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Effect of the secondary air distribution layer on separation density in a dense-phase gas–solid fluidized bed

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ABSTRACT

Dry coal separation has been the most significant process in the field of coal beneficiation to date, because of its special advantage of operation with no water consumption. Mineral dry separation research has received wide attention, particularly in countries and regions experiencing drought and water shortages. During the process of dense coal gas–solid fluidized bed beneficiation, the material is stratified according to its density; the high density material layer remains at the bed bottom, and thus the high density coarse particle bed becomes an important influencing factor in fluidized bed stability. In the steady fluidization stage, a small number of large radius bubbles are the direct cause of unsteady fluidization in the traditional fluidized bed. The dispersion effect of the secondary air distribution bed for air flow is mainly apparent in the gas region; when the particle size exceeds 13 mm, the secondary air distribution bed has a synergistic effect on the density stability of the upper fluidized layer. When the particle size is small, especially when less than 6 mm, particles will constantly move, accounting for instability of the secondary air distribution bed and distorting the stability of the upper fluidized bed. Under optimum operation conditions, the probable deviation E of gas–solid separation fluidized with a high density coarse particle layer can be as low as 0.085 g/cm^3.

1. Introduction

High efficiency clean coal resource utilization is very important to guarantee China's energy supply and energy security, saving resources as well as protecting the environment. Coal beneficiation is becoming widely adopted and is subjected to continual research and development as the main clean coal technology and is considered a simple but effective coal upgrading method. To date, wet coal separation is the dominant technique; however, with global coal mining gradually shifting to arid and cold regions and the increasing problem of serious water resource shortages [1], there is an urgent need to develop high efficiency dry beneficiation technologies. Since dry coal technology has the key advantage of operation with no water consumption, it may be considered the most significant process in the field of coal beneficiation today [2]. Focused on countries and regions experiencing drought and water shortages, dry mineral separation research has received wide attention and dry coal separation technology and equipment is being rapidly developed [3,4]. At present, there are three main types of rapidly developing dry coal beneficiation techniques: combined type dry coal dressing technology, air jigging and the air dense medium fluidized bed technology for dry coal separation [5–14].

During the process of coal beneficiation, the material is stratified according to its density and the high density material layer remains at the bed bottom; thus a high density coarse particle bed becomes an important influencing factor in fluidized bed stability. Further study is required into the high density material layer of the gas–solid separation fluidized bed to provide a research basis for use when optimizing the method's operation and separation performance.

2. Air distribution characteristics and mechanisms of the secondary air distribution bed

In the "distribution plate region" of the gas–solid separation fluidized bed, air flow velocities are variable when passing through the distributor orifices. Under initial conditions, low velocity bubbles form directly at the orifice; however, with the increase of air flow, air at the orifice will gradually transform into jet flow which will split into bubbles after rising to a certain height. Of course, not all gas will transform into bubbles; Toomey [15] suggested that the amount of air which forms bubbles near the air distributor only

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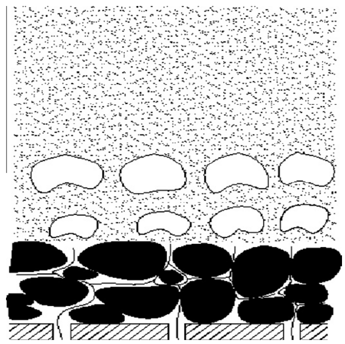

Fig. 1. Tree-disperse structure formed by a secondary air distribution layer.

accounts for one third of the total amount of gas entered into the bed, with most air remaining in the emulsion phase, mixed with solid particles. This also affects bubbles merging and their growth in the course of bubbles rising.

In the gas–solid suspension system, regardless of the formation of bubbles or after the merger division, all had greater effect on the stability of gas–solid fluidized bed. Rowe [16] found, using photography, that bubbles were able to carry near-bottom particles upward, forming particles that were back-mixing because of the existence of a wake vortex during ascent. Back-mixing contributed to the uniform distribution of particles and prevented the stratification of the fluidized bed to some extent. Conversely, back-mixing interfered with the mineral bed that had been separated and is generally considered unfavorable for separation.

