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Full Length Article

Fluidization characteristics and fine coal dry beneficiation using a pronation-grille baffle dense phase medium fluidized bed

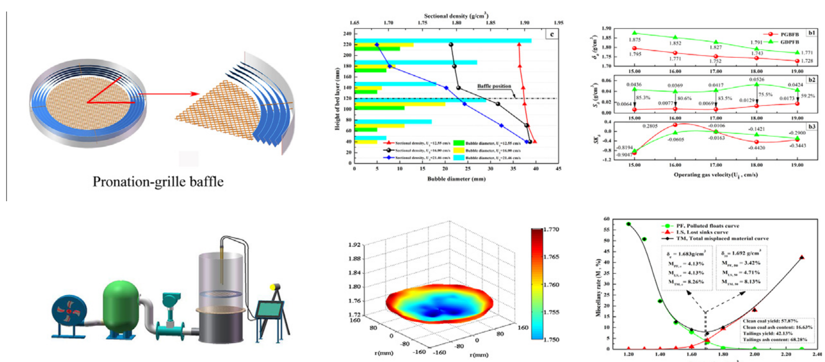
Enhui Zhou, Yuemin Zhao *, Chenlong Duan *, Xuliang Yang, Xiaodong Yu, Guofeng Li, Yongzheng Liufeng, Xuchen Fan, Yadong Zhang

School of Chemical Engineering & Technology, China University of Mining & Technology, 221116 Xuzhou, China
Key Laboratory of Coal Processing and Efficient Utilization of Ministry of Education, China University of Mining & Technology, 221116 Xuzhou, China

HIGHLIGHTS

- A novel pronation-grille baffle dense phase medium fluidized bed for fine coal beneficiation was proposed.
- The collaborative optimization of the baffle structure and operating factors were studied.
- The fluidization characteristics and density distribution regularities were investigated.
- The beneficiation performance was evaluated and the E value was 0.091 g/cm^3.

GRAPHICAL ABSTRACT



Pronation-grille baffle dense phase medium fluidized bed

Fluidization characteristics and separation efficiency

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ABSTRACT

The fluidization of Geldart B particles commonly falls under the bubbling fluidization category, where the coalescence of bubbles is the dominant phenomenon. If the diameter of bubbles becomes too large, the fluidization quality will deteriorate and lead to significant maldistribution of bed density. In this study, a pronation-grille baffle was introduced into a gas-solid dense phase fluidized bed (GDPFB) in order to improve fluidization quality. This was termed as a pronation-grille baffle dense phase medium fluidized bed (PGBFB). The inhibitory effect of the pronation-grille baffle on the coalescence of bubbles and the large-scale particles back mixing, as well as the collaborative optimization of the baffle placing height and operating gas velocity were investigated. The density standard deviation (S_δ) and density skewness (SK_δ) were employed to evaluate the uniformity and stability of the bed density distribution. According to the experimental results, the S_δ of a PGBFB was substantially reduced by 83.7%, compared to a GDPFB, and the lowest SK_δ value was decreased to −0.0106, significantly improving the uniformity and stability of the bed density. Additionally, the beneficiation experiments were performed on a 1–6 mm raw coal in a PGBFB. The beneficiation results showed that the probable error, E, was 0.091 g/cm^3 and the ash content of clean coal was 16.63%, being reduced by 21.76%, compared to the ash content of the raw coal. This indicates that fine coal beneficiation using a PGBFB can provide a simple and efficient way for coal cleaning in arid and cold regions.

* Corresponding authors at: School of Chemical Engineering & Technology, China University of Mining & Technology, 221116 Xuzhou, China.
E-mail addresses: ymzhao_paper@126.com (Y. Zhao), llaoduan@126.com (C. Duan).

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1. Introduction

Coal is one of the world's most important fossil fuels and is an essential requirement for the global efforts, in order to achieve universal energy access and alleviate energy poverty [1]. The International Energy Agency projects global coal demand to annually grow by 0.4% through 2040 [2]. Coal is still the main energy supporting power source in many countries [3]. To ensure the continuously efficient use of coal, it is necessary to adopt advanced technology in order to minimize coal pollution. Coal beneficiation is the solution for clean coal technology. Currently, wet coal beneficiation technologies dominate the global scene among coal beneficiation technologies. However, the wet processes consequently demand a large amount of water and are difficult to be employed in regions with limited water supplies or accessibility. To this end, the wet coal beneficiation technologies are restricted and dry coal beneficiation technologies, which do not need water for processing, are increasingly receiving attention by various countries [4,5].

Several dry coal beneficiation technologies, including air jigs [6], FGX separator [7], air tables [8,9] and gas-solid dense phase fluidized beds [10,11] have successively been developed. Particularly, a gas-solid dense phase fluidized bed (GDPFB), using Geldart B [12] magnetic powder as heavy medium, has been effectively applied to lump coal beneficiation, obtaining a probable error, E, value within the range of 0.05–0.07 g/cm^3, due to the fact that the adjustable range of separation density is relatively wide [13,14]. In recent years, fine coal production increased continuously during the process of coal mining, with the fully mechanized coal mining technology being widely used [15,16]. It is difficult to efficiently separate fine coal within a GDPFB, due to several unfavorable conditions caused by the big bubbles, such as local turbulences, channel flow, dead zone, particles agglomeration and uneven density distribution in the bed. In order to obtain a uniform density and a stable fluidized bed that contains micro-bubbles, which is suitable for fine coal beneficiation, national and international studies have been performed focusing on how to reduce the size and number of bubbles within a GDPFB.

