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Deash and desulfurization of fine coal using a gas-vibro fluidized bed

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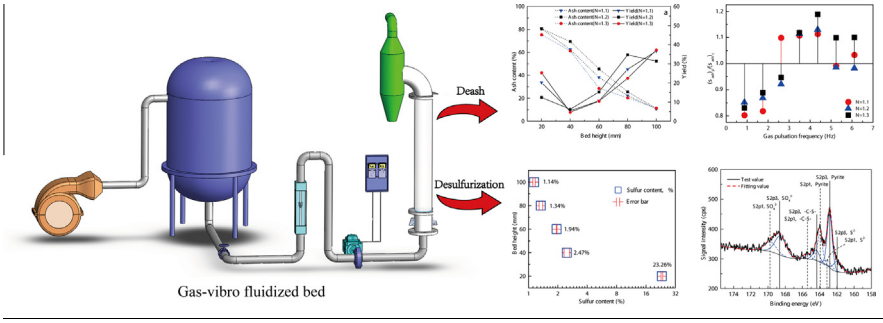
HIGHLIGHTS

- A gas-vibro fluidized bed was proposed for deash and desulfurization for fine coal.
- Ash segregation standard deviation was proposed to evaluate separation efficiency.
- Separation efficiency can be modified by the active pulsing gas significantly.
- Inorganic sulfur was removed efficiently using the gas-vibro fluidized bed.

GRAPHICAL ABSTRACT



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ABSTRACT

Coal is one of the most important primary energy sources worldwide. With the shortage of water resources and increasing acid rain, the studies on dry coal beneficiation have become more and more important. In this study, a gas-vibro fluidized bed introducing active pulsing gas into an air-dense medium fluidized bed was used for the deash and desulfurization of fine coal. The effects of gas velocity and pulsation frequency on the separation efficiency were investigated. The results show that acted by the active pulsing air flow the separation efficiency was enhanced when the pulsation frequency (f) ranged from 3.49 Hz to 5.24 Hz. Inorganic sulfur species such as pyrites and sulfate were removed efficiently. The SO_2 emission during coal combustion could be reduced evidently after separation.

1. Introduction

Coal is one of the most important primary energy sources worldwide. The BP Statistical Review of World Energy 2014 show that the coal's share of global primary energy consumption reached 30.1%, the highest since 1970 [1]. Coal is the major raw material of coal-fired power plants [2], chemical plants, and steel plants. However, there are many harmful elements in raw coal. Sulfur is the major harmful element and is oxidized to SO_x, the major source of acid rain. Coal separation is the most economical and effective approach to remove sulfur from raw coal. Wet separation technologies such as dense medium cyclone, teeter bed separator, and floatation are popular in coal preparation plants. However, with the shortage of water resources, wet separation technologies, which waste a lot of water, cannot satisfy the demand of coal separation in arid regions. Low-rank coals, which slime with water, cannot be cleaned by wet separation technologies. Therefore, the studies on dry coal beneficiation have become very important in coal separation.

The compound dry cleaning separator (FGX dry separator) [3] has been used to separate gangue from raw coal. The size fraction of coal that can be separated effectively using the FGX dry separator was −63.5 + 4.75 mm, and the probable error E value was 0.17. The air jigging machine made by Allmineral Co. was used to

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separate the high-ash and high-sulfur coal in Brazil [4]. The ash content of the coal was reduced from 52.32% to 47.11%, and the probable error E value was 0.26. An air-dense medium fluidized bed (ADMFB) [5–8] separator, which was defined as the separating fluidized bed, was proposed by the China University of Mining and Technology to separate −50 + 6 mm coal. The probable error E value of the ADMFB was 0.05. And then, scholars all over the world have been engaged into the dry beneficiation based on the ADMFB [9–13]. Furthermore, the separation efficiency of the ADMFB was much higher than those of the FGX and air jigging machine. However, with increasing content of −6 mm fine coal, the ADMFB cannot work well. Thus, fine coal dry beneficiation technology becomes increasingly important. And dry coal beneficiation technology for fine coal became one of the hotspots [14–18].

In this study, a gas-vibro fluidized bed [19,20] that supplies vibration energy to a fluidized bed separator is proposed for the deash and desulfurization of fine coal. The velocity of the gas compressed into the gas-vibro fluidized bed fluctuates periodically. Because of the vibration energy obtained from the active pulsing gas, the fluidization quality was improved for fine coal beneficiation [21–23]. The deash and desulfurization characteristics obtained using the gas-vibro fluidized bed were investigated.

2. Experimental

The schematic of the separation system based on the gas-vibro fluidized bed including an air supply system, a flowmeter, an active pulsing gas generator, a fluidized bed separator, and a dust collector is shown in Fig. 1. An active pulsing air flow generated by an electrically actuated butterfly valve is used as fluidizing agent, which velocity fluctuates with time periodically. Therefore, the vibration energy of the pulsing air flow has been introduced into the fluidized bed. In a fluidized bed separator, the heavy medium is fluidized by compressed air, thus generating a uniform and stable bed. The raw coal fed into the fluidized bed is separated according to the difference in the densities between particle and bed [24].

