



The joint action of saline water and flotation reagents in stabilizing froth in coal flotation



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ARTICLE INFO

Article history:

Received 3 February 2014

Received in revised form 5 January 2016

Accepted 12 January 2016

Available online 14 January 2016

Keywords:

Froth stability

Saline water

Flotation reagents

Synergistic interactions

ABSTRACT

The previous study indicates that both reagent usage and the variation of water conductivity affect froth stability and therefore coal flotation behavior. In this study, Central Composite Rotatable Design (CCRD) was conducted to investigate the interaction¹ of saline water with collector (diesel) and frother (MIBC) in controlling froth stability which was indicated by air recovery. The results show that a significant interaction (see footnote 1) existed between flotation reagents and water conductivity, which affected froth stability, combustible matter recovery and the mineral matter content of flotation concentrate. Frother and salt ions had a joint action in producing a more stable froth. On the other hand, collector and salt ions had a joint action in reducing the combustible matter content of flotation concentrate and the combustible matter recovery. A methodology was developed to avoid overly stable froth and maximize coal flotation performance by adjusting reagent additions based on water conductivity.

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1. Introduction

Saline water is an important part of the Australian mining industry. In Australia, borehole water or sea water with a high ionic strength has to be used on mine sites for production, site rehabilitation, and downstream processing due to the scarcity of fresh water. Most Australian coal mines have adopted water re-use as a means for making freshwater savings. However, water re-use results in increased salinity in site water stores, which is driven largely by evaporation and ongoing salt inputs from soil, minerals and groundwater (Vink et al., 2009). Flotation relies on a large amount of water and therefore the impact of saline water on flotation performance has received increasing attention (Peng et al., 2012). One of the impacts of saline water is the creation of overly stable froth which has been observed in the previous study (Wei et al., 2014) and coal flotation plants that use saline water with a high ionic strength. This overly stable froth causes high gangue entrainment and is difficult to handle in downstream processes.

The water quality in a flotation plant can change over time (Liu et al., 2013; Luukkanen et al., 2003; Stén et al., 2003). A survey of water quality has been conducted in coal flotation plants in Australia. It shows that large variations in water conductivity appear in three categories: the water with a minimum conductivity of 268 $\mu\text{S}/\text{cm}$, the water with an average conductivity of 4782 $\mu\text{S}/\text{cm}$ and the water with a maximum

conductivity of 10,000 $\mu\text{S}/\text{cm}$ (Ofori et al., 2005). The variation in water conductivity affects the froth characteristics and consequently the flotation performance (Liu et al., 2013). A study of water conductivity levels and coal flotation yield over 6 months has showed that the froth characteristics closely correlate with the flotation performance (Ofori et al., 2009). In order for these coal flotation plants to maintain the operation targets on combustible matter recovery and the mineral matter content of flotation concentrate, flotation reagent schemes (frother and collector dosages) have been altered (Vink et al., 2009). For example, at German Creek coal flotation plant, the operators employ low frother and collector dosages when inflow water conductivity is high and high frother and collector dosages when inflow water conductivity is low based on their operating experience (Vink et al., 2009). However, the operators do not have reagent management strategies for the variation of water qualities and only simply alter the reagent levels by trial and error, as limited studies have been conducted to identify the suitable methods of reagent management with a variation in water conductivity in coal flotation plants.

Water constituents can have a joint action with the chemical reagents added to flotation circuits in affecting the flotation response (Liu et al., 2013). Both surface active compound (frother) and surface-inactive compound (inorganic salt) are able to inhibit bubble coalescence thereby reducing bubble sizes and stabilizing bubbles. It has been reported that the ability of frother to create small bubbles and stable froths is augmented by saline water. With an increase in frother concentration, the surface tension of the solution decreases but the ability of frother to decrease surface tension is enlarged in electrolyte solutions (Castro et al., 2013). Saline water also enlarges the frothability

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¹ A term in statistics meaning that the effect of two or more variables is not simply additive.

of frother compared to de-ionized water (Castro et al., 2013; Ofori et al., 2009). The Marangoni dynamic elasticity effect which is the “self-healing” capacity of a film against external disturbances (Wang and Yoon, 2008) has been proposed to explain the joint action between frother and saline water. The elasticity effect is possible if a layer with a gradient of concentration is formed at the interface. In the presence of electrolytes, the elasticity effect generated by the accumulation of frother at the interface increases as frother molecules are displaced from the aqueous solutions by electrolytes (Castro et al., 2013).

