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Effect of flotation reagent adsorption by different ultra-fine coal particles on coal flotation

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ABSTRACT

The impact of ultra-fine coal particles on the flotation of coarse coal particles is investigated in this work. Flotation experiments of three coal samples were conducted. The results showed that the recovery of coarse coal particles (>74 μm) decreases when low-ash ultra-fine coal particles are added into coal samples, whereas the addition of high-ash ultra-fine coal particles has very slight impact on it. Measurements of contact angle and wetting heat were conducted to examine the interaction between ultra-fine coal particles and flotation reagents. The results showed that low-ash ultra-fine coal particles have very strong adsorption to both collector and frother, whereas high-ash ultra-fine coal particles have strong adsorption to collector but weak adsorption to frother, which indicates that frother may play a more important role in the recovery of coarse coal particles.

1. Introduction

Froth flotation is used widely for the separation of fine coals. In recent years, the proportion of ultra-fine coal particles (usually finer than 74 μm) increases due to the popularization of mechanical mining and heavy media separation technology. Ash content of ultra-fine coal particles is higher than that of coarse particles (Zhang et al., 2013a). Ultra-fine coal particles usually contaminate flotation concentrate. Therefore, the quality of clean coal in many coal preparation plants deteriorates. Effective separation of ultra-fine coal particles has become a serious challenge in coal preparation.

Flotation is a complex process involving interactions between liquid (bulk water and reagents), solid and air phases. Ultra-fine particles tend to have high surface energy so their interaction with other phases is very active. The phenomenon of concentrate contamination has been studied for a long time and three mechanisms have been discovered. Water entrainment is the most extensively investigated mechanism and many mathematical models have been established (Bisshop and White, 1976; Warren, 1985; Kirjavainen, 1989, 1992; Savassi et al., 1998; Cilek and Umucu, 2001; Stevenson et al., 2007; Yianatos and Contreras, 2010). Another mechanism is that ultra-fine particles may attach to coarse floatable particles and transport to forth with them. In the case of coal, Arnold and Aplan (1986) and Xu et al. (2003) disclosed that montmorillonite would attach severely to coarse coal particles, whereas kaolinite and illite would attach to coarse coal particles to a very small extent. The last mechanism of entrainment is the coating of water layer around bubble surfaces. The coating process occurs rapidly so that the attachment of hydrophobic particles to bubbles is prevented (Ata et al., 2002; Ata, 2009; Oats et al., 2010). However, some researchers found that the coating of ultra-fine particles can help stabilize bubbles and promote the recovery of coarse particles (Rahman et al., 2012; Zhang et al., 2013b).

Ultra-fine particles can contaminate flotation concentrate on the one hand, but on the other hand, they can also influence the recovery of coarse particles. Their impact on the recovery of coarse particles is determined to a great extent by the interaction between ultra-fine particles and flotation reagents. Ultra-fine particles have strong adsorption to flotation reagents (Tao et al., 2000; Bazin and Proulx, 2001; Manev and Nguyen, 2005; Gupta et al., 2009). Excessive adsorption of collector would reduce the probability of coarse particles to be collected. On the other hand, excessive adsorption of frother would diminish frother's effect of preventing bubble coalescence (Tao et al., 2000). Bubbles become instable so particles would detach from them more easily. There are various ultra-fine particles in coals. Adsorption of different flotation reagents by different ultra-fine particles still remains unclear. In this work, flotation experiments of three coal samples with the addition of ultra-fine coal particles with different ash contents were conducted. The adsorption of collector and frother by ultra-fine coal particles was also investigated through measurements of contact angle and wetting heat to explore its impact on the recovery of coarse coal particles.

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2. Experimental

2.1. Materials and preparation of samples

Coal sample finer than 500 μm from Huangyanhui mine located in Xiyang County, Shanxi, China, was separated to different densities using organic liquid mixed of benzene, carbon tetrachloride or bromoform at an appropriate ratio. The products of $-1.3\ g \cdot cm^{-3}$ and $+1.8\ g \cdot cm^{-3}$ fractions were cleaned, filtered, dried and then dry-ground for 5 min. The grinding products were sieved through a 74 μm screen to obtain ultra-fine particles finer than 74 μm. The ash contents of ultra-fine particles of $-1.3\ g \cdot cm^{-3}$ and $+1.8\ g \cdot cm^{-3}$ fractions were 5.07% and 61.20% respectively.

Three coal samples respectively from Wanbei, Linfen and Yanzhou, China, were selected to conduct flotation experiments in this work, which are called WBC, LFC and YZC in the following for short. Size analysis of these three samples is shown in Table 1.

2.2. Flotation experiments

Flotation tests were conducted in a 1.5 L XFD flotation cell using 90 g of coal sample with or without the addition of 10% weight of ultra-fine particles of different ash contents. N-dodecane and 2-octanol were respectively used as collector and frother. Three dosage levels are listed in Table 2. The impeller speed of flotation cell was 1900 r/min and the aeration rate was 0.25 m^3/h. Each sample of 90 g was first agitated with tap water in flotation cell for 2 min. Then the collector was added into the pulp and the pulp was conditioned for another 2 min. After that the frother was added and an additional 0.5 min of conditioning was kept. Subsequently, air was introduced into the cell and the pulp was floated for 3 min. The concentrates were sieved through a 74 μm screen. Tailings and sieved concentrates were filtered and then dried in an oven for 5 h for further analysis.

