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Contact angle and induction time of air bubble on flat coal surface of different roughness

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ABSTRACT

The wettability of coal is an important parameter for representing the surface hydrophobicity and floatability of coal particle, and hence determines coal flotation behavior. The wettability of coal is primarily governed by the surface functional groups. However, the role of surface topography in the wettability of coal has not attracted enough attentions. This paper was to investigate the effect of roughness on the wettability of coal by measuring the contact angle between air bubble and flat coal surface. Besides, a new method to measure the contact angle is introduced. The shape of the bubble is fitted by both the circle and the ellipse. The lump coal particles were used as coal sample and polished by sand papers of different meshes to gain the specific flat coal surfaces of different roughness. The attachment time measurements and Wenzel theory were used to further explain why the surface roughness has significant effects on the contact angle of air bubble on coal surface. Throughout this paper, it was found that the wettability of coal was decreased with the increase of surface roughness. The water may be entrapped in the pores/cracks of rough coal surface which prevents the attachment between coal surface and bubble as well as the spreading of three-phrase contact line. Therefore, both the attachment time and contact angle were decreased with the increase of roughness.

1. Introduction

The wettability of materials plays an important role in the particle handling and industrial applications [1,2]. In conventional coal flotation, the coal particle with high surface hydrophobicity and low wettability are easily collected by bubbles and forwarded into the foam product (clean coal) whereas the particles with hydrophilic surface owning high wettability are difficult to be collected by bubbles, and hence staying in the flotation pulp forming the tailings [3–6]. The surface property of coal is complicated, and it is considered to be relevant to the metamorphic grade and the composition of minerals in coal particle [7]. The metamorphic grade has significant effects on the functional groups on coal surface while the composition of minerals determines the role of minerals on coal surface hydrophobicity. The coal flotation performance is also determined by particle size [8].

In general, the hydrophobic surface is repelled with liquid and attracted with gas [9,10]. The factors affecting the wettability and hydrophobicity of coal surface can be divided into two aspects [11]. As shown in Fig. 1, the first aspect is chemical property, and it mainly includes the compositions of both minerals and functional groups. For minerals composition, the content of hydrophilic minerals, such as quartz and kaoline, directly influences the wettability of coal surface. Besides, the proportion of hydrophilic groups (C—O, C═O, etc.) and hydrophobic groups (C—C, C—H, etc.) also affects the surface wettability [12–14]. Reported studies have paid many attentions to the influence of chemical property on coal surface wettability [15–18]. The current methods to measure coal surface wettability include sessile drop method, capillary penetration methods, and Wilhelm plate method etc. usually ignore the influence of physical property by using smooth surfaces for measurements [19]. Therefore, the effects of physical property of coal surface are ignored during the conventional measurements of wettability and hydrophobicity.

In recent years, some researchers begin to focus on the influence of physical property on the hydrophobicity of minerals and coal. Physical property can be divided into two aspects. For example, particle shape has been proved to an important factor influencing minerals flotation [20–23]. Koh et al. [24] suggested that the angular particles have a better flotation recovery than spherical particles, and the angular particles have a lower induction period. The second aspect is the surface topography or roughness. Rezai et al. [25] suggested that the surface roughness can stimulate the rupture of the intervening aqueous film, so that the particles could contact with the bubbles more easily. The surface roughness can also increase the flotation rate of quartz particles. The spherical microscopic particles of nano-sized roughness need to

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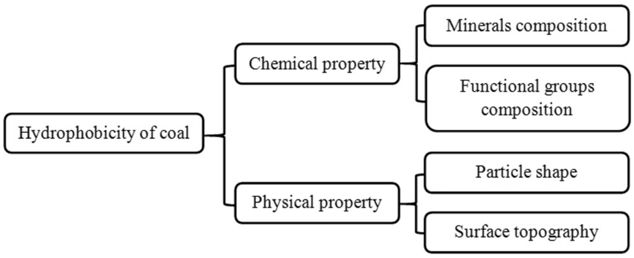

Fig. 1. Chemical/physical factors affecting coal wettability and hydrophobicity.

overcome less energetic barrier to attach to the bubbles. It indicates that particles with nano-sized roughness are more hydrophobic than those with smooth surface [26]. In other words, surface roughness enhances the hydrophobicity of particles that makes it attach to the bubbles easier.

