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REGIONAL FEATURES ANALYSIS OF PLUGGED HOLES OF DENSE PHASE GAS-SOLID SEPARATION FLUIDIZED BED

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Abstract: In contrast to traditional coal separation, dry separation does not require water and does not cause water pollution. Dense phase gas–solid fluidized beds are used for dry separation. The plugged holes in the air distributor should be tested to ensure the stability of these beds for particle separation. The pressure fluctuation is sensitive to these plugged holes. This sensitivity can be tested and diagnosed by determining the standard deviation of the pressure fluctuation. In areas with partial blockage, that is the areas with weak fluidization, a decrease in the volume fraction of the particles and in the pressure differences in the transverse of the bed results in an increase of the standard deviation of the pressure fluctuation, thereby stimulating the lateral mixing of medium-sized particles. The standard deviation and the mixing intensity decrease axially. The value of sensitivity of the plugged holes in the air distributor decreases as the height of the bed increases. The features of air distributors affect the surrounding areas. The distribution law determining the influence of plugged holes on the beds is symmetrical. As the blockage of the fluidized bed distributor region increases, the mean square error of the pressure fluctuation in the related regions increases. The intensity of the effect is proportional to the distance to the plugged holes.

Keywords: *gas-solid fluidized bed for separation, pressure fluctuation, plugged holes regions, features analysis, plugged holes sensitivity*

Introduction

Coal plays a predominant role in China's energy consumption structure (National Bureau of Statistics of China, 2012). As the main energy source, coal will make great contributions to the national economic development for a long time (IBGE census, 2011). Meanwhile, it will also bring serious environmental pollution for its raw coal of poor quality, and high ash and sulfur content. Low ash coal with less than 10% ash

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content accounts for 15%-20% of recoverable deposits. High sulfur content coal with more than 1% sulfur content accounts for 33% of the total. Coal preparation is an economic and effective method to reduce smoke dust and SO_2. It is the prerequisite of deep processing of coal and one of key technologies of energy conservation and emission reduction (World Energy Council, 2010). More than two-thirds of coal resources in China are distributed in arid areas. As the coal mining is transferred to arid areas, wet coal preparation is under restrictions. Moreover, because of ample lignite resources which are easy to slime, it is inappropriate to adopt wet separation. Therefore, it is necessary to develop effective dry separation (Chen and Yang, 2003, Dong et al., 2013 and Luo et al., 2008).

Compared to traditional coal separation, dry separation does not need water and will not cause water pollution. Coal dry beneficiation with air dense medium fluidized bed, an effective dry separation, is the research focus and difficulty in the field of coal dressing (Breuer et al., 2009; Sampaio et al., 2008; Weinstein et al., 2007 and Prashant et al., 2010). The performance of air distributors of dense phase gas-solid separation fluidized bed is vital to the stability of the separation of beds (Luo et al., 2002; Macpherson et al., 2011; Zhao et al., 2010a, 2010b, 2011). During the process of separation, plugged holes always appear in the part of air distributor. However, documents about the forecast and influence of blocking areas in dense phase gas-solid separation fluidized bed are still rare (Oshitani et al., 2012 and Wang et al., 2013). For the points of pressure waves, fluctuation signals of the absolute pressure include the pressure fluctuations and pressure fluctuation of bed caused by partial bubble motion and the spreading of pressure fluctuation. (Song et al., 2012; Oshitani et al., 2010; Yoshida et al., 2011) This paper uses statistic analysis to analyze pressure fluctuation signals of dense phase gas-solid separation fluidized bed, forecast the areas of plugged holes, and explore basic features of pressure fluctuations and mean square deviations in blocking areas in air distributors

Characterization methods

The mean value of pressure is

$$\overline{P} = \frac{1}{n}\sum_{i=0}^{n} P_i$$

while the mean square deviation of pressure fluctuation is

$$\Delta P = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(P_i - \overline{P})} \ .$$

Taking pressure fluctuation of fluidized beds as the standard of judging the fluidization quality and the stability of beds, the sensitivity of different positions of fluidized beds to plugged holes can be judged from D-value of mean square of pressure fluctuation around plugged holes in air distributors :

$$S = \frac{\Delta P_b - \Delta P_a}{\Delta P_a}.$$

In this formula, P_i, $\overline{P}$ and ΔP represent instantaneous value, mean value and mean square deviation separately. ΔP_a and ΔP_b separately represent the mean square in front and back of air distributors.

