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Dry beneficiation of fine coal using planar air jets

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ABSTRACT

In this study, a novel separation method deploying planar air jets was proposed for the dry beneficiation of −6 + 2 mm fine coal and a laboratory separation equipment was established. The separation principle of this method was based on the separation of horizontal movement trajectories of coal particles depending on the density differences when passing through the flow field of a planar air jet. The effects of operational parameters, including air jet velocity, air jet angle, feeding height, and feeding rate, on the beneficiation performance were experimentally studied and the results showed that all of these parameters had significant effects to varying degrees. The results also showed that the separation accuracy, the probable error E, is 0.2, indicating that this method can effectively beneficiate fine coal in a dry way.

1. Introduction

Coal plays a vital role in global energy mix. In 2015, coal's share of global primary energy consumption is 29.2% [1]. Coal beneficiation can improve coal quality by removing the gangue minerals and is the most effective and economic method for clean processing of coal resources [2–5]. In the last several decades, the yields of −6 mm coal during coal mining increase significantly owing to the wide applications of fully mechanized mining technology. Recent processes of fine coal beneficiation can be roughly classified into two categories: wet processes and dry processes. Wet processes [6], including teeter bed separation, spiral separation, shaker table separation and coal slurry dense medium cyclone separation, are dominantly deployed in coal preparation plants nowadays. These processes need large quantities of water. However, in drought coal-producing areas, there is no adequate water available for coal preparation [5,7]. Furthermore, wet processes easily generate coal slurry with high viscosity [2]. The technological and economic challenges make many coal preparation plants choose to emit coal slurry without permission, causing serious environmental pollution. Comparing with wet processes, dry processes have many advantages, especially no water use and no coal slurry emission [8], and therefore, are more suitable for coal processing in drought regions.

Recent dry processes for fine coal beneficiation under study are roughly classified into three categories based on the separation principle: (I) external force enhanced air dense medium fluidized bed separation, (II) pneumatic separation, and (III) compound dry separation, which has been well reviewed in our previous publication [9]. Air jet has been widely used in several industrial fields, including ventilation, particle dewatering, solid waste treatment, chemical engineering, metal smelting, and aircraft [10]. Recent developments in the field of solid waste treatment deploying air jet will be the reference points for dry beneficiation of fine coal. Netherlands-based Company Nihot Recycling Technology develops a drum separator using air jets for the separation of municipal solid waste or construction & demolition waste [11]. This drum separator is a combination of a fan, a separating section with a rotating drum and a connecting expansion chamber. The mixed waste particles fall from a conveyor and then conduct free settling processes. On one side, an air jet blows these falling particles with a certain elevation angle. Lighter particles are easily blown away from the original trajectory and reach the upper surface of a clockwise rotating drum. The drum pushes the particles towards a connecting chamber. Finally, lighter particles fall down the bottom of the chamber and are collected as a product. Denser particles are less affected by the air jet and approximately keep the original falling trajectory. However, the fundamental studies about the mechanism and factorial analysis of air jet beneficiation are not reported in recent literature.

In this study, we attempted to introduce air planar jets into the field of fine coal dry beneficiation. However, it was noted that comparing with municipal solid waste or construction & demolition waste, fine coal had a relatively continuous density distribution, which made it more difficult to be separated. Thus, the effects of main operational factors such as air jet velocity, air jet angle, feeding height, and feeding rate on beneficiation performance should be carefully and systematically studied. Besides, the beneficiation performance of this method was evaluated in our study.

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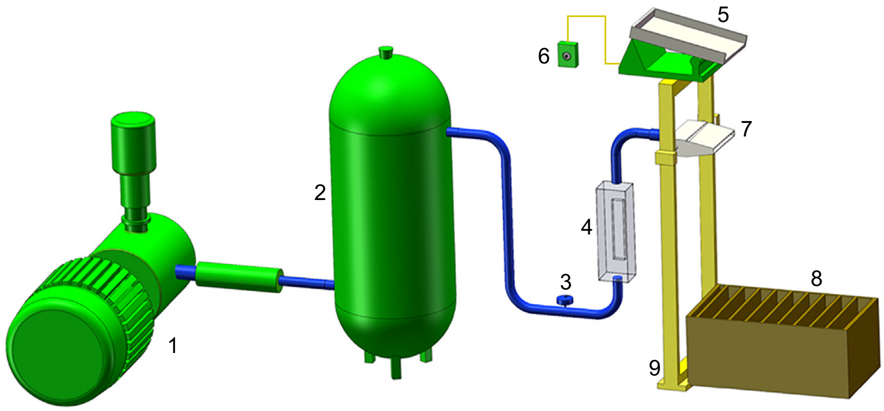

Fig. 1. Schematic diagram of the experimental apparatus. 1 Roots Blower; 2 Pressure tank; 3 Valve; 4 Flowmeter; 5 Vibrating feeder; 6 Regulator; 7 Air knife; 8 Container; 9 Metal support.

