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Effect of saline water on the flotation of fine and coarse coal particles in the presence of clay minerals

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ABSTRACT

This research addresses two important issues confronting coal flotation plants in Australia, the use of saline water and the processing of clayey coal. Two coal samples obtained from BHP Billiton Mitsubishi Alliance (BMA) and Xstrata were tested to represent coarse coal flotation and fine coal flotation, respectively. Saline water with low, medium and high ionic strengths and individual electrolytes encountered in the flotation plants were used. It was found that saline water had a more pronounced effect on fine coal flotation than coarse coal flotation despite similar mineral compositions and clay mineral types present. Although saline water increased froth stability in both fine and coarse coal flotation, coal particle aggregation only occurred between fine coal particles resulting in an increased recovery of coal particles as well as the entrapment of fine gangue minerals.

1. Introduction

In Australia, saline water is an important issue in mineral processing. Due to the scarcity of fresh water many flotation plants have to use groundwater or sea water with high salinity. In coal preparation plants, water has been re-used and resulted in an increase in the salinity due to evaporation and ongoing salt inputs from groundwater and run off from spoil.

The effect of saline water on coal flotation has been studied. In general, saline water increases coal yield during flotation compared to fresh water. This has been attributed to the increased bubble–particle attachment during flotation. Yoon (1982) and Paulson and Pugh (1996) proposed that reduced bubble sizes and increased population in electrolyte solutions increased the encounter efficiency of bubble–particle attachment. Fuerstenau et al. (1983) and Yoon and Sabey (1989) attributed the increased bubble–particle attachment to the reduction of zeta potential of both bubbles and particles resulting from the compression of electrical double-layers in the presence of electrolytes. Another mechanism proposed is that the inorganic electrolytes destabilize the hydrated layers surrounding coal particles and reduce their surface hydration therefore enhancing the bubble–particle attachment (Klassen and Mokrousov, 1963). Nanobubbles or nanopancakes have been also observed to form on coal surfaces in electrolyte solutions facilitating bubble–particle attachment (Mishchuk, 2005; Zhang and Ducker, 2007).

With the depletion of high-grade ores, low-grade ores which are usually fine-grained and complex, have to be mined and processed. In order to concentrate these low-grade ores, fine grinding to liberate valuable minerals from gangue minerals is required prior to flotation. It has long been established that fine particles (<10 μm) exhibit low flotation rate and recovery (Trahar and Warren, 1976), while the best flotation rate and recovery occur in the 10–100 μm particle size range for base metal minerals (Sutherland and Wark, 1955). The low flotation rate and recovery have been attributed to the low bubble–particle collision efficiency (Gaudin, 1957; Sutherland, 1948). Fine particles follow the streamlines around the bubbles due to their small inertial force and do not collide with the bubbles using conventional flotation machines. In coal flotation the exact relationship between the particle size and flotation is complex and not well understood, mainly due to the aggregation of fine particles during flotation (Polat et al., 2003). Wang and Peng (2013) found that saline water enhanced the aggregation of −38 μm coal particles resulting in the increased recovery of both combustible matter and fine gangue minerals.

Meanwhile, the flotation of coarse particles has also been a challenge confronting the mining industry. Poor floatability of coarse sulphide mineral particles greater than 150 μm has been observed in a number of studies (Crawford and Ralston, 1988; Gontijo et al., 2007; Humeres and Debacher, 2002). In coal

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flotation, there is also a linear decrease in coal flotation performance with increasing particle size in the range of 127–505 μm (Humeres and Debacher, 2002). Two main reasons have been attributed to the poor recovery of coarse particles, inefficient collision of coarse particles and bubbles failed to generate stable aggregates, and insufficient buoyancy failed to float the heavy particle aggregates (Schulze et al., 1989; Weber and Paddock, 1983). During flotation, effective collecting of the particles occurs when the collision of particles and bubbles generates a stable bubble–particle aggregate that could rise to the surface of the pulp. However, for coarse particles, the process of attachment to an air bubble is limited by the acceleration of the bubble–particle complex, because if it exceeds a critical value, the particle will detach (Dai et al., 2000; Trahar and Warren, 1976). The probability of detachment increases as the particle size increases (Sutherland, 1948). Besides, coarse particles are too heavy. The downward gravity force component dominates the whole force balance, leading to the settlement of coarse particles through the froth (Van Deventer et al., 2002).

Clay minerals present a widespread problem in the flotation of all kinds of minerals. They can coat mineral surfaces and increase pulp viscosity resulting in low mineral flotation recovery (Arnold and Aplan, 1986; Wang et al., 2013). Meanwhile clay minerals contaminate flotation concentrate through entrainment and entrapment due to the fine particle size (Wang and Peng, 2013). In coal flotation, more and more clayey ores have been processed. However, currently an effective way to treat clayey ores is not available. Clayey ores are normally blended with none-clayey ores at a very small proportion and then floated. It is expected that none-clayey ores will be run out shortly and clayey ores have to be processed.