Equipment and characteristics of materials

Equipment

This paper uses the model machine of dense phase gas-solid fluidized bed separator with 280 mm diameter and 500 mm height under the normal pressure. As seen in Fig 1, the whole system is made up of air supply system, air flow control system, fluidized bed model, dust pelletizing system, differential pressure measuring installation and data acquisition system. The fluidized bed consists of the upper chamber, air distributor and lower chamber. For test and observation, the upper chamber is made up of organic glasses. The air distributor is a group of steel multi-orifices with 3mm aperture. Two-double industrial filter cloth between multi-orifices at the bottom is used as air distributor. In order to study the features of partial blocking areas in the air distributor of dense phase gas-solid separation fluidized bed, the round air distributor is homogeneously divided into eight regions which are marked as A, B, C, D, E, F, G

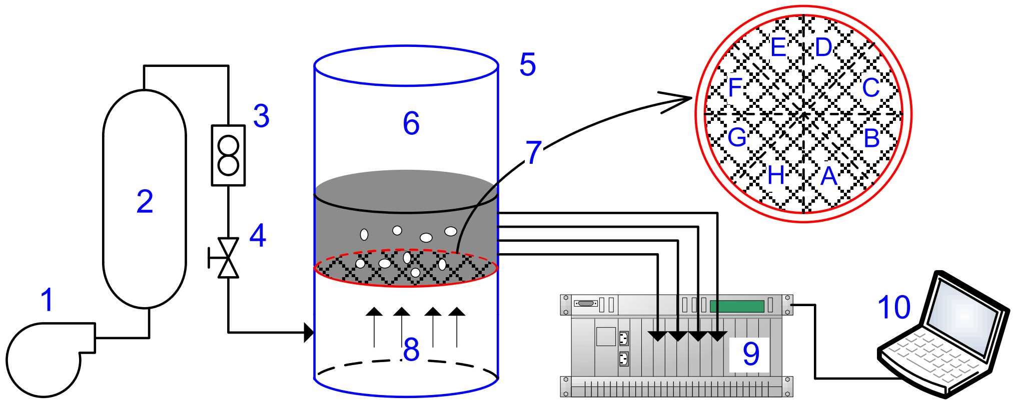

Fig. 1. The model device of gas-solid fluidized beds for separation and the partition of air distributors: 1 – Roots blower, 2 – Air-drum, 3 – Rotameter, 4 – Blast gate, 5 – Model of gas-solid fluidized bed, 6 – Fluidized bed, 7 – Air distributor, 8 – Air chamber, 9 – Data acquisition system, 10 – Computer

and H. Region A is a problem area due to plugged holes while other areas are associated areas influenced by the plugged holes. The pressure is measured by a JYB-G intelligent pressure transmitter, then converted to the pressure signal through the amplifier and finally achieves transformation between voltage signals and digital signals, stores computer information and processes data through the original Lab Jack U12 data acquisition device. The height of the fluidized bed is 200 mm. Fig 1 shows the height of test points in corresponding areas of partitions of air distributors.

Characteristics of materials

Geldart B magnetite powder with wide size fraction and high density which used in coal separation as the medium solid particle was used in the tests. True density is 4200 kg/m^3 and bulk density is 2470 kg/m^3. The particle size of main fractions ranges from 0.074 mm to 0.300 mm. Its magnetic material content is 99.71% and saturation magnetization is 77.21 $A\cdot m^2/kg$. The magnetite powder is screened by sieve shaker. The result can be seen from Table 1. The distribution range of the main particle size of magnetite powder is 0.15–0.10, 0.20–0.15, 0.01–0.074 and 0.30–0.20 mm. These four particle size fractions account for 91.77% of the whole. For there are little particles whose diameters are more than 0.300 mm or less than 0.074 mm, this research uses dominant size fraction as medium particles of fluidized beds. Moreover, the magnetic material content of Geldart B magnetite powder approaches 100%, with high purity and intensive magnetization and is beneficial to the formation of homogeneous and stable fluidized beds.

