-vibro fluidized bed, Fuel,2015,155: 55-62

Dong. Liang, Zhao.Yuemin, Duan. Chenlong,et al. Characteristics of bubble and fine coal separation using active pulsing air dense medium fluidizedbed, Powder technology,2014,257:40-46

Dong, L. Zhou, L. Cai, C. Duan, Y. Zhao, and Z. Luo, 2016, Fluidization Characteristics of a Pulsing Dense-Phase Gas–Solid Fluidized Bed for High-Density Separation of Fine Anthracite: Energy & Fuels, v. 30, p. 7180-7186.

E. Löffler, Application of the FGX separator in the enrichment of catalagzi coal: A simulation study. 2010.18:562-570

Mohanta, S., C. S. Rao, A. B. Daram, S. Chakraborty, and B. C. Meikap, 2013, Air Dense Medium Fluidized Bed for Dry Beneficiation of Coal: Technological Challenges for Future, v. 31, p. 16 - 27.

Wang, X. S., and M. J. Rhodes, 2005, Using pulsed flow to overcome defluidization: Chemical Engineering Science, v. 60, p. 5177-5181.

Y. Zhao, L. Tang, Z. Luo, C. Liang, H. Xing, C. Duan, S. Song, Fluidization Characteristics of a Fine Magnetite Powder Fluidized Bed for Density-Based Dry Separation of Coal. Separation Science & Technology, 2012.47:2256-2261

Y. Zhao, G. Li, Z. Luo, B. Zhang, L. Dong, & Liang, C., et al. Industrial application of modularized dry coal beneficiation technique based on a novel air dense medium fluidized bed. International Journal of Coal Preparation & Utilization.2017

Y. Zhao, L. Tang, Z. Luo, C. Liang, H. Xing, W. Wu, and C. Duan, 2010, Experimental and numerical simulation studies of the fluidization characteristics of a separating gas–solid fluidized bed: Fuel Processing Technology, v. 91, p. 1819-1825.

Zeilstra, C., M. A. van der Hoef, and J. A. M. Kuipers, 2013, Experimental and numerical study of solids circulation in gas-vibro fluidized beds: Powder Technology, v. 248, p. 153-160.