Some previous studies have introduced the concept of applying an external force to the GDPFBs, in order to improve fluidization performance of the fluidized bed. Luo et al. [17,18] introduced vibration energy into a GDPFB to form quasi particulate fluidization conditions and managed to separate 0.5–6 mm fine coal, showing that the probable error, E, was 0.07–0.23 g/cm^3. Macpherson and Galvin [19] also introduced vibration energy into a GDPFB and adopted sand as the heavy medium, for −8 mm fine coal beneficiation, and the corresponding E value was 0.07 g/cm^3. Fan et al. [20] and Song et al. [21] imposed a magnetic field on a GDPFB to form a magnetically stabilized fluidized bed, which was used to separate 1–6 mm fine coal, and the E value was 0.066 g/cm^3. Duan et al. [22] and Dong et al. [23,24] introduced an additional periodic pulsing air flow into a GDPFB, to separate 1–6 mm fine coal, and the corresponding E values were between 0.085 and 0.19 g/cm^3. In addition, there were also some studies where a gas-solid fluidized bed was applied without any heavy medium, in order to separate fine coal. Yang et al. [25,26] proposed applying an autogenous medium within a fluidized bed, based on vibration energy, to beneficiate −6 mm fine coal, with corresponding E values between 0.175 and 0.225 g/cm^3. Weitkaemper et al. [27] applied autogenous medium fluidized bed without vibration energy to separate −2 mm fine coal and resulted into a variety of products with different calorific values and ash content. Dwari and Hanumantha [28] and Bada et al. [29] performed a study on tribo-electrostatic separation for −0.3 mm and −0.13 mm fine coal, respectively. Consequently, the ash content of raw coal was reduced more than 20%. Although the above beneficiation methods played an important role for improving the separation efficiency of fine coal, many unwanted effects may occur due to the introduction of an external force. For example, the average size and density properties of fed particles were changed, the secondary pulverized coal content was increased and a higher amount of energy was consumed. These drawbacks inhibit any further attempt to improve the separation effect.

There are also studies [30,31] that attempted to add baffles to reduce the average size and number of bubbles and improve the fluidization quality of gas-solid fluidized beds with Geldart B particles, as the main particle size composition, in the field of chemical industry. The commonly used baffles mainly include horizontal baffles [32,33] or vertical baffles [34–36]. These baffles could effectively reduce the average size and number of bubbles, particles agglomeration and dead zone, reduce channel flow, improve the flow - solid contact, enhance gas exchange between the bubble phase and emulsion phase, and meet the needs of the gas-solid heat transfer and mass transfer in chemical industry. In a conventional GDPFB, the bed density distribution is not uniform [37,38]. In the radial direction, the bed layer was like a ring nuclear structure which center area was sparse and side wall area was relatively thick. In the axial direction, the bed layer showed a sparse upper area and a denser lower area.

Based on the research results of previous studies, in the present study it is proposed to add a baffle in a GDPFB to improve fluidization quality. However, the traditional baffles hindered back mixing and axial diffusion of gas and solid between the upper and lower sides of the baffle, affecting the stability and uniformity of the fluidized bed. In this paper, a pronation-grille baffle was developed and installed into a GDPFB. The fluidization characteristics and density distribution regularities in a pronation-grille baffle dense phase medium fluidized bed (PGBFB) were investigated. Furthermore, the beneficiation performance for separating 1–6 mm fine coal was experimentally evaluated.

2. Experimental

2.1. Experimental apparatus and materials

A schematic diagram of a PGBFB system is illustrated in Fig. 1. It mainly includes a gas supply system, a PGBFB separator and a data processing system. The gas supply system includes a blower, a buffer tank and an electromagnetic valve. The PGBFB separator consists of a pre-gas distribution chamber, a gas distributor, the beneficiation chamber and a pronation-grille baffle. The beneficiation chamber is a vertical cylinder with an inner diameter of 320 mm and a vertical height of 450 mm, made from transparent organic glass. The pronation-grille baffle was placed horizontally in the beneficiation chamber. The pronation structure was made of iron (Fig. 2), arranged at the periphery and tilted inwards, with

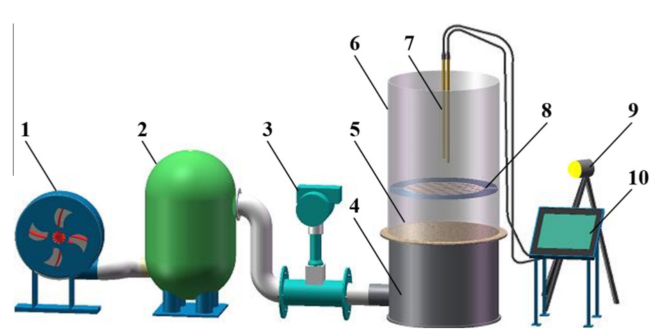

Fig. 1. Schematic diagram of the PGBFB system. 1 – blower; 2 – buffer tank; 3 – electromagnetic valve; 4 – pre-gas distribution chamber; 5 – gas distributor; 6 – beneficiation chamber; 7 – density measurement device; 8 – pronation-grille baffle; 9 – high speed camera; 10 – signal processor.