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Flow pattern transition and coal beneficiation in gas solid fluidized bed with novel secondary distributor

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ABSTRACT

Gas solid fluidized bed (GSFB) is an effective method of dry coal separation. In this study, porous sponge was introduced into a typical gas solid fluidized bed as secondary air distribution layer (PSFB) to stabilize the fluidized bed layer. The difference between PSFB and GSFB in flow pattern transition process was studied. Compared with GSFB, the minimum gas velocity and bed density fluctuation decreased while bed expansion ratio increased in PSFB. Furthermore, the distribution of bubble phase and emulsion phase were more homogeneous in PSFB. Under the operational conditions, the results of coal preparation in a PSFB showed that the ash content of clean coal was 10.25% .The probable error (E) was 0.095 g/cm^3, indicating that PSFB could provide a novel way for a good performance of dry coking coal beneficiation.

1. Introduction

Coal as the main fossil energy, which accounts for 28.1% of the world's primary energy consumption, especially in China [1–6]. In 2016, China's coal production was 3.41 billion tons, which accounted for about 63% of China's primary energy consumption [7]. However, more than 2/3 production of coal is distributed in the arid and water shortage areas of Western China, so it is difficult to use wet method for coal preparation. It is imperative to carry out the high efficiency dry coal separation for coal upgrading [8–12]. In this stage, there are some typical and mature dry separation technology such as table type air separators [13], air jig [14], compound dry separator [15,16] and gas solid fluidized bed [17,18]. Among these, gas solid fluidized bed has the features of high precision and simple process, which is a hot research topic in dry separation area [19].

In the gas solid fluidized bed, with the change of operating conditions, the flow pattern of the fluidized bed will change, from the fixed bed to the particulate fluidization state, and then gradually change into the bubbling fluidization state [20]. Particulate fluidization presents a very homogeneous fluidization structure [21], which provides an ideal separation environment for coal separation. In the process of separation, the uniformity of air distribution also has influence on flow pattern transmission of fluidized bed. The function of air distributor is to give a certain resistance to the airflow to provide a uniform airflow distribution above the air distributor, in order to prepare conditions for obtaining favorable fluidization conditions [22,23]. However, with the increase of airflow, the blast to air distributor increased, the bubble is not uniform, and the motion of particles in fluidized bed shows instability. The uneven distribution of airflow leads to channeling and backmixing slugging phenomenon. The bed is difficult to reach the ideal separation fluidization state, and the energy input increases [24].

In addition, many scholars have carried out a great deal of research on how to maintain the stability of density in fluidized bed. One of the important factors is the design of air distributor. Air distributor is generally divided into microporous plate type [25,26], porous plate type [27], blister type [25,26] and so on. The design of the air distributor is closely related to the pressure drop [27–30]. The calculation method of resistance coefficient of different forms of air distributor is proposed [31], the formula for the critical pressure drop of the distributor [32,33] and the pressure drop ratio of the distributor [31] were given. There is a close relationship between the opening rate of and the opening mode of the air distributor [25]. The method of determining the aperture spacing and the effect of aperture spacing on the bubble were stud-

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Nomenclature

E	probable error, g/cm^3
g	gravitational constant, $g = 9.8$ m/s^2
H	bed height, mm
H_0	bed height in existing operating parameters, mm
H_{mf}	bed height in critical fluidization state, mm
H_f	the bed expansion height, mm
n	the total number of observation points for a certain period
N	the fluidization number, which is the ratio of the max value of pulsating airflow velocity and the minimum fluidization velocity
ρ_i	the bed density when t = i, g/cm^3
$\overline{\rho}$	the average value of the bed density in a certain period, g/cm^3
ρ_{bed}	bed density, g/cm^3
ΔP	bed pressure, Pa
R	value of air flow in the fluidized bed, m^3/h
r	radius of fluidized bed, m
T	separation time, s
U	the gas velocity for the experiment, m/s
U_0	the minimum fluidized gas velocity, m/s
$U_{mf(GSFB)}$	the minimum fluidized gas velocity of GSFB, m/s
$U_{mf(PSFB)}$	the minimum fluidized gas velocity of PSFB, m/s

Greek letters

σ	the standard deviation of the density fluctuation
φ	bed expansion ratio

ied [34]. Bubbling conditions were observed during variations in the gas velocity and the distributor pressure drop. Low pressure drop of the air distributor could ensure the uniform gas distribution [35]. The effect of superficial gas velocity and air distributor hole-size on the bubble hydrodynamics were studied both in 2-D and 3-D fluidized bed simulation [36].

