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Influence of coal particles on froth stability and flotation performance

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ABSTRACT

Solid particles have significant effect on flotation froth. In this research, the effects of coal particles of different size and hydrophobicity on froth stability and flotation performance were studied. The froth stability was measured in both the froth formation and froth decay processes by maximum froth height, froth half-life time and water recovery. The results show that fine particles of moderate hydrophobicity contributed most to maximum froth height in the froth formation process and were most favorable for flotation. Fine hydrophilic particles stabilized the froth in the froth formation process but the froth half-life time was very short due to the high water solid ratio. High hydrophobic particles of both fine and coarse size fractions greatly increased the froth half-life time in the froth decay process. But the froths were very rigid and the maximum froth heights were very low. The presence of fine hydrophobic particles was very unfavorable for the recovery of coarse particles.

1. Introduction

In froth flotation, mineral particles are agitated in the pulp with flotation reagents and bubbles. Hydrophobic particles can attach to bubbles and then report to the froth. It has been discovered that the froth is also selective (Seaman et al., 2004, 2006; Amelunxen et al., 2014) and the final recovery of valuable minerals is determined to a large extent by froth recovery. Welsby et al. (2010) further proposed that froth recovery can also affect the valuable mineral recovery in the pulp zone owing to the particles that drop back to the pulp from the froth.

Froth recovery is mainly affected by bubble coalescence and water drainage. Bubble coalescence causes bubble vibration, which leads to the detachment of particles (Ata, 2009, 2011; Wang, 2015). Water drainage is helpful to increase the quality of final concentrate by rejecting the entrained hydrophilic fine particles (Ata et al., 2004; Zheng et al., 2006; Wang et al., 2015). In industry, the froth height is often increased to obtain better concentrate grade. But it should be noted that drainage does vary in different heights of the froth. The extent of drainage at the bottom of the froth is much larger than that on the top (Schwarz and Grano, 2005).

Froth is very complex and is affected by multiple factors. In respects with particles, main factors that affect froth stability are solid concentration and particle shape, size and hydrophobicity (Hunter et al., 2008). Extensive research has been conducted on the effect of particle size using various materials. It has been found that fine particles have more profound influence on froth stability (Ozmak and Aktas, 2006; Aktas et al., 2008; Ata, 2012; Rahman et al., 2012; Wang et al., 2014). In the case of particle hydrophobicity, many researchers (Johansson and Pugh, 1992; Ata et al., 2002, 2003, 2004; Kaptay, 2004; Schwarz and Grano, 2005) used the methylated quartz as model mineral and they promoted that there exists a critical particle contact angle around 65° for which the froth is the most stabilized and particles with higher contact angle collapse the froth. There is also research (Dippenaar, 1982a,b; Kaptay, 2004) conducted on the mechanism of film rupture by varied particles. However, the underlying reason why particles with the critical contact angle can stabilize the froth is still unclear. Since the size range of coal in flotation is much wider (usually finer than 500 μm) than other minerals, it is unknown whether the effect of particle hydrophobicity on froth stability of methylated quartz can be applied to coal.

To date, there is little research focused on the effect of particle hydrophobicity of coal on froth stability and no practical application of the particles with the critical contact angle in flotation improvement was proposed. In this research, a bituminous coal sample was divided into different size and density fractions. Flotation experiments and froth stability measurements under the same conditions were conducted to figure out how different coal particles affect froth stability and flotation performance.

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There are various methods to measure froth stability. They can be divided into dynamic and static measurements (Farrokhpay, 2011). In dynamic measurements, aeration is kept and the formation and breakage of bubbles in the froth are at dynamic equilibrium. In static measurements, aeration is stopped after the froth has been stabilized and only bubble breakage happens. The dynamic measuring methods include maximum froth height (Barbian et al., 2003, 2005; Aktas et al., 2008), bubble size analysis (Ata et al., 2003; Kuan and Finch, 2010; Wang and Peng, 2014), air recovery (Neethling and Cilliers, 2008; Qu et al., 2013), water recovery (Ata et al., 2004; Zheng et al., 2006; Wiese et al., 2010), etc. The typical static measurement is the froth half-life time (Zanin et al., 2009; Tang et al., 2010). In most cases, only one method was used and the results were consistent with the flotation performance. Sometimes different measurements were combinedly carried out. Qu et al. (2013) once studied the relationship between the flotation performance and the froth stability measured by air recovery and maximum froth height. The results were in good consistency. Zanin et al. (2009) used maximum froth height and froth half-life time together to measure the industrial flotation froth and the results were also consistent and in line with the flotation performance. Tang et al. (2010) first pointed out the inconsistency between maximum froth height, froth half-life time and water recovery. They concluded that the different measures of froth stability are not different ways of measuring the same thing, but measurements of different aspects of what is loosely termed froth stability. Maximum froth height is affected significantly by the bubble bursting on the top of the froth. Froth half-life time is mainly determined by the drainage of the froth. The drainage in every position of the froth can affect the final result. Unlike maximum froth height and froth half-life time, which are stand-alone measurements, water recovery is measured during flotation experiments. It is affected by many other factors, such as flotation time, scrapping speed and scrapping depth (for mechanical flotation cell). The water taken into account is from the final concentrate, which overflows from the concentrate launder, so it is also affected by concentrate yield.

