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Surface physical properties and its effects on the wetting behaviors of respirable coal mine dust

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ABSTRACT

In the present research work, coal dust physical properties as well as its wetting behaviors were analyzed systemically. The influences of different surfactants on coal dust's wetting behaviors were also investigated and compared with deionized water. Research results show that the finer the coal particle sizes, the more complex the coal particle micro structures are, which may cause the poor wetting abilities. Among the three different coal dust samples, the wetting performance is poor for the coal with higher volatile content due to the easier release of volatile matter and the easier formation of gas film around the particle. The fractal dimension and contact angles are presenting perfect correlations. With the increase of the fractal dimension, the contact angle would increase correspondingly, which indicates a poor wetting performance. The wetting behaviors of coal dust could be greatly improved by adding surfactant in the deionized water. However, the species of surfactant and its contents in the solvent are the two important factors for dust wetting abilities enhancement. For the two selected surfactants, sodium dodecyl sulfate (SDS) may be a better choice and 0.2% concentrations are recommended during coal dust suppression applications. Based on the experimental results, a wetting dynamic model was built to simulate coal dust wetting process. The calculated values agreed well with the experimental results.

1. Introduction

Occupational overexposure to coal mine dusts would result in coal workers' pneumoconiosis (CWP) and silicosis, both disabling and possibly fatal lung diseases. Although remarkable progress has been made over the past several decades, severe cases such as CWP are always being reported among coal miners [1].

Improving ventilation and water spray are the two primary controlling methods used for dust suppression aimed to protect workers from overexposure to the respirable coal dust [2,3]. Therefore, coal dust wetting ability may have a significant influence on dust suppression efficiency by water spraying method [4].

Coal dust physical characteristics including both the macroscopic and microscopic structures, which govern the shape of liquid droplets on solid surfaces, are still posing several challenging questions. Since the spreading of liquids on solid substrates is of interest to many practical applications and industrial processes, extensive experimental investigations and theoretical works have also been performed in the past to understand, to model and to predict the shape of interfaces formed between liquid and solid surfaces. The abilities of a droplet spreading over a coal particle surface are always controlled by the overall free energy at the phases interface. If the total free energy of the liquid spreading at the solid surface is lower, the wetting process would be spontaneous. Therefore, in the conventional researches, the wetting ability of coal had been concerned seriously because of its importance in flotation and oil agglomeration of coal in water to remove significant amounts of the mineral matters [5–7]. The wetting abilities of coal with liquid are usually determined by their contact angles. Therefore, contact-angle measurements have been extensively used to assess coal surface wetting behaviors.

The contact angle of a droplet or a bubble on the polished single mineral surface is always measured through the vapor or liquid phases, which are commonly determined by sessile drop or sessile bubble techniques. Previous results show that most particles' contact angles are always influenced by its particle size, surface roughness and surface chemical heterogeneities.

The adsorption of surfactants on solid surfaces from aqueous solutions is important for regulating some properties including wetting, dispersion, and rheology. The modifying abilities of surfactants to the interfacial properties even at lower concentrations have led to their widespread use in numerous applications in the mineral, environmental, pharmaceutical, biological, agricultural, cosmetic, textile, and coatings industries [8,9]. Wu investigated dust suppressing behaviors using two kinds of surfactants and water glass as the wetting agents. The wetting performances of dust with various particle sizes, water contents and compositions were investigated among all selected wetting agents. He proved that particle size and water content of

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Table 1
The proximate analyses of the coal samples (air dried basis).

Sample no.		Particle size (d_{p50}/μm)	Proximate analysis (w/w%)			
			FC	VM	Ash	M
Anthracite (No. 1)	No. 1-1	11.15	73.66	11.34	12.99	2.03
	No. 1-2	35.42	71.99	9.99	16.45	1.57
	No. 1-3	84.65	64.60	9.18	24.61	1.61
Bituminous coal (No. 2)	No. 2-1	3.607	76.18	16.41	6.48	0.95
	No. 2-2	10.33	75.37	16.12	7.61	0.91
	No. 2-3	44.30	73.30	15.35	10.48	0.88
Lignite (No. 3)	No. 3-1	8.596	36.12	46.74	5.26	11.88
	No. 3-2	37.31	37.71	45.88	4.75	11.66
	No. 3-3	78.41	39.06	44.61	4.52	11.82

the dust are the two important factors for dust suppressions. The superfine dusts are much more difficult to be wetted [10].

In the present research work, three kinds of coal in different ranks were selected and screened into three different particle size distributions. The contact angles of deionized water and two kinds of active surfactants with coal particles were measured using optical contact angle analyzer. In addition, the wetting behaviors (contact angles) were also correlated with coal particle's physical fractal dimensions.