In the practical separation process, the gangue in raw coal sinks at the upper end of the bottom distribution plate because of its high density, and is then discharged by the scraper. Because of the continuous separation process, the accumulation and the elimination of gangue layer on the air distribution plate is in a state of dynamic equilibrium. The existence of a gangue layer under a state of dynamic equilibrium at the upper end of the distribution plate further leads to the gas entering into the "distribution plate region", therefore, it is often referred to as the secondary air distribution bed.

The secondary air distribution bed, which is composed of a gangue layer, has important effects on the behavior of air in the "distribution plate region". When the gas escapes from orifices on the distribution plate, because the existence of the gangue layer is not conducive to bubble formation when gas leaves the distributor, the gas can only flow to the solid bed layer by air flow through the gangue particle gaps. The gangue layer accumulates on the distribution plate. Because there are gaps between the gangue particles, it is easy for the gangue layer to form a criss-cross "tree dispersion" structure (Fig. 1). This structure has a number of tandem channels, leading to each air stream emerging from orifices of the distribution plate to disperse into many strands of airflow. The number of bubbles eventually formed consequently increases, and the bubble diameter reduces into a microbubble form, which is of great consequence for the stability of the upper fluidized bed.

The average diameter of the initial bubbles formed by the distribution plate can be obtained using the following formula:

$$D_{b,o} = 1.38g^{-0.2}[A_D(\upsilon - \upsilon_{mf})]^{0.4} \quad (1)$$

where A_D is the area affected by each orifice of the distribution plate, which can be calculated using formula (2):

$$A_D = \frac{S_b}{n_o} \quad (2)$$

where S_b is the total cross-sectional area of the distribution plate, and n_o is the number of channels in the distribution plate. In a distributor with a secondary air distribution bed, because the "tree dispersion" structure increases the original number of channels indirectly (eventually decreasing the initial bubble diameter), a large number of microbubbles are generated in the secondary air distribution plate.

3. Experimental apparatus and materials

In order to study the influence of the secondary air distribution bed on the fluidization characteristics of a gas–solid fluidized bed, the experimental apparatus shown in Fig. 2 was used. The bed body in the fluidized-bed model is a rectangular structure (300 mm × 200 mm × 500 mm) made of organic glass, which is favorable for observing the fluidization of the bed layer. The gas flow in the fluidized bed is controlled by a valve, so as to obtain a fluidized bed layer of various porosities and to measure the bed pressure drop.

To obtain better fluidized conditions, magnetite powder is used as the heavy medium and the fixed bed height is 134 mm in this experiment. The magnetite particle size composition is shown in Table 1.

Moreover, to simulate the actual separation operations and to form the secondary air distribution bed in the experimental model, the gangue produced by the dry separating operation in the field was used as the experimental material and sieved to several particle size fractions: 6–3 mm, 6–13 mm, 13–25 mm, and 25–50 mm for comparative experiments. To ensure the gangue layer distributes as in the natural accumulation on the distributor, the valve was opened before the experiment; the gangue was then placed inside after the bed was fluidized. Partially unsettled gangue was pulled after gangue settlement to ensure that the fluidized bed layer was not disturbed by unsettled gangue. There are few studies reported in the literature on the determination of the secondary air distribution bed height, therefore from a combination of practical work experience and the above experimental research, 10 mm was taken as the reference height. This remains to be verified by further studies.

4. Results and discussion

4.1. Influence of the gangue layer on the fluidization characteristics

As shown in Table 2, the variance of the pressure drop was 0.018 in the ordinary fluidized bed. However, the minimum variance of the pressure drop was 0.004 in the fluidized bed with a secondary air distribution layer. The results indicate that the secondary air distribution layer plays an important role in promoting the stability of the fluidized bed. The dense medium solid was fluidized earlier in some areas of the ordinary fluidized bed, according to the upper descending velocity method, which demonstrates that the initial fluidization gas velocity was low in the ordinary fluidized bed. This phenomenon was caused by the

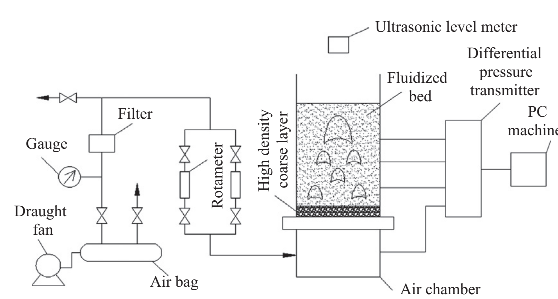

Fig. 2. Model of the gas fluidized bed.