Furthermore, particle and gas properties play a key role in successful design air distributor together with the critical pressure drop ratio, and aperture size, geometry and spacing; these strongly influence jet penetration, dead zones, particle sifting, attrition and mixing [37]. In recent years, more attention has been paid to secondary air distribution. The optimization function of secondary air distribution layer in gas-solid fluidized bed to verify the density uniformity of the bed was investigated [38]. The stability distribution of a bed density in vibrated fluidized bed with pronation-grille baffle was studied [39]. High density coarse particles [40] and 0.074–0.3 mm magnetite powder [41] were used as secondary air distribution layer to enhance stability of fluidized bed.

In this paper, due to the uneven air distribution in the fluidized bed and difficulty of flow pattern transition, based on the typical gas solid fluidized bed (GSFB), porous sponge was introduced as novel secondary air distributor in the fluidized bed (PSFB). The purpose of PSFB was to make flow pattern transition happen in low energy input and provide stable separation environment over wide range of operation parameters. In combination with the above contents, the pressure drop, density fluctuation, bed expansion and bubble movements both in GSFB and in PSFB were compared. Moreover, the separation performance both in PSFB and GSFB of 13–6 mm coal were studied.

2. Experimental study

2.1. Apparatus

The experimental system was shown in Fig. 1. As shown in this figure, the experimental system was composed of the separation system and the testing system. The separation system was composed of frequency transformer, roots blower, pressure tank, rotor flow meter and fluidized bed. The air pressure of the system was 0.2 Mpa. The inner diameter of the fluidized was 120 mm and height was 300 mm. The ratios of aperture of air distributor used in this study was 12.5%. The size of aperture in air distributor is 3 mm. In the fluidized bed with traditional air distributor, several unfavorable conditions such as local turbulences, channel flow, dead zone, particles agglomeration and uneven density distribution caused by the big bubbles and uneven structure were occurred [39,40]. In this case, without the introduction of an external force field, the addition of porous sponge as secondary air distributor is introduced in this study to could make the whole bed reach a steady fluidization state. The schematic diagram of porous sponge was shown in Fig. 2. The diameter and thickness of porous sponge were 120 mm and 30 mm respectively. When talking about the porosity of porous sponge, the evaluation index of porous sponge is par per inch (PPI). It is related to the number of pores and the size of pores. The smaller PPI indicates smaller number of pores with relatively larger pores. Because 90 PPI porous sponge has smaller pore diameter and lots of pores, the air flow into the fluidized bed through porous sponge is more even, the uniformity of air distribution is improved and the channeling phenomenon

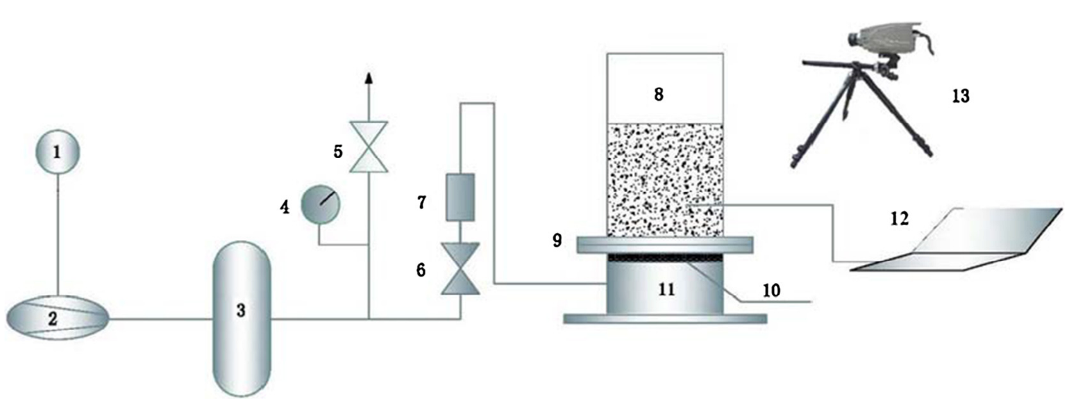

Fig. 1. Schematic diagram of the experimental system with a gas-solid fluidized bed (1) frequency transformer, (2) roots blower (3) pressure tank, (4) pressure gauge, (5) valve, (6) rotor flow meter, (7) valve, (8) separation bed, (9) air distributor, (10) porous sponge, (11) air distribution chamber, (12) measurement system, (13) high speed camera system.

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