2.3. Determination of contact angle and wetting heat

Coal particles finer than 74 μm of $-1.3\ g \cdot cm^{-3}$ and $+1.8\ g \cdot cm^{-3}$ fractions were sampled for the measurements of contact angle and wetting heat with n-dodecane and 2-octanol. The measurement of contact angle was conducted using a DSA100 contact angle analyzer (Kruss, Germany). About 0.3 g of the ultra-fine coal particles was pressed under a pressure of around 2500 psi (170 atm) using a tablet machine for 2 min to form a pellet. A drop of reagent was placed on the pressed pellet gently, and a video was taken immediately after the drop contacted the pellet. Afterwards, the image after 1 s of the drop contacted the pellet was taken from the video to determine the contact angle by fitting a tangent to the shape of the sessile drop on the microscopic image.

The measurement of wetting heat was conducted using a Setaram C80-II microcalorimeter (France). Details and operation of the equipment can be seen in other literatures (Zehioua et al., 2009). There are two parallel closed cells of the machine. About 0.5 g of the ultra-fine coal particles was placed in a steel sleeve in one cell and the sleeve was isolated by a membrane on top of it. 2.5 cm^3 of flotation reagent was placed in the cell but outside the sleeve. The temperature in the cell was adjusted to 298.15 ± 0.05 K. Then the membrane was punctured and the flotation reagent flowed into the sleeve. And the other parallel cell went through the same operation simultaneously except that there were no particles in the sleeve. The heat flows in the two cells were recorded. And the heat release during the wetting was calculated from the difference of heat flow between the two cells.

Table 1
Size analysis of coal samples.

Size (μm)	WBC		LFC		YZC	
	Rate (%)	Ash content (%)	Rate (%)	Ash content (%)	Rate (%)	Ash content (%)
500–250	4.23	12.96	1.51	14.29	4.24	35.03
250–125	5.74	13.21	30.18	18.57	15.43	34.19
125–74	41.25	21.53	14.27	23.41	25.30	33.50
74–45	20.13	29.89	22.61	27.10	20.14	33.90
−45	28.64	46.77	31.43	40.20	34.89	47.34
Total	100.00	29.60	100.00	27.92	100.00	38.58

Table 2
Levels of reagent dosage.

Dosage level	Level 1	Level 2	Level 3
Collector (g/t of coal)	250	500	750
Frother (g/t of coal)	40	80	120

3. Results

3.1. Flotation results

3.1.1. Flotation result of overall size fraction

Flotation experiments of three coal samples with or without the addition of ultra-fine coal particles of different ash contents were conducted. Fig. 1 shows the flotation results of the overall size fraction of the three samples for three reagent dosage levels. The marks M1, M2 and M3 on the horizontal axis refer to samples with or without the addition of different ultra-fine particles. M1 represents samples without the addition of ultra-fine particles, while M2 and M3 respectively represent samples with the addition of 10% weight of low-ash or high-ash ultra-fine coal particles. It can be seen that the yield and ash content of M1 and M3 are almost the same for all the three reagent dosage levels, while the yield and ash content of M2 are the lowest. The yield gap between M1 and M2 reduces as the reagent dosage increases. For dosage level 3, the gap almost disappears.

We can find that Fig. 1 contradicts with our common sense. As low-ash ultra-fine particles were added in M2, the concentrate ash content of M2 should be lower and the yield of M2 should be higher than that of M1 and M3. The ash content accords well to this expectation, but the yield goes to a total opposite way. On the other hand, as high-ash ultra-fine particles were added in M3, there should be an aggravation of flotation concentrate contamination and an increase of concentrate ash content. But the concentrate ash content of three samples for dosage level 1 and level 2 does remain the same as that of M1. For dosage level 3, the concentrate ash content of WBC and YZC even decreases while only the ash content of LFC increases as expected. These unusual results will be explained by the analysis of flotation concentrate of different size fractions in the following sections.

3.1.2. Flotation result of coarse size fraction

The flotation result of coarse size fraction (>74 μm) is shown in Fig. 2. It is similar with the result of overall size fraction except that the yield reduction of M2 is larger and does not disappear for dosage level 3. It could be seen from Fig. 2 that the addition of low-ash ultra-fine particles significantly decreases the recovery of coarse coal particles, especially for low reagent dosage level. Therefore, the yield reduction of coarse coal particles may be caused by the strong adsorption of flotation reagents by low-ash ultra-fine particles, as the yield reduction of coarse coal particles for M2 gets smaller as the reagents increases. For example, the yield of YZC decreased more than 18% for dosage level 1 but the reduction is less than 10% for dosage level 3. However, the addition of high-ash ultra-fine particles seems to have no influence on the flotation of coarse coal particles.

3.1.3. Flotation result of ultra-fine size fraction

It can be seen from Fig. 3 that the yield of ultra-fine particles (<74 μm) increases when low-ash ultra-fine particles are added (M2). And the increase gets smaller as the reagent dosage increases.