Table1. Particle size distribution of the medium solid (Geldart B)

size fraction (mm)	magnetite powder productivity (%)	size fraction (mm)	magnetite powder productivity (%)
1.00–0.63	0	0.15–0.10	28.95
0.63–0.50	0	0.10–0.074	24.69
0.50–0.30	3.77	0.074–0.05	1.79
0.30–0.20	10.59	–0.05	2.67
0.20–0.15	27.54	Total	100

Results and discussion

Stability and sensitivity at various bed heights

Researchers in the field of fluidization have adopted several methods to analyze the pressure signals in fluidized beds. These methods include statistical analysis (time domain), frequency analysis (frequency domain), and non-linear analysis (such as chaotic method) (Chen et al., 2006; Bi et al., 1996; Croxford et al., 2011). The mean value and mean square deviation of the pressure fluctuation at the test points of the fluidized bed reflect the characteristics of gas–solid two-phase flow in the fluidized beds (Table 2). This study conducts a detailed analysis of the influence of the stability of fluidized beds and the regional statistical characteristics caused by partially plugged holes. As shown in Fig. 2, regions A, B, C, and D are selected as the objects of study to analyze the mean square deviations and sensitivity of the pressure fluctuation at different heights of the bed.

Table 2. The height of test points

Test Point	Distance from air distributor /mm	Test Point	Distance from air distributor /mm
1	180	3	80
2	130	4	30

In the experiment, superficial fluidization velocity is fixed at 1.50 U_{mf} (minimum fluidization velocity). The mean square deviations of the pressure fluctuation in region A are observed as 0.00248, 0.00304, 0.00247, and 0.00189 when none of the holes in the air distributor are plugged. The mean square deviations of the pressure oscillation at a bed height of 80 mm are higher than those in any other area. These deviations further increase to 0.00399 when the plugged holes cover 75% of the air distributor. Sensitivity S is less than that at a bed height of 30 mm. Sensitivity S of the plugged holes in regions B, C, and D decreases with increasing bed height. The fluidized gas is generally considered to initially enter the bed in the form of jet flow. The influence of plugged holes is increased when planar porous plates are used as fluidized beds.

The mean square deviations of the pressure fluctuation in the fluidized region increases axially, reaching a maximum and then dropping down when no holes are plugged. Less pressure fluctuation occurs at the top than the bottom of the bed. The mean square deviation, rather than the mean value, in all of the areas is significantly influenced by plugged holes under the same superficial fluidization velocity. Consequently, the stability of the bed is reduced. Pressure fluctuations are primarily caused by forward flow regions at the bottom of the bed and bubble movement. At the same gas speed, partially plugged holes cause uneven air distributors, resulting in an increased intensive forward flow region at the bottom of the bed and bigger bubbles. Moreover, plugged holes decrease the mean square deviation of the pressure fluctuation at the middle and bottom of the bed. The mean square deviation of the pressure fluctuation at the forward flow region is approximately equal to and is consistent with the changes in speed along the height of the bed.

The analysis of the mean square deviations of the pressure fluctuation at various heights of the bed in the region A and the related regions B, C, and D reveal that sensitivity S of the plugged holes in air distributors decreases with increasing bed height. The changes in pressure fluctuation caused by plugged holes are more obvious near the air distributor, that is, the value of *S* increases as the test point approaches the air distributor. Thus, a 30 mm height is selected as the test height in this study. The standard deviation of the pressure fluctuation in region A increases initially and then decreases axially (the height of the bed).

