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Process optimization for arsenic removal of fine coal in vibrated dense medium fluidized bed

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ABSTRACT

The dry separation of fine coal provides a feasible, low-cost and pollution-free method for the pre-arsenic removal from coal prior to combustion. In this study, the arsenic (As) occurrence of the coal from Wangjiazhai coal mine in China and the corresponding migration law in the dissociation process were investigated. Accordingly, it was proposed for the vibrated dense medium fluidized bed (VDMFB) to be utilized, where it was suitable to separate the fine coal for As removal. The fluidization characteristics and the improvement of fluidization quality under the collaborative effect of vibration amplitude (A), vibration frequency (f) and air velocity (U_a) were also explored. It was discovered that the fluidized bed density was uniform and beneficial to separate coal through settling velocity when the fluidization number, N_v, was 1.0–1.83 with A of 0.5–3 mm and f of 5–30 Hz. Moreover, the bed density was driven to periodically fluctuate in a low range, based on the periodic vibration energy input in the bed. Furthermore, thirteen separation experiments for fine coal with various parameter combinations were executed through the *Box-Behnken RSM* method. The results demonstrated that the three operation parameters importance on the segregation degree of As content (S_{As}) was as follows: vibration amplitude > air velocity > vibration frequency. Compared to raw coal, the As content of the clean coal was reduced by 81.06%, whereas a 90.29% of As was concentrated into the tailing, indicating that the VDMFB can achieve a satisfactory performance for the dry arsenic removal in coal.

1. Introduction

Coal constitutes one of the most important fossil fuels in the world, providing protection for the global electricity supply, the steel production and the fuel supply [1,2]. However, in the burning process of coal containing arsenic (As), As enters the environment along with smoke, dust and fuel gas, consequently resulting in environmental pollution [3]. In view of concern for environmental protection, a variety of control technologies for As emission during coal processing have been developed, such as roasting, leaching and adsorption, which highly reduces the As discharge [4–6]. The common feature of these technologies is that they all focus on the treatment of As that has been discharged [7]. The As is only removed from the flue gas and the dust. The amount of As discharged into the air is reduced, whereas the remaining As which enters the solid residue might still be leached into the water and soil, thereby polluting the environment and endangering the human health [8]. Although the absorption rate of As discharged during coal combustion can be improved by adjusting the combustion conditions, adsorbent dosage and operating temperature [9,10], the effect of As removal from the source is preferable and the cost is lower. Therefore, removing As as soon as possible prior to coal combustion is one of the solutions to directly reduce the As emission during the coal combustion process. Simultaneously, the resource recycling on the removed As not only controls the As emission in coal combustion, whereas it also provides the As material, which is utilized as a rare additive for the production of semiconductors and high strength alloys [11].

The coal separation is the source technology of clean coal by physical methods to remove sulfide minerals, silicides and other harmful substances in raw coal prior to utilization [12,13]. During the coal physical separation, the migration of trace hazardous elements depends on the corresponding occurrence. The vast majority of harmful trace elements in the mineral-bound or the inorganic state can be removed [14]. The As is mainly associated with pyrite and is suitable for removal through the physical coal preparation technology [15]. The common

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centrifugal force field [16], the flotation [17], the jigging [18] and other wet separation technologies can be applied for the coal and others mineral mater separation with high accuracy. If these technologies are utilized to beneficiate coal rich in harmful trace elements, certain hidden dangers will appear. The harmful trace elements in coal are partly dissolved in the solution and precipitated out of the coal along with the solution, consequently becoming a potential source of acid solutions that destroy the soil, pollute the water quality and endanger the environment [19]. Although the wet coal preparation has fulfilled the corresponding purpose, it might bring about the secondary pollution. By contrast, the dry separation technology without water is significantly feasible.

In the decades of development, there have been a series of dry coal separation technologies based on different principles and different advantages. Different research groups in many countries such as Canada, USA, India, Japan, South Africa, Australia, China and so on, have contributed in various ways in the development of this technology. Some drying techniques for lump coal (> 6 mm) separation have been gradually mature. Gupta R [20,21], Sahu AK[22,23], Zhao Y[24,25], Mohanta S[26,27], Oshitani J[28,29] and their respective team studied the separating mechanism, the optimization scheme of equipment structure parameters and operating parameters, and the influence of material properties on the separation efficiency for the air dense medium fluidized bed (ADMFB). The probable separation error has been reduced to less than 0.08 g/cm^3. As a mature lump coal dry separating system, FGX dry separator and dry air jig have also been industrialized application. Parekh BK [30] and Honaker RQ [31] applied FGX dry separator to upgrade low-rank coal with a combustible recovery ratio of more than 90%. Dry air jig is mainly used to remove gangue from raw coal, which ash removal ratio is higher than 50% [32,33]. X-ray-transmission separator [34] also has the similar effect on removing gangue. For fine coal (1–6 mm), it is difficult to separate simply by gravity because of the little difference of particle size and shape between coal and other impurities. Therefore, many scholars have introduced magnetic field, electric field, vibration or pulsating airflow to strengthen the separation efficiency, forming magnetically stabilized fluidized bed [35], tribo-electrostatic separator [36,37], vibrated fluidized bed [38,39] and air table [40]. The uniformity and stability of bed density in magnetically stable fluidized bed is greatly improved by driving the magnetite powder to be aligned. But the cost of applying magnetic fields is too high and more suitable for the processing of rare precious metals. The main feed size for tribo-electrostatic separator is below 0.5 mm. In the air table, the material is separated primarily according to the difference in particle shape and mass, rather than by density.

