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Experimental investigation on the wettability of respirable coal dust based on infrared spectroscopy and contact angle analysis

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ABSTRACT

Respirable dust does great harm to human health. In this paper, we focused on the wetting characteristics of respirable coal dust, and the effect of functional groups of respirable coal dust on its wettability was investigated. We selected five different types of coal samples (Lignite, Gas fat coal, Coking coal, 1/3 Coking coal, and Anthracite) from some typical mining areas in China. We used a Fourier Transform Infrared Spectrometer (FT-IR) to obtain the IR spectrum of the respirable coal dust, and the percentage of functional groups for each respirable coal dust was obtained by the peak area normalization method and then analyzed. And the wettability of respirable coal dust was evaluated by contact angle measurement. It is found that the benzene rings, aromatic hydrocarbons with benzene rings, aliphatic hydrocarbons with methyl, methylene, and so on, which have carbon-containing macromolecular structures, are hydrophobic. While the oxygen-containing functional groups represented by hydroxyl and carboxyl groups, and silicates and carbonate minerals are hydrophilic. Besides, the results show that respirable coal dust of different metamorphic grade coals has different wettability. This study has important theoretical significance for understanding the wettability of respirable coal dust.

1. Introduction

Coal is one of the most important basic energy sources in the world. But in the process of exploitation and utilization of coal resources, a large amount of dust will be produced [1], posing a serious threat to the health and safety of workers. And the harm of dust with different particle sizes to human body is different. Dust with a large particle size can be seen by the naked eye and are difficult to be breathed into. While respirable coal dust with an aerodynamic diameter of <10 μm can enter into the lungs and is difficult to extract [2]. Therefore, respirable dust is the most serious occupational hazard in coal mine. Long term inhalation of high concentrations of respirable dust could lead to pneumoconiosis, which is an incurable fibrous lesion of the lung tissue. Pneumoconiosis is one of the most extensive and serious occupational diseases in coal mine [3–6]. So the coal mining countries all over the world attach great importance to the control of respirable dust, and have done a lot of useful studies. And the most common way to reduce dust concentration is water spray, in which the wetting of dust by water is of primary importance. Therefore, scholars have paid much attention to the wettability of coal dust [7–12]. Such as Yang studied the surface chemical structure, surface electrical properties, and the surface wetting mechanism of coal dust by an infrared spectrum experiment, a dust electrophoresis experiment, and downward penetration experiment [11]. Zhou and Cheng analyzed the mineral components in coal dust (inorganic hydrophilic composition represented by ash content and the optical vibration of quartz), surface functional groups of coal dust (organic hydrophilic composition represented by aromatic hydroxyl groups), and organic macromolecular structure (relative hydrophobic composition represented by stretching vibration of C—H in aromatic ring and carbon content), which played an important role in coal dust wettability [12]. To summarize, previous studies have investigated coal dust wetting mechanism from both the contact angle and surface tension of the macro aspect as well as the chemical structure of coal dust. However, most studies were limited to large particles of dust [7,8,11–16]. In other words, existing studies are not specifically concerned with the wetting characteristics of respirable dust. Because as the particle size of coal dust changes, the

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wettability of dust also changes. And as mentioned above, respirable dust is the most harmful part of the dust. Thus, it is quite necessary to specifically study the wettability of respirable coal dust. What's more, for the analysis of the IR spectra of coal dust, the absorbance ability of coal dust was usually evaluated by peak height. However, due to the influence of sample and instrumental factors, the peak position of the spectrum would be offset at different degrees and the characteristic peaks interfere or overlap with each other, causing errors and poor reproducibility [17–19]. So it is not accurate to use peak height for quantitative analysis.

In this context, the present paper studied the wetting characteristics of respirable coal dust. The microstructure of respirable coal dust was obtained using an FT-IR spectrometer, which can obtain the information of chemical bond or functional group quickly and accurately [20]. In order to overcome the shortage of using peak height to evaluate the absorbance of absorption peaks, we used peak area for spectral analysis on coal dust, which has good reproducibility and high accuracy in containing all of the spectral information. Then, we analyzed the functional groups of respirable coal dust. Combined with the contact angle measurement, we investigated the relationship between the wettability of respirable coal dust and its functional groups. This study is of important theoretical significance for understanding wettability of respirable coal dust at the micro level.