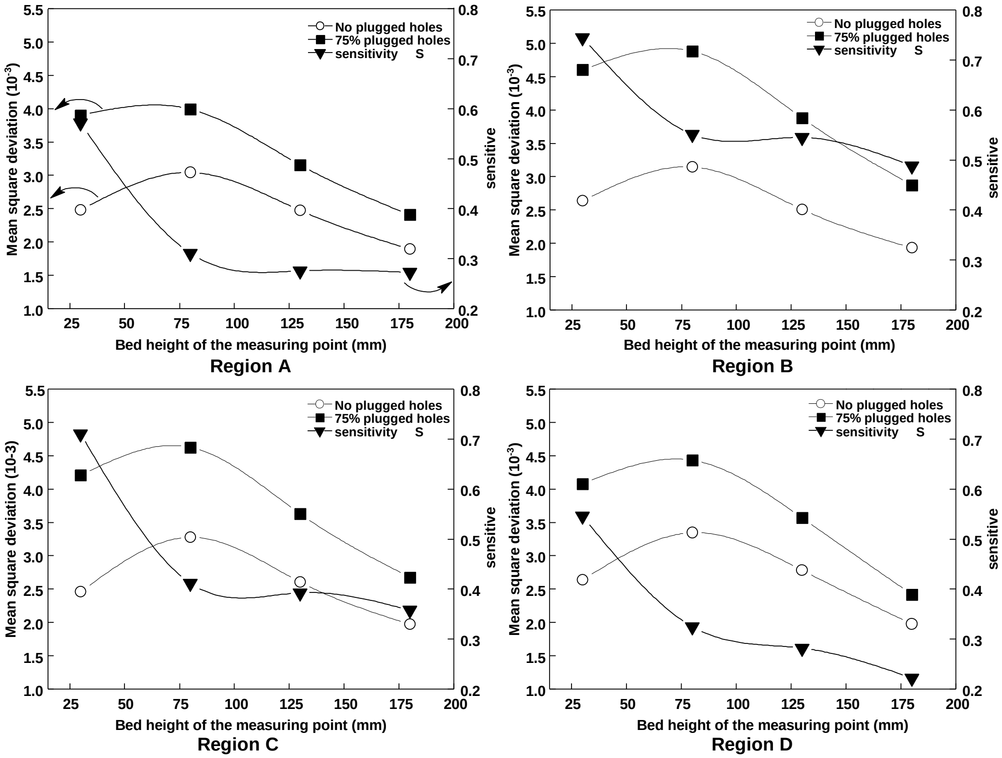

Fig. 2. Mean square deviation of pressure fluctuation and sensitivity

Influence of gas velocity on plugged holes

This study analyzes the distribution law of bed instability caused by plugged holes at various fluidized gas velocities. As shown in Fig. 3 the percentage of plugged holes in area A is 75%, and the measuring point is at a bed height of 30 mm. At this measuring point, the superficial gas velocities are U_{mf}, 1.25 U_{mf}, 1.5 U_{mf}, and 1.75 U_{mf}. As shown in Fig. 1, A is the problem area, and the other areas are associated areas influenced by the plugged holes. The superficial gas velocity increases with an increase in the mean square deviation of the pressure fluctuation in region A, suggesting that pressure fluctuation in the bed is becoming increasingly severe. The pressure fluctuations in the adjacent related regions H and B are greater than that in region A. These fluctuations in regions H and B symmetrically and progressively decreases to the sides from region A. These findings suggest that the distribution law of the influence of the plugged holes is symmetrical from the blockage problem area, and the influence of the partial blockage problem in the air distributor progressively decreases in the form of diffusion.

The experiment shows that the pressure caused by plugged holes varies at different lateral positions at the bottom of the bed layer. Bubbles with significant lateral movement appear in regions B and H. These bubbles improve the particle cross-mixing in the fluidized beds. The mean square deviation of the pressure fluctuation in region A is significantly greater than those of the two sides. Region A exhibits weak fluidization and the other two regions exhibit strong fluidization because of the difference in speed between the two sides of the fluidized gas velocities. An ascending medium stream can be observed because of the entrainment of air bubbles. The influence of the blockage problem is reportedly beneficial to the dense particle phase at the bottom of the weak fluidization region, which exhibits a significant downward trend under its own weight. Particles in strong fluidized regions turn entrained bubbles upward again. The bubble activity on the bed layer of region A is relatively weak, resulting in decreased medium flow, which in turn results in large-scale horizontal diffusion flow of particles within the fluidized bed.