In this study, the effect of saline water with different salinity levels on the flotation of fine and coarse coal particles in the presence of clay minerals was investigated. Fine and coarse coal samples were supplied from Xstrata and BHP Billiton Mitsubishi Alliance (BHP BMA), respectively.

2. Experimental

2.1. Materials

The fine coal sample (CoalA) was obtained from an Xstrata coal plant. In the laboratory, the sample was screened to −150 μm for flotation following the procedure established in the plant where coal particles greater than 150 μm are treated by the gravity concentrator. The size distribution of the flotation feed was measured by a Laser Diffraction Malvern Mastersizer (Model No MSX14) and the result is shown in Fig. 1. The sample has more than 40% particles smaller than 38 μm. The flotation feeds were analysed by XRD and results are shown in Table 1. The sample contains about 7.3% clay minerals such as kaolinite, smectite, and illite. The combustible matter content is about 83% in the flotation feed.

The coarse coal sample (CoalB) was obtained from a BHP BMA coal plant. The sample was screened with the −710 μm fraction being the flotation feed. Mineral compositions are shown in Table 1 with about 7.4% clay minerals such as kaolinite, smectite, and illite. The combustible matter content is about 83% in the flotation feed. The size distribution of the flotation feed obtained by wet sieving is shown in Fig. 2. 50% of the particles are greater than 150 μm.

MIBC (Methyl Isobutyl Carbinol) and diesel, industrial grade, were used as frother and collector, respectively. They are used in both flotation plants where the coal samples were supplied.

Saline water with low, medium and high salinity levels were made and used in this study following the study by Ofori et al. (2009) who conducted a survey of Australian Coal preparation plants regarding the quality of process and make-up water used in the plants. They found a wide variation in water quality in terms of salinity, types and concentrations of ions from plant to plant and summarised the data by giving the minimum, medium and maximum values of the concentration of the major ions to give an indication of variation in composition of process water. The compositions of the saline water with low, medium and high salinity levels are shown in Table 2. The major ions are Na^+, Mg^{2+}, Ca^+, K^+, SO_4^{2+}, Cl^- and HCO_3^-. They were dissolved in de-ionised water.

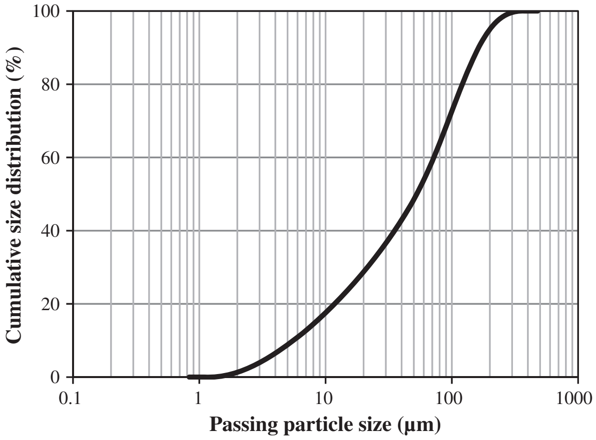

Fig. 1. The size distribution of CoalA flotation feed.

2.2. Flotation

After screening, CoalA or CoalB was transferred to a 2.5 dm^3 JK Batch Flotation Cell at about 5% and 15% solids, respectively. The natural pH of the coal slurry was about 9.0 due to the buffet effect of saline water. CoalA slurry was conditioned with diesel (160 ml/t) and MIBC (110 ml/t) for 2 min at an agitation speed of 900 rpm, while CoalB slurry was conditioned with collector (110 ml/t) and frother (170 ml/t) at an agitation speed of 700 rpm. During the flotation test, four concentrates were collected after cumulative times of 1, 2.5, 5, and 10 min. The flotation froth was scraped every 15 s. These flotation conditions in the laboratory were established to match plant mass and combustible recovery. Flotation products were combusted at 815 °C for 2.5 h to obtain the mineral and combustible matter contents (Oats et al., 2010).

2.3. Froth stability measurement

Froth stability and bubble size measurements were carried out using VisioFroth software developed by Metso Minerals Cisa. The camera was set up above the flotation cell and connected with a laptop. The measurement area was 15.9 cm × 15.9 cm. The camera signals were relayed back via an ethernet cable and an optical fibre to a central processing computer. When flotation commenced, the

Table 1
CoalA and CoalB mineral compositions analysed by XRD.

Sample	CoalA −150 μm	CoalB −710 μm
Unidentified/amorphous	82.9	84.7
Quartz	5	5.1
Kaolinite	3.9	3.8
Calcite	–	1
Muscovite	2.8	–
Mixed layer illite/smectite	3.4	3.6
Siderite	1	1.5
Pyrite	0.4	0.3
Albite	–	–
Diopside 1	–	0.1