In this research, the froth stability was combinedly measured by maximum froth height, froth half-life time and water recovery so as to get relatively overall information of the froth, including the extents of bubble coalescence and water drainage under different conditions. A parameter named "water solid ratio" was used to indicate the extent of drainage in the froth decay process. A high non-overflow flotation cell was used to measure the maximum froth height and the froth half-life time. The conditioning and aeration conditions were kept absolutely the same as those in the flotation experiments.

2. Experimental

2.1. Materials

A run-of-mine bituminous coal sample was acquired from a coal preparation plant in Zaozhuang, China. Table 1 shows the proximate and ultimate analysis of the sample. The as-received sample was sieved using screens of 500, 250, 125, 74 and 45 μm to obtain coal particles of different size fractions. Table 2 shows that the fraction of the particles finer than 74 μm was more than 57% and the ash content was higher than that of other size fractions. The particles finer than 74 μm were separated to different density fractions, namely <1.5, 1.5–1.8 and >1.8 g cm^{-3}, in a centrifugal machine in different organic liquids that mixed of benzene, bromoform and carbon tetrachloride. The particles of different density fractions were dried in an oven for 5 h at 60 °C. The ash contents of the particles of <1.5, 1.5–1.8 and >1.8 g cm^{-3} density fractions were 4.93%, 24.85% and 74.65% respectively.

The measurements of particle size and contact angle of the <74 μm fine coal particles of different density fractions were conducted using S3500 laser particle size analyzer (Microtrac, the US) and DSA100 contact angle analyzer (Kruss, Germany). Fig. 1 shows that the d_{80} of the particles of <1.5, 1.5–1.8 and >1.8 g cm^{-3} density fractions were 58.04, 37.80 and 17.86 μm respectively. The low density particles were coarser than the high density ones. This is because there were more phyllosilicate minerals, which were likely to degrade, in the high density fraction. Fig. 2 shows that the contact angles of the particles of <1.5, 1.5–1.8 and >1.8 g cm^{-3} density fractions were 95°, 72° and 43° respectively.

2.2. Flotation experiments

All flotation experiments were conducted in a 0.5 L XFD flotation cell using 25 g of coal. Kerosene and 2-octanol were used as the collector and the frother. The dosages of the collector and the frother were 2.5 kg/t and 0.5 kg/t. The flotation reagents were over-dose and were much more than that normally used. The impeller speed and the aeration rate were fixed to 1900 r/min and 0.20 m^3/h. The coal was first agitated with the tap water in the flotation cell for 3 min. Subsequently, the collector was added and another 2 min of conditioning was kept. Then the frother was added and 0.5 min later the aeration valve was opened. Four concentrates were collected after cumulative time of 0.5, 1, 1.5 and 2.5 min after aeration. During the flotation, no adding water was applied and the froth height was indulged to decrease from the initial value (which varied in different experiments) to almost nil so as to highlight the influence of different particles on froth stability and flotation performance. The concentrates with water were weighed to calculate water recovery and water solid ratio. It should be noted that the water recovery and water solid ratio were calculated from the water in the overflow concentrates. As the water near the bottom of the froth was more than that near the top of the froth (Schwarz and Grano, 2005; Tang et al., 2010), the value of the water solid ratio of the whole froth should be higher. All the concentrates and tailings were filtered and then were dried in an oven for 5 h at 60 °C.

2.3. Froth stability measurements

A high non-overflow flotation cell was designed to record the froth height. This device was modified from that of Barbian et al. (2003) and is shown in Fig. 3. The height of this cell was twice higher than that of the original flotation cell that was used in the flotation experiments. The isolated dam-board could be put on

Table 1
Proximate and ultimate analysis for the bituminous coal sample.

Proximate analysis (ad)				Ultimate analysis (daf)				
Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	C (%)	H (%)	N (%)	O (%)	S (%)
2.36	27.73	34.41	35.50	80.83	5.68	1.38	11.53	0.57

d: air-dry basis.
daf: dry ash-free basis.