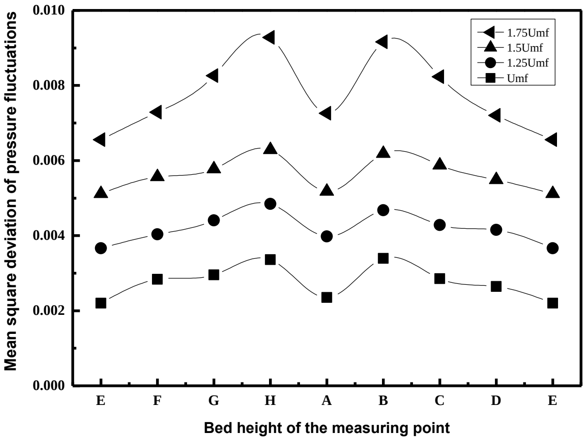

Fig. 3. The mean square deviation of pressure fluctuations with different gas velocity

A modified air distributor has been used in the distributor section, for uniform mixing of the gas moving as fine bubbles to the fluidizing section (Jena et al., 2009). The bottom zone of using three types of distributor plates (Paiva et al., 2004.) and hydrodynamic characteristics (Sobrino et al., 2009) are investigated by obtaining measurements of pressure and radial voidage profiles. A technique (Paiva et al., 2004.) to estimate the porosity fluctuations of the dense phase in the bottom of the bed is also proposed. But these studies focus on the performance of the new type of gas distributor and ignore the blocking problem and stability in the long run. The blockage area prompts strong particle disturbance at the bottom of the bed layer (Fig. 4). The mixing action only partially occurs at the intersection of the blockage areas and the regions with strong fluidization. The horizontal velocity of the particles is very low. Mixing is weak in the bed. Fraction differences exist between the particles and the signal feature (Fig.

3), because of the influence of the plugged holes suggesting that the mean square deviation of the pressure fluctuations on both sides progressively decreases as the areas of regions B and H increase. The decrease in mean square deviation is more obvious with an increase in fluidized gas velocity.

This experiment proves that the partial plugging of holes in specific areas cause lateral bubble movement in dense phase gas–solid separation fluidized beds. By analyzing the plugged holes in this area, the following factors can be revealed: the strong and weak fluidized regions, the differences in the volume fraction of particles, the pressure difference in the transverse of beds, the increase in the standard deviation of pressure fluctuations, and the strengthening of the lateral mixing of medium particles. The emergence of two or more strong fluidized regions near the blockage areas can be considered a means of judging its regional features.

