RESEARCH ON AIR DENSE MEDIUM FLUIDIZED BED FLUIDIZATION CHARACTERISTICS UNDER THERMAL CONDITIONS

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Abstract - The thermal fluidization and separation characteristics of air dense medium fluidized bed were investigated by measuring the pressure drop in the rectangular fluidized bed model which is made of organic glass. The relationship between critical fluidization velocity and air inlet temperature was built up. Meanwhile, the bed layer density stability affected by air inlet temperature was reflected by the fluctuation of pressure drop and bed density. Experimental results shows that the temperature field can improve fluidization characteristics in a certain range; When the air inlet temperature is about 120℃, the value of bed pressure drop fluctuation standard deviation can reach the minimum value of 0.5 Pa. The value of bed density fluctuation standard deviation is lower as the temperature is between 80℃and 120℃. The separation performance is verified by using the model machine to separate raw coal, the results revealed that when *T* is120℃, the probable error E value reaches 0.09. Indeed, by substituting the normal air into thermal, it provides a good approach to improve the separation performance, and the basic theory to regulate the operation indexes in practical separation process is also established.

Keywords - Fluidized bed; temperature; fluidization characteristics; separation

INTRODUCTION

The air-dense medium fluidized bed sorting technology is an efficient separation technology for coal dry separation, which provides a new path and mode for the development and application of coal preparation technology in arid and dry areas of the world[1,2]. The main principle is that a pseudo-fluid formed by air and dense medium is used to separate materials by density, so a uniform and stable bed density is an important condition to ensure the accuracy of material separation. The stability of the bed is affected seriously by the density and viscosity of the medium. However, the long-term operation of the system inevitably leads to the rise of the separating temperature. The properties such as density and viscosity of the gas phase are affected by the temperature, which will inevitably affect the fluidization properties of gas-solid two-phase fluidization.

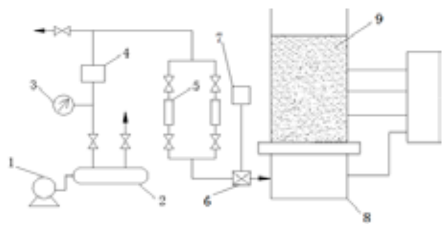
(Lettieri P. et al., 2001) measured the effect of temperature on the critical fluidization velocity of particles in a small-sized fluidized-bed apparatus with an inner diameter of 105 mm. The experimental results show that the critical fluidization rate of different particles varies with the temperature. (Hilligardt K. et al., 1987, Guo Q. J., et al., 2002) studied the change law of the fluidized Geldart D particle with the bubble size, and found that the rising temperature will cause the reduction of bubble size, which will inevitably affect the uniformity of the fluidized bed stability. As a result, many of the basic properties of the fluidized bed will change due to the increased operating temperature of the bed, which illustrated in (Otake T., et al., 1975, Fan L. T., et al., 1986, Mii J., et al., 1973). Researches of (Siegell J. H.1988, Tone S., et al.1974, Botterill J S M, 1977) on the effect of temperature on the fluidized bed has focused mainly on the change rate of chemical reaction process, . Therefore, it is necessary to study the fluidization characteristics and uniformity stability of the thermal fluidized bed. This not only provides theoretical guidance for the setting of operating parameters in the actual production process, but also provides technical support for integration technology of lignite drying and sorting.

EXPERIMENTAL SYSTEM AND METHODS

Experimental system

The experiment system is mainly composed of five parts: air supply system, fluidized bed system, heating system, temperature control system and measurement system, as shown in Fig. 1. A roots blower was used to supply the air for the fluidized bed system, and the experiment pressure was controlled at 0.02 MPa. The butterfly valve was adjusted to control the air flow according to the rotor flow meter. The air flow was heated by an air duct heater and the temperature was adjusted by a PXR5TEY1-8W000-C heating controller, so that the temperature fluctuation range was less than 2℃. The bed pressure drop was calculated by the liquid level difference in U-tube pressure measurement device.

The fluidized bed is mainly composed of three parts: separation bed, air chamber and air distributor. The rectangular bed (300mm×200mm×500mm) is made of transparent plexiglass for the convenience of observation. The air distributor consists of a plexiglass perforated plate and a double-layer filter cloth, and the diameter of holes of the porous plate is 3 mm with an opening ratio of 22.5%. The lower air chamber is welded by a steel plate. The fixed height scale of the bed side is used to calibrate the height of the fluidized bed and the sampling height. In addition, to facilitate the measurement of bed pressure drop during fluidization, a pressure point was set at 30 mm intervals on the side of the bed, and a plug-in pressure probe was prepared to measure the internal pressure drop.