2. Experimental

2.1. Experimental apparatus

The schematic diagram of the experimental apparatus is depicted in Fig. 1. The experimental apparatus consists of an air knife, an electromagnetic vibrating feeder, a container, and an air supply system. The air knife comprises an air inlet, a chamber, and an outlet in the shape of a thin slit with a width of 1 mm and a length of 147 mm. Ambient air with a controlled volumetric flow rate enters the chamber and then jets out from a thin slit, generating a field of air planar jet. A cuboid container made of stainless steel comprises several parallel troughs divided by vertical plates and the horizontally separated coal particles entering different troughs can be collected respectively. The air supply system consists of a roots blower, a pressure tank, a gas flowmeter, several valves, and connecting pipes.

2.2. Materials

In this study, the feed coal having a size fraction of −6 + 2 mm was investigated and the results of the float-sink test experiment were given in Table 1. The preparation of this size fraction of coal particles was carried out by screening because of the external moisture content of the feed coal was 0.8% in this study. Fig. 2 shows the size distribution characteristics of the feed coal and it can be seen that there is an approximately inverted-V distribution with an average size of 3.95 mm. It is noted that the moisture content of fine coal significantly affects the screening efficiency and then coal samples with high moisture content should be pre-dried. In practice, the pneumatic classification processes can be deployed to prepare the feed coal. Furthermore, the inorganic mineral impurities accompanied to raw coal were also measured by using the X-ray diffraction method, as shown in Fig.3. It can be seen clearly that the main mineral impurities in raw coal are quartz (2.643 g/cm^3) and kaolinite (2.598 g/cm^3).

Table 1
Results of float-sink test experiment of the investigated −6 + 2 mm coal.

Density fraction (g/cm^3)	Yield (%)	Ash content (%)	Cumulative float		Cumulative sink	
			Yield (%)	Ash content (%)	Yield (%)	Ash content (%)
−1.3	4.71	4.39	4.71	4.39	100.00	26.92
1.3–1.4	38.75	8.07	43.46	7.67	95.29	28.03
1.4–1.5	14.56	18.92	58.02	10.49	56.54	41.71
1.5–1.6	10.15	24.68	68.17	12.61	41.98	49.62
1.6–1.7	8.36	32.83	76.53	14.81	31.83	57.57
1.7–1.8	5.36	42.56	81.89	16.63	23.47	66.38
1.8–2.0	3.47	51.53	85.35	18.05	18.11	73.43
>**2.0**	14.65	78.61	100.00	26.92	14.65	78.61
Total	100.00	26.92				

2.3. Calculation of the yield and ash content of product

Coal particles after separation fall into several continuous troughs and the ash content decreases gradually from the left side to the right side of the container demonstrated in Fig. 1. The separation performance can be evaluated by the yield of clean coal with certain ash content. The corresponding relationship between yield and ash content can be obtained from the accumulations of yield and ash content successively starting from the first trough having coal particles on the right side of the container to the last trough having coal particles on the left side of the container. For example, the yields and ash content corresponding to different troughs from right to left are x_1, x_2, …, x_n and a_1, a_2, …, a_n, respectively, and we assume that $x_1 = 10\%$, $x_2 = 15\%$, $a_1 = 8\%$, and $a_2 = 10\%$, and then the accumulative yield and ash content of coal particles in the first two troughs are $x_{1,2} = x_1 + x_2 = 25\%$ and $a_{1,2} = (x_1 * a_1 + x_2 * a_2)/x_{1,2} = 9.2\%$. Thus, data on the correspondence between the accumulative yield and ash content can be obtained by this mean and then are used to draw a curve by which we can gain a yield corresponding to any ash content. Obviously, the accumulative ash content increases with the corresponding accumulative yield.

3. Theoretical basis

Dry beneficiation of fine coal using planar air jets is based on the separation of horizontal movement trajectories under the function of

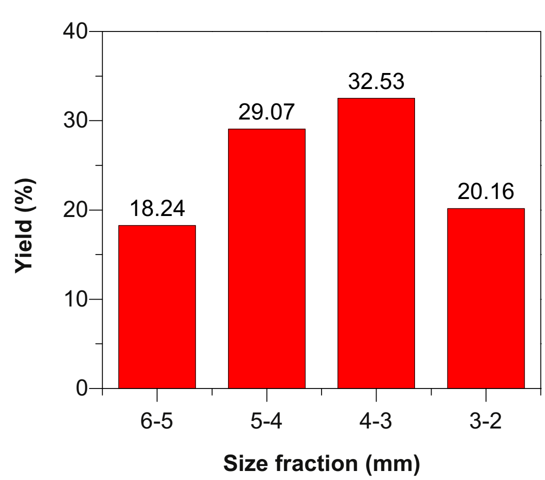

Fig. 2. The size distribution of coal particles investigated.