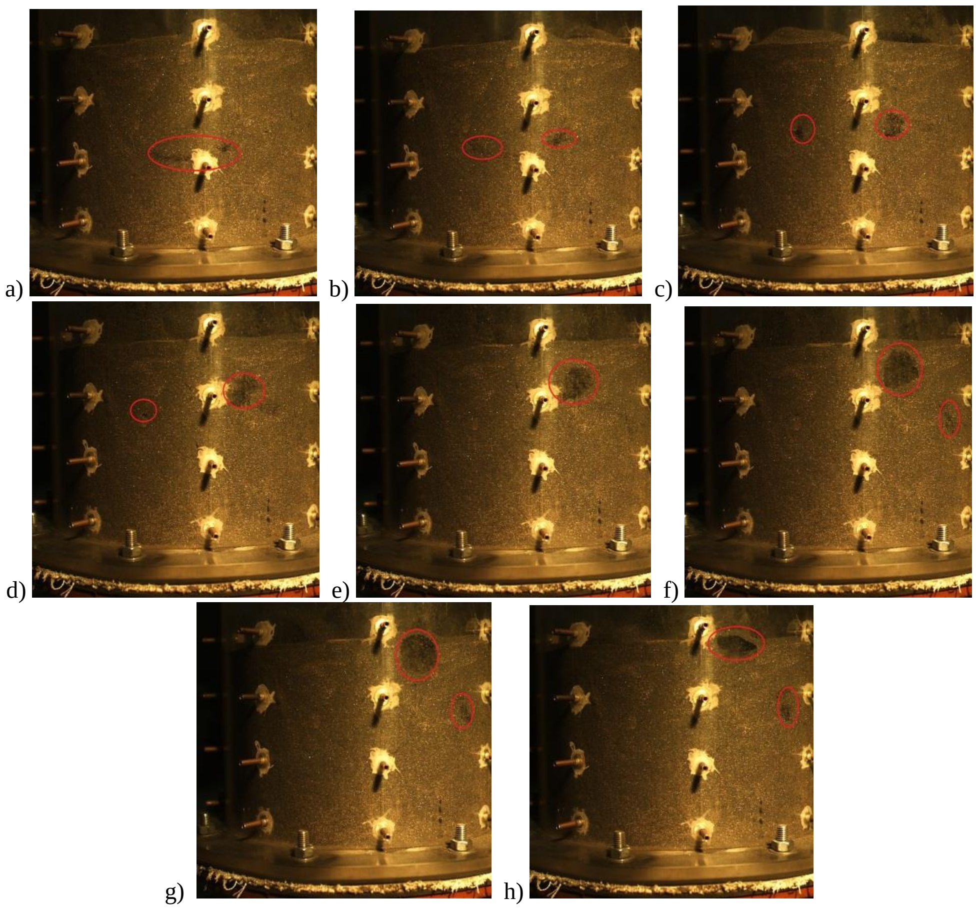

Fig. 4. Bubble behavior caused by plugged holes in air distributors

Influence of blockage area on stability

Previous studies (Schaaf et al., 2002; Lim et al., 2007 and Martin et al., 2011) have mostly focused on the pressure drop and structure of air distributors for dense phase gas–solid fluidized bed. The blockage area is a major factor that influences the regional characteristics of air distributors in a dense phase gas–solid separation fluidized bed. This study analyzes the blockage area of a bed under $1.75U_{mf}$ of gas velocity.

The height of the fluidized bed is 200 mm, and the measuring point is from an air distributor at a bed height of 30 mm. The distribution law, which is affected by the plugged holes on the bed, is symmetrical to the blocked regions; thus, this study merely analyzes the macro-signal features of the blocked regions A, B, C, and D. As shown in Fig. 5, in Area A, the mean square deviation of the pressure fluctuations of the bed first increases and then decreases as the number of plugged holes increases. Increasing the number of plugged holes causes a decrease in average fluidized gas velocity and results in the non uniformity of wind velocity distribution; thus, the uniformity of the average fluidized gas velocity and the wind velocity distribution is considered the main factor influencing the stability of bed. Increasing the number of plugged holes also results in the uneven distribution of gas velocity, which causes the pressure differences near the air distributor and the increase in pressure fluctuation.

When the percentage of plugged holes increase from 0% to 25%, the effect of the non uniformity of gas velocity distribution is significantly more obvious than the effect of the decrease in the average fluidized gas velocity. Therefore, the mean square deviation of the pressure fluctuation increases as the percentage of plugged holes in this range increases. When the percentage of plugged holes increases from 25% to 50%, the effect of the average fluidized gas velocity intensifies as the velocity decreases. However, the non uniformity of wind velocity distribution is still a major factor influencing the bed stability near the air distributor. When the percentage of plugged holes increases from 50% to 75%, the fluidized air velocity becomes the major factor influencing pressure fluctuation. The fluidized gas velocity in this region sharply decreases, and the heterogeneity of wind velocity distribution is improved; thus, the effect of the non uniformity of wind velocity distribution on the bed gradually becomes less significant than the effect of the decrease in fluidized gas velocity. When the percentage of the plugged holes increases from 75% to 100%, the fluidized air velocity becomes increasingly smaller. The mean square deviation of the pressure fluctuation and the disturbance of medium-sized particles begin to decline at the bottom of the bed, thereby gradually improving the stability of the bed.