1-Roots blower 2-Air tank 3-Manometer 4-Filter 5-Flow meter 6-Air duct heater

Fig.1. Experimental system

Materials

Dense medium is the wide size fraction of magnetite powder whose true density is 4200 kg/m^3, the magnetic content is 99.71%, and the magnetization is 77.21 emu/g. Raw coal of 25~13mm was selected as separation materials. In order to ensure the consistency of the selected material properties and simplify the experiment, different density particles were coated with different colors. The density distribution and their ratio are shown in Table 1.

Table 1 Float-sink components of raw coal

Density fraction（kg·cm^{-3}）	Weight/g	Yield/%
<1.4	46.00	12.85
1.4～1.5	81.41	22.74
1.5～1.6	15.14	4.23
1.6～1.8	17.58	4.91
1.8～2.0	16.79	4.69
>2.0	181.11	50.59
Total	358	100

Experimental methods

After the dense mediums were added into the fluidized bed, the roots blower and air duct heater were opened in sequence. The air flow goes into the air tank through the roots blower, then heated by the air duct heater as it is stable. The air volume and air pressure were regulated by the main air damper and bypass air valve. When the outlet air reached the target temperature, the valve was opened to take the air into the lower air chamber of the bed, and the air flow was evenly distributed into the bed by the air distributor. The height of the static bed is designed at 180mm.

As the gas velocity increases, pressure drop of the bed changes. During the experiments, pressure drop was measured at different locations in the vertical direction of the fluidized bed. The arrangement of the pressure measurement points on the cross section of the bed was shown in Fig. 2. The fluidized properties of the fluidized bed were determined by plotting the bed fluidization curve and the standard deviation of the fluidized bed pressure.

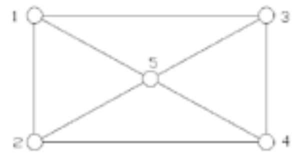


Fig.2. The distribution of pressure measurement points on a cross-section of fluidized bed

The standard deviation of the pressure drop fluctuation is calculated by the formula (1).

$$\sigma_p = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(p_i - \bar{p}\right)^2} \qquad (1)$$

Where σ_p is the standard deviation of the pressure drop fluctuation; N is the number of measured pressure group, p_i is the pressure value of i^{th} group; $\bar{p}$ is the average pressure of all groups.

The bed density is calculated by the static equation (2). The standard deviation of the density fluctuation is calculated by the formula (3).

$$\Delta p = \rho g \Delta h \qquad (2)$$

$$\sigma_\rho = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(\rho_i - \bar{\rho}\right)^2} \qquad (3)$$

Where Δp is the pressure difference between two fixed points; ρ is the density between two points; Δh is the distance between two points. σ_p is the standard deviation of the pressure drop fluctuation; p_i is the i^{th} group pressure value; $\bar{p}$ is the average pressure of all groups.

RESULTS AND DISCUSSION

The impact of temperature on the critical fluidization gas velocity

The critical fluidization gas velocity (U_{mf}) of the bed is the minimum operating gas velocity at which the bed changes from a fixed state to a fluidized state. It is also a key parameter to evaluate the fluidization behavior of the granular material. Therefore, it is necessary to study the critical fluidization gas velocity.

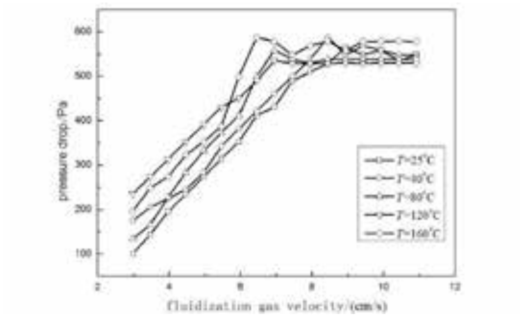


Fig.3. Fluidization characteristics curves at different temperatures

In order to verify the relationship between the critical fluidization gas velocity and the temperature, fluidization curves at different inlet temperature were obtained. In Fig. 3, the fluidization curves gradually shift to the left with the inlet gas temperature increases. The critical fluidization gas velocity was determined according to the intersection of the oblique line of the fixed bed and the horizontal line of the fluidized bed. The critical fluidization velocity decreases with the increasing temperature. The critical fluidization gas velocity of different temperature is shown in Fig. 4.

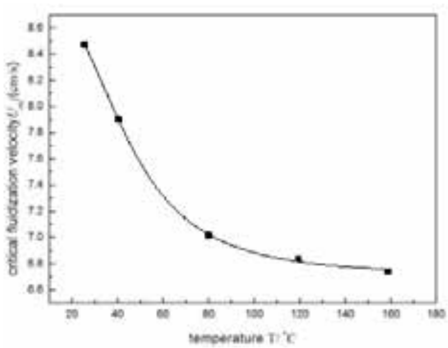


Fig.4. Regression curve between critical fluidization velocity and temperature

In Fig. 4, regression analysis was carried out by Origin 8.5, and the regression model between the critical fluidization gas velocity and the inlet temperature was obtained and shown in formula (4).

$$U_{mf} = 6.69 + \frac{2.17}{1+\left(T/43.59\right)^{2.85}} \quad (4)$$

The regression coefficient was 0.99766, which indicated that the model was more accurate. There is a negative correlation between the critical fluidizing gas velocity and the inlet temperature.