Magnetic powder with a density and bulk density of 4600 and 2650 kg/m^3, respectively, was used as the heavy medium. The size distribution of the magnetic powder is shown in Fig. 2. The average diameter of the magnetic particles, $\bar{d}$, was 232 μm, as calculated using Eq. (1). The dominated size fraction of the magnetic particles was 100–500 μm.

$$\bar{d} = \sum_{i=1}^{n} d_i \gamma_i \tag{1}$$

where d_i is the diameter of the ith size fraction, and γ_i is the yield of the ith size fraction.

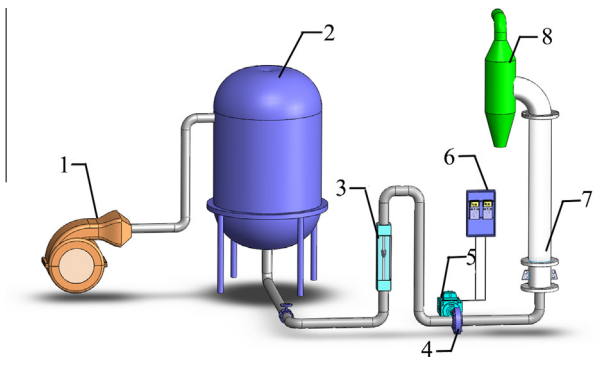

Fig. 1. Schematic of gas-vibro fluidized bed separation system: 1 – blower; 2 – buffer tank; 3 – flowmeter; 4 – butterfly; 5 – electric motor; 6 – inverter; 7 – fluidized bed separator; 8 – cyclone.

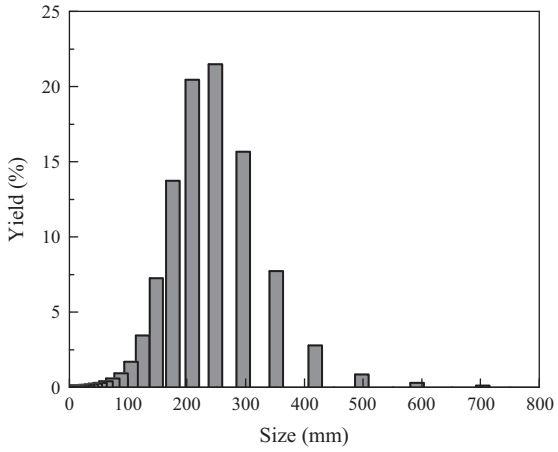

Fig. 2. Size distribution of magnetic powder.

3. Methods and theories

The content of ash, which is valueless and incombustible, is the major index evaluating the quality of coal. The ash content of coal increases with the density of coal particles. The process of separation in a fluidized bed separator can be defined as ash segregation. To evaluate the efficiency of ash segregation, the fluidized bed is cut into n layers in the height direction after separation and numbered $1-n$ from the top to the bottom of the bed. The coal particles in each layer were obtained to analyze their ash content and yield. Furthermore, an index named as ash segregation's standard deviation (*ASSD*) is proposed, as described in Eqs. (2) and (3).

$$\sigma_{ash} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}[A(i)-\bar{A}]^2} \tag{2}$$

$$\bar{A} = \sum_{i=1}^{n} A(i)\gamma(i) \tag{3}$$

where σ_{ash} is the *ASSD*; $A(i)$ is ash content of the ith layer; $\bar{A}$ is the weighted average ash content of all the layers, and the theoretical value is equal to the ash content of the raw coal; and $\gamma(i)$ is the yield of the ith layer. When the separation efficiency is zero, the ash content of the coal sample in each layer should be equal to that of the raw coal, the ash distribution all over the bed is uniform, and the *ASSD* should be equal to zero. The larger the value of *ASSD* the better the ash segregation.

To investigate the deash characteristics of fine coal in the gas-vibro fluidized bed, the *ASSD* index was employed. The schematic of stratified sampling is shown in Fig. 3. The static bed height of the gas-vibro fluidized bed was 100 mm. Firstly, the compressed air was given into the bed, and a gas-vibro fluidized bed was generated, and then, raw coal was fed into the bed from the top of the bed and segregated by density. After separation, the compressed air was cut off suddenly, and the bed was cut into five layers every 20 mm in the height direction. The first layer had clean coal, the second and third layers had middlings and others had tailings. Furthermore, the ash and sulfur analysis was conducted.

Desulfurization is one of the purposes of coal separation. The desulfurization of coal before firing can reduce the environmental pollution caused by SO_x. X-ray photoelectron spectroscopy (XPS) was used to investigate the desulfurization characteristics in the gas-vibro fluidized bed and the chemical constituents of sulfur in raw coal, clean coal, and tailings.