Region B is the nearest to region A among all the relevant regions. Thus, this region has the greatest pressure fluctuation and the most obvious variation in sensitivity. As shown in Fig. 5, the mean square deviation of the pressure fluctuation increases as the blockage area increases. When the percentage of plugged holes ranges between 25% and 75%, the variation rate of the mean square deviation of the pressure fluctuation is smaller than that of the blocking percentages ranging from 0% to 25% and from 75% to 100%.

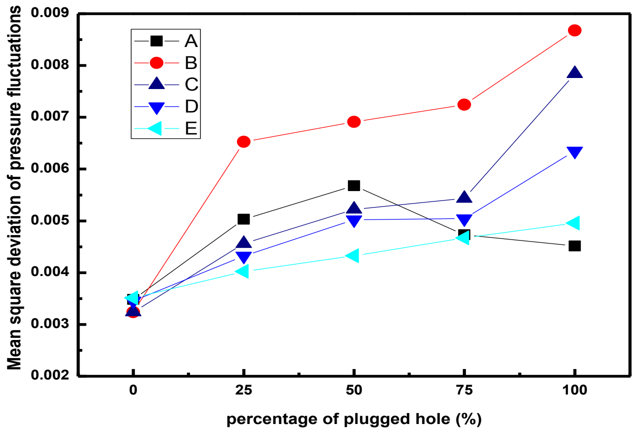

Fig. 5. Plugging hole area of fluidized bed pressure fluctuation variance

The effect of distributor hole-size on the bubble hydrodynamics (M et al., 2007) air distributor geometry (the opening fraction, different hole size and number) (Seong et al., 2005) on the fluidization characteristics were studied. An attempt has been made to study the stability characteristics of different cross-sectional shapes of fluidized bed having same cross-sectional area (Sahu et al., 2013). But they did not consider the blockage area and relevant regions stability characteristics. The paper researched the blockage area characteristics and the rule of relevant regions the stability characteristics. The mean square deviation of the pressure fluctuation in all the relevant regions is mainly prompted by the varying pressures in the blocked areas and the variations in fluidized air velocity, which together lead to the variations in fluidized air velocity in the relevant regions. Moreover, the mean square deviation in pressure fluctuation increases as the blocking acreage increases. The order of the effect intensity of region B, C, D, and E corresponds with their respective distances from region A.

Conclusion

This research suggests the plugged holes in the air distributor should be tested to ensure the stability of these beds for particle separation. The pressure fluctuation is sensitive to these plugged holes. The sensitivity can be tested and diagnosed by determining the standard deviation of the pressure fluctuation. The pressure fluctuations signal is a way to present its macro-signal features of the interaction in the bottom of the bed. In areas with partial blockage, that is the areas with weak fluidization, a decrease in the volume fraction of the particles and in the pressure differences in the transverse of the bed results in an increase in the standard deviation of the pressure fluctuation, thereby stimulating the lateral mixing of medium-sized particles. The standard deviation and the mixing intensity decrease axially. The value of sensitivity (S) of the plugged holes in the air distributor decreases as the height of the bed increases. The blocking area not only occurs partially, but often there are different degrees of blocking in the whole. The uneven distribution law of density is caused by blocking. All these parameters should be explore and a further analysis is needed.

Regional features of plugged holes is that the standard deviation of the pressure fluctuation in region A increases initially and then decreases axially (the height of the bed), the mean square deviation of the pressure fluctuations on both sides progressively decreases as regions B and H (nearby problem region) increase, the order of the effect intensity of region B, C, D, and E corresponds with their respective distances from region A. The features of air distributors affect the surrounding areas. The intensity of the effect is proportional to the distance to the plugged holes. The regional features were used to detect gas distributor plugged holes and uneven distribution of gas in the industrial fluidized bed.

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