The impact of temperature on the bed pressure drop

Figure 5 shows the standard deviation of the pressure fluctuation at different inlet temperatures at $U\text{-}U_{mf} = 2$ cm/s. The standard deviation of the pressure drop in the bed of ordinary fluidized bed is 9.91 Pa. In the case of hot air the standard deviation of the pressure drop in the fluidized bed can reach 0.50Pa, which indicates that the thermal air flow has some effect on the stability of the fluidized bed in a certain temperature range. This is because the increasing temperature changes the pressure distribution in the fluidized bed, thus affects the bubble growth process. At the same time, it can be seen that when the temperature reaches 160℃, the standard deviation of bed pressure drop fluctuates greatly and the stability of the bed decreases. The reason is that the phase boundary between the bubble phase and the emulsion phase is unstable, the standard deviation of fluctuation becomes larger. So the operating temperature must be controlled in the appropriate range to reduce the pressure drop fluctuation range, thereby enhance the stability of the fluidized bed. In this experiment, when the operating temperature is about 120℃, the pressure drop fluctuation is the smallest, and the bed is basically in a stable state.

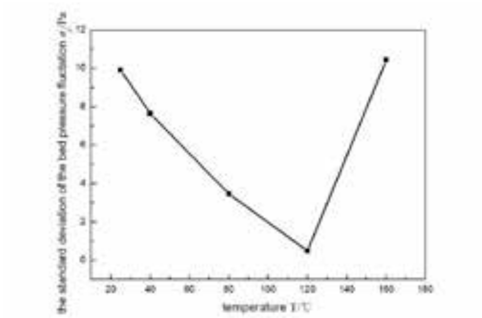


Fig.5. The standard deviation of the bed pressure fluctuation under different temperature at $U-U_{mf}$=2cm/s

Effect of temperature on bed stability

Five points of the cross-section in the bed were chosen as the measure points, the location distribution of these points is shown in Fig. 2.

Fig. 6. shows the lateral density distribution of the bed height of 40~60mm. It can be seen from the figure that under the condition of hot air, the standard deviation of bed density fluctuation of fluidized bed decreases with the increase of fluidization gas velocity, and the bed layer tends to be stable. But they have little relation under low temperature. By the analysis of standard deviation of density distribution, when the gas temperature rises, the standard deviation of the bed density fluctuation is reduced and the fluctuation situation is eased. When the gas velocity is 7.94cm/s, the standard deviation of bed density fluctuation decreased with the rising temperature. When the temperature reached 120℃, the standard deviation of bed density fluctuation fade from 0.341 at room temperature to 0.196. But the tendency will disappear with the continue rising of temperature and turn to increase. When the temperature reached 160℃, the standard deviation increases to 0.316. When the gas velocity is 8.93cm/s and 9.92cm/s, the temperature raised to 120℃, the standard deviation of bed density fluctuation fade from 0.326 and 0.198 at room temperature to 0.183 and 0.114 separately. So, when the temperature is around 120℃, the minimum value occurs in the standard deviation curve of bed density fluctuation, the density fluctuation of the fluidized bed is small and tends to stabilization.

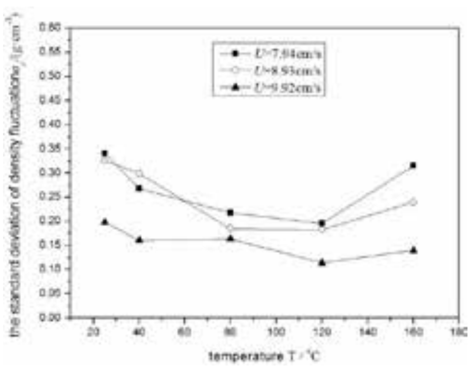


Fig.6. The fluctuation variance of the layer density of 40～60mm

The variation of lateral density at the height of 80~100mm and 120~140mm were shown in Fig. 7 and Fig. 8. As a whole, the temperature plays a role in promoting the density stability of the fluidized bed in a certain temperature range. When the temperature ranges from 80~120℃, a lower value area appears in the standard deviation of the density fluctuation, and the change of bed density is moderate. From the micro perspective, if the individual heavy particles were seen as microscopic individuals, each affected by air drag and suspension. It is in a random movement similar to the Brown movement, the temperature rises, gas density decreases, viscosity increases, the drag force acting on particles is relatively large, and especially have a great promotion to the uniform mixing of coarse particles. From the macro perspective, when the gas-solid fluidized bed was seen as a unit, the rising temperature makes the particle size distribution become uniform, improves the uniformity and stability of the bed, and reduces the standard deviation of the bed density fluctuation. However, when the temperature exceeds the range and reaches 160℃, the back mixing phenomenon of dense medium is more intense, and the fluidization becomes worse, which has a significant impact on the separation. This is due to the impact of new unstable factors produced by high temperature, such as high temperature leading to the obvious change of the bubble size, location channeling phenomenon induced by large viscosity.