As a trace element, the absolute content of As in coal is low and the moderate dissociation is the basis for efficient removal, which requires the separation equipment to have a good separation effect for the fine coal. Based on this, the air dense medium fluidized bed, the air jigging and the FGX dry separator, which are suitable for the lump coal beneficiation and the tribo-electrostatic separation and the magnetically stabilized fluidized bed that are usually applied for the pulverized coal separation, are not suitable for As removal due to the extremely high or extremely low feeding size limit. By contrast, based on the arsenic occurrence analysis of the studied coal samples, vibrated dense medium fluidized bed [41,42], which is suitable for 1–6 mm coal separation by density, has more advantages for As removal. In this study, the occurrence, distribution and optimal dissociation size of As in the studied coal samples were first analyzed. The fluidization characteristics, the separation mechanism and the parameter optimization methods during As removal in the VDMFB were mainly investigated.

Table 1
Results of the screening test and float-and-sink test for 50–1 mm raw coal.

Screening test		Float-and-sink test					
Size fraction (mm)	Yield of mass (%)	Density fraction (g/cm^3)	Yield of mass (%)	Ash content (%)	Yield of ash (%)	Arsenic content (μg/g)	Yield of arsenic (%)
50–25	45.3	< 1.3	4.19	7.01	0.84	2.24	0.31
25–13	29.6	1.3–1.4	16.01	10.99	5.00	5.42	2.85
13–6	15.4	1.4–1.5	9.87	17.44	4.90	9.95	3.22
6–3	3.9	1.5–1.6	16.27	25.90	11.99	20.34	10.85
3–1	5.8	1.6–1.7	17.74	33.32	16.81	34.45	20.04
Total	100	1.7–1.8	12.09	38.79	13.34	41.68	16.52
		1.8–2.0	7.82	49.96	11.11	52.17	13.38
		> 2.0	16.00	79.16	36.02	62.60	32.83
		Total	100.00	35.16	100.00	30.50	100.00

2. Experimental

2.1. Materials

The coal samples studied are from Wangjiazhai coal mine in Guizhou province, China. The size and density distribution of 50–1 mm raw coal were analyzed by screening test and float-and-sink experiment, with the results reported in Table 1. The 50–25 mm and 25–13 mm in the raw coal are the dominant size fractions, and the yield of most density fractions is not much different. Both the content of As and ash increases with increasing density, and most of the As accumulates in the > 1.5 g/cm^3 component. It reveals that As in such raw coal is mainly present in inorganic minerals, and there is a possibility of separating by density.

The medium powders used in the fluidization experiments is Geldart B magnetite particles, which physical properties are shown in Table 2. Since the density of the Geldart B magnetite powder is relatively high, it can be mixed with the rising air to form a homogeneous gas-solid mixture with a density of 1.2–2.2 g/cm^3, which coincides with the density of the different components in coal. In addition, the magnetite powder has magnetism, and is easy to be separated from the coal product after the separation operation so as to be recycled.

2.2. Experimental procedure

Experimental apparatus is schematized in Fig. 1 which is divided into three parts: air supply, fluidization and monitoring. The blower, buffer tank, airflow valve and electromagnetic flowmeter are connected in series, and the air is stably inputted into the fluidized bed. The airflow enters fluidization chamber after being uniformly distributed by the pre-air distribution chamber and air distributor. RC-2000 digital vibration exciter is able to produce a vertical sinusoidal vibration with the frequency of 0–100 Hz and the vibration amplitude of 0–5 mm. The fluidization chamber is connected with the air distributor, pre-air distribution chamber and vibration exciter in series by flanges, so that the synchronous vibration with the exciter can be carried out. The fluidization chamber made of plexiglass is 200 mm in inner diameter, where the uniform fluidization environment for coal separation is formed. PCB-208 force sensors and differential pressure sensor are respectively used to measure the collision force and bed pressure in the process of

Table 2
Main physical properties of magnetite powder.

Size fraction (mm)	Yield (%)	Ture density (g/cm^3)	Bulk density (g/cm^3)	Content of magnetic material (%)
0.3–0.2	58.07	4.59	2.26	> 90
0.2–0.1	41.93	4.61	2.29	> 90