2. Experimental

2.1. Coal sample selection and proximate analysis

According to China National Standard GB/T 5751-2009, coal is classified into lignite, bituminous coal, and anthracite [21]. In this paper, we choose five different kinds of coal samples from some typical mining areas. They are Beizao lignite, Pindingshan gas fat coal, Yangliu coking coal, Yuanzhuang 1/3 coking coal, and Xinqiao anthracite. The coal samples are collected from the driving face with normal geological structure. First, the surface oxide layer of the coal seam is stripped. Then, the cutting groove method is used to obtain coal sample. After the coal samples are collected, the proximate analysis of the five selected coal samples was conducted using a 5E-MAG6700 automatic proximate analyzer (Changsha Kaiyuan Instrument Co. Ltd., Changsha, China), referring to China National Standard GB/T 212-2008 [22].

2.2. Preparation of dust samples and size distribution test

Respirable dust with an aerodynamic diameter of <10 μm is micro dust and ultra-micro dust, which is difficult be seen by the naked eye. In order to prepare the respirable dust samples, we sorted and filtered the coal dust of five coal samples using a 2000 target standard sieve after grinding. Then placed the sample in a glass below the sieve, so we were able to view the dust sample through the accumulation of dust on the glass, and gathered to an observable amount of micro dust.

After the preparation of dust samples, we used a Winner 2000 laser particle size analyzer (Jinan Winner Particle Instrument Stock Co., Ltd., Jinan, China) to test the size distribution of dust particle. The Winner 2000 laser particle size analyzer uses the scattering principle and free reflection technology which gives true results for any distribution of particle sizes. For determining the coal dust particle size, first we opened the laser particle size analyzer and preheated it for 10–15 min. Then, we cleaned the sample preparation system with anhydrous ethanol filling the sample pool. After that, we started the circulation pump, and ran for 10–15 min. The anhydrous ethanol is discharged from the drain pipe, repeatedly cleaning the sample pool. Then, we dissolved approximately 25 mg of coal dust in 200 ml anhydrous ethanol and placed the sample in the sample pool, where agitation and ultrasonic waves were used to promote the dispersion of the coal dust samples. Then, we used laser particle size analysis software to measure the particle size range in the sample pool. The data of multiple sets were measured, and then the average particle size range was calculated.

Fig. 1. Fourier transform infrared spectrometer.

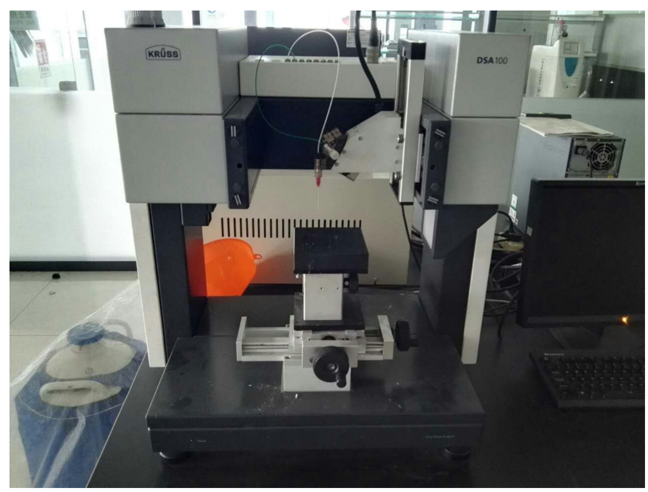

Fig. 2. KRUSS DSA100 optical contact angle measuring instrument.

Table 1
Industrial analysis results of coal samples.

Samples	Mad%	Aad%	Vad%	*F*cad%
Lignite	6.25	6.88	36.41	50.46
Gas fat coal	0.95	8.55	30.12	60.38
Anthracite	2.19	8	4.73	85.08
Coking coal	1.12	21.32	22.40	72.57
1/3coking coal	7.32	23.41	27.58	65.31

Table 2
Particle size distribution of coal dust.

Particle size/μm	Lignite	1/3 Coking coal	Coking coal	Anthracite	Gas fat coal
d10	4.2	3.19	4.22	4.85	3.43
d50	6.64	5.60	6.85	7.78	7.59
d90	9.94	7.79	10.24	11.86	10.23
Mean	6.85	7.09	7.06	8.08	7.89

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