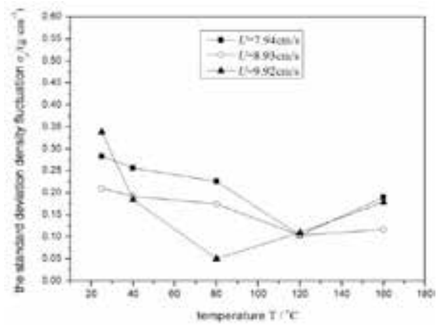
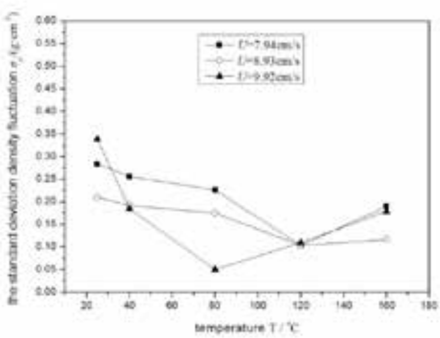


Fig.7. The fluctuation variance of the layer density of 80～100mm



Fig,8. The fluctuation variance of the layer density of 120～140mm

Separation experiments

In order to further verify the separation performance of hot air dense medium fluidized bed, the raw coal separation test was carried out on the model machine. The following is mainly to investigate the influence of two factors of temperature *T* and fluidized gas velocity *U* on the separation efficiency. In order to make fluidized bed in the uniform bubble state which is benefit for separation, the fludized gas velocity is controlled at 10.47~13.78cm/s and the temperature at 80~120℃ to make the bed in a relatively stable state. It was determined that 5min is the best separation time by exploratory experiment. Cut off the gas source immediately when the separation was finished and divide the bed into two layers uniformly. The materials of upper and lower layers were taken out in turn. The upper layers is coal and the lower layers is gangue after screening away dense mediums. The two products were weighted, and the probable deviation *E* was obtained by the distribution curve for the evaluation norm of the separation effect. The results of separation experiments is shown in Table 2. The calculated equation of *E* as follows:

$$E = (\delta_{75} - \delta_{25})/2 \tag{5}$$

Where δ_{75} means the corresponding density at the distribution ratio of 75%, δ_{25} means the corresponding density at the distribution ratio of 25%.

Table 2 Summary sheet of separation test results

Factors / Test number	Temperature T，℃	Fluidization velocity U，cm/s	Probable deviation E，g/cm^3
1	80	10.47	0.295
2	80	12.13	0.155
3	80	13.78	0.185
4	120	10.47	0.175
5	120	12.13	0.140
6	120	13.78	0.090
7	160	10.47	0.215
8	160	12.13	0.130
9	160	13.78	0.185
Blank	25	12.13	0.220

From the analysis of Table 2, all the experimental materials are mismatched to some degree, the probable deviation of separation experiments is up to 0.220 at room temperature, and the stability of bed is poor. A lot of light products are mismatched into precipitate, and obvious stratification is existed in the bed. On the contrary, the separation effect has some improvement, and the probable deviation can reduce to $0.09g/cm^3$ at the optimal conditions. It clearly demonstrates that the separation effect of air dense medium fluidized bed under thermal conditions is better than that of the ordinary air dense medium fluidized bed.

CONCLUSIONS

(1) Both the theoretical derivation and the experimental formula show that the temperature affects the critical fluidization gas velocity, the higher the temperature is, the smaller the critical fluidization gas velocity is.

(2) With the increase of gas velocity, the ordinary fluidized bed will fluctuate in different degrees after the gas velocity reaches the critical fluidization velocity. However, the fluctuation of bed pressure drop reduced under the hot air condition, the standard deviation of pressure drop fluctuation has a minimum value of 0.5Pa when the temperature is controlled around 120℃, and the bed remains stability.

(3) The separation effect of air dense medium fluidized bed under thermal conditions is better than the ordinary air dense medium fluidized bed. The separation effect gets the best value when the temperature is 120℃, and the possible deviation E value can be reduced to $0.09g/cm^3$.

NOTATION

σ_p	standard deviation of pressure drop fluctuation	p_a	p	pressure	p_a
N	number of measured pressure group		ρ	density	kg/cm^3
Δh	distance between two points	cm	U_{mf}	critical fluidization gas velocity	cm/s

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