However, the surface roughness was also reported to reduce the hydrophobicity of the minerals [27]. Yekeler et al. [28] observed that there is large number of smooth talc particles in the flotation concentrate, and the rough particles are mostly distributed in the tailings. It indicates that the smooth particles are more hydrophobic than the rough ones. Zawala et al. [29,30] concluded that the rough particles have a preferable flotation recovery because of a faster rate of film thinning and a lower particle–bubble energy barrier. However, contrary to these findings, especially for this electrode material, the materials of rough surface do not necessarily increase the hydrophobicity, and the rough surface is not conducive to the thinning of the hydration film. As for hydrophobic materials, the adhesion force between water and high rough solid is larger than that between water and low rough solid because of nano-bubbles and hydrophobic force [31]. The super-hydrophobic material is produced under a specific range of roughness or a specific texture [32], and the hydrophobicity will be decreased for the excessively smooth or excessively rough surface.

In this study, two kinds of low-ash coal particles, coking coal and anthracite coal, were used to conduct the bubble contacting tests and induction time test. The lumps of low-ash coal with different roughness were obtained by the polisher using sandpapers of different meshes. The three-phase contact angles and induction time were used to reflect the wettability and hydrophobicity of coal surface as well as the strength of adhesion between coal surface and bubbles in the absence of flotation reagents.

2. Materials and experimental

2.1. Coal samples

The coking coal samples were collected from Tianchen Coal Preparation Plant in Shandong province of China. The anthracite samples were selected from Taixi Coal Preparation Plant in Ningxia province of China. The coal lumps were chosen to be polished by sandpapers of different meshes. Industrial analysis and elemental analysis of the coal samples are provided in Table 1.

2.2. Polishing treatment

The MP-2B polish-grinding machine (Shanghai light phase preparation equipment Co., Ltd.) was used to polish the coal surface instead of artificial polishing. The sandpapers of different meshes (120, 240, 320, 400, 600, 800, 1000, 1500, 2000, and 3000) were made by MATADOR in Germany.

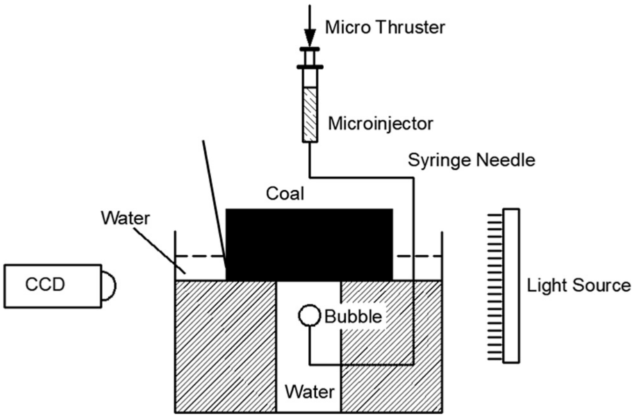

Fig. 2. Bubble contacting test device.

2.3. Surface roughness measurement

The surface roughness of coal lump surface was measured by surface roughness measurer (Mitutoyo SJ-210), which is connected to the computer to record the data. The Ra index was chosen to show the roughness of different coal surfaces. On the work lines, the two dimensional topographies were drawn by computer. The value of roughness was the average of ten measurements on two comparative lumps.

2.4. Bubble contacting experiment

A single bubble was controlled to contact with the coal surface in the water, and the bubble system device is shown in Fig. 2. The bubble spread on the coal surface, and then the stable three-phase contact line is formed. In order to ignore the effect of bubble size on the values of contact angle, the diameter of bubble was controlled to be about 2 mm.

The transparent sink is made of plexiglass acrylic. In addition to a large shallow groove, there are two deep grooves in the sink. The sink is filled with deionized water, and the water is made just out of the lower surface of coal. The gas in the micro injector is slowly pushed out by a micro thruster above. Then the bubble, formed in the water, is repeated adjusted to remain the bubble size consistently. The bubble rise slowly with the micro injector and its syringe needle is made of stainless steel. When the bubble is just in contact with the coal surface, the micro injector begins to move down. The CCD video camera was recorded by the images and videos of this process, and the results were connected to the computer for the subsequent analysis. The contact angles in this paper are measured when the bubbles are stably contacting with coal surface.

2.5. Contact angle measurement

A new method is used to measure the contact angle. In general, the contact angle refers to the angle which is between the gas–liquid interface at the intersection of gas, liquid and solid, and the angle is between the liquid and the solid–liquid boundary. Usually, the shape of

Table 1
Proximate analysis and ultimate analysis of coal samples (%).

Sample	Mad %	Ad %	Vdaf %	FCd %	St.d %	Odaf %	Cdaf %	Hdaf %	Ndaf %
coking coal	1.06	5.05	9.52	85.91	0.20	3.04	92.55	3.41	0.79
anthracite	1.68	11.88	34.33	57.87	0.57	9.44	83.52	5.03	1.36

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