2. Experimental procedure

2.1. Experimental materials and apparatus

Three kinds of coal (anthracite, bituminous coal and lignite) were selected, crushed and screened separately into three samples with different particle sizes. The proximate analyses of the coal samples are listed in Table 1. Particle size distributions of each sample are analyzed by a leaser size analyzer (LS-100Q). Coal particle's microstructure was analyzed by ASAP2020M analyzer and the particle surface morphological characteristics were tested by scanning electron microscope (S-3000N). The contact angles of the particle's surface with deionized water as well as two kinds of active surfactants were measured systemically using drop shape analyzer (DSA100).

2.2. Basic theory and methods

Regardless of the measurement technique employed, determination of the contact angle is often based on the premise stated in Young's contact angle (CA) equation (Eq. (1)) [11,12]. The equation describes an equilibrium force balance at the three-phase interface (Fig. 1) [13]. The relation between the three interfacial tensions (IFT) is given as follows [14],

$$\sigma_{\text{liquid–vapor}}\cos(\theta) = \sigma_{\text{solid–vapor}} - \sigma_{\text{solid–liquid}} \quad (1)$$

where θ is the unique, equilibrium contact angle, $\sigma_{\text{liquid–vapor}}$ is the liquid–vapor interfacial tension, $\sigma_{\text{solid–vapor}}$ the solid–vapor interfacial tension, and $\sigma_{\text{solid–liquid}}$ the solid–liquid interfacial tension [15].

According to Young's equation, the nature of repellency in air–water–solid three phase systems is controlled by the surface energy of the solid [16]. Compared with the liquid–vapor interface, the interfacial tension (IFT) of the solid–vapor interface is sufficiently high on a completely wetting substrate. Under this condition, water would spread spontaneously and the contact angle is 0° [16,17]. Conversely, on water repellent or harder wetting substrates, water would not spread spontaneously because the surface energy of the substrate (solid–vapor IFT) is lower than that of water (liquid–vapor IFT). Under this condition, water acts as a non-wetting fluid and would rest on the surface at some angle greater than 90°.

In present experiments, one drop shape analysis system of DSA100 type (manufactured by KRÜSS, German) was employed for contact angle measurement. Once the samples were prepared, the deionized water was pumped out of the needle and onto the sample surface automatically. And the sequential images were captured by a high speed camera supported by the DSA100. Each test movie lasted about 2 min until the droplet maintained a basic stability shape. Following the scanned images, the contact angles were analyzed semi-automatically using the software by selecting points to draw a horizontal baseline where the drop contacted the sample surface and manually tracing the drop interface-profile on the images. Then, the length of baseline and tangent line to the drop profiles was calculated using a non-spherical fit at the end of the baseline for left sides of the water drop (Fig. 2).

3. Results and discussions

3.1. Particle size distributions and its effects on wetting performance of coal mine dust

Three different Chinese coal mine dusts were collected actually and the samples were screened manually into three different size

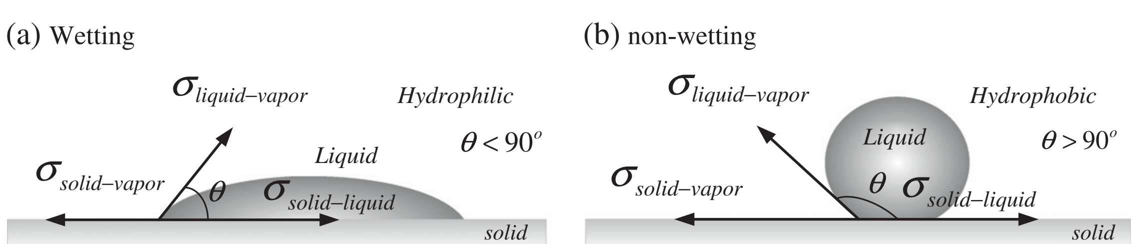

Fig. 1. Schematic illustration of the liquid–solid wetting principle on the planar surfaces.

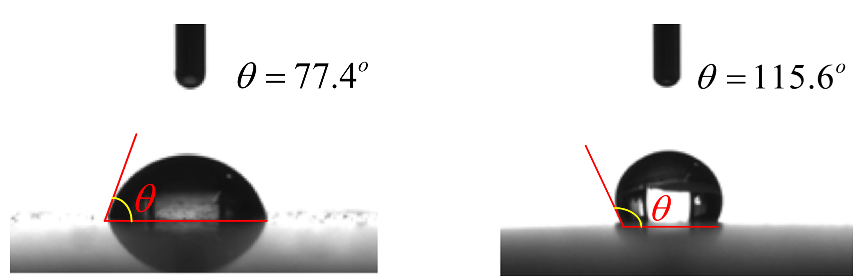

Fig. 2. Example of contact angle calculation using non-spherical fit on left side of drops.