Collector also affects the froth properties. Sodium isobutyl xanthate (SIBX) was found to destabilize the froth when used along with polypropylene glycol frother in the flotation of sulfide ores using water containing various salts (Wiese et al., 2011). Manev and Pugh (1993) demonstrated that polyethylene oxide (a non-ionic frother) associated with negatively charged potassium ethyl xanthate collector at the air/water interface. Xanthate collector reduced the equilibrium thickness of the water film between air bubbles due to the suppression of electrostatic repulsion, causing bubble coalescence and consequent destabilization. A similar observation was found in phosphate flotation where the anionic frother (sodium alkyl ether sulfate) lost its ability to stabilize the froth in the presence of fatty acid collector (El-Shall et al., 2000).

In fact, the joint action of collector and frother in flotation has been studied since 1950s. Leja and Schulman (1954) demonstrated that frother molecules associated with collector molecules at solid-liquid and air-water interfaces affecting mineral flotation. Plaksin and Khaginskaya (1957) investigated the joint action of xanthate and pine oil on the flotation of a number of sulfide minerals and found that an increased amount of pine oil brought about a distinct increase in flotation recovery. Lekki and Laskowski (1971) studied the joint action of α -terpineol as the frother and xanthate as the collector in the flotation of chalcocite. They stated that depending on the surface potential of the mineral, an adsorption or desorption of α -terpineol took place on the mineral surface. While the collision with the bubble containing an excess of surface active agent on its surface favored diffusion, α -terpineol affected the thickness of the fluid film near the solid surface changing the probability of collision and attachment. The study by Lekki and Laskowski (1971) clearly indicated the importance of the selection of optimum consumptions of collector and frother reagents in the practice of flotation.

The objectives of this paper is to identify the synergy of saline water and flotation reagents (frother and collector) in coal flotation and develop a guideline for flotation reagent usage based on the variation of water conductivity to avoid overly stable froth problems while producing satisfactory coal flotation performance in terms of combustible matter recovery and the mineral matter content of flotation concentrate.

2. Experimental

2.1. Materials

The coal sample examined in this study was obtained from a Glencore coal flotation plant in the Bowen Basin in the state of Queensland, Australia. A quantitative XRD analysis shows that this coal sample composes of 82.9% unidentified/amorphous mineral, 5% quartz, 3.9% kaolinite, 2.8% muscovite, 3.4% mixed illite/smectite, 1% siderite and 0.4% pyrite. The size of the coal sample is $\sim 150 \mu\text{m}$ which is the same as the coal flotation feed size in the plant. The combustible

matter content of the coal sample is 82% based on the burning test in an oven at 815 °C for 2 h.

Simulated process water was used in this study. Salts were added to deionized water to produce three types of simulated process water with a minimum, medium and maximum conductivity or salinity which occur in Australian coal flotation plants (Ofori et al., 2005; Ofori et al., 2009). Table 1 shows the compositions of the simulated process water together with pH and conductivity. MIBC and diesel were used in this study as frother and collector, respectively. They have been used in Australian coal flotation plants. The range of collector and frother dosages as well as the water conductivity used in this study are as follows:

Diesel (Col) 128–384 g/t.

MIBC (Fro) 145–145 g/t.

Water conductivity (Cond) 0.18–12.24 mS/cm.

The range of collector and frother dosages was determined based on the baseline dosages used in the coal flotation plant, 80 g/t frother and 256 g/t collector which were set as the center point dosages for the CCRD experiments. The maximum and minimum collector and frother dosages for the CCRD experiments were then chosen in a way to allow the center points to be set using equations in Table 2. The minimum and maximum conductivity of the simulated process water were used to calculate the center point conductivity and the low and high conductivity of the artificial water for CCRD experiments using the equations in Table 2. In order to obtain the artificial water with a low conductivity (2.52 mS/cm) or high conductivity (9.90 mS/cm) for the CCRD experiments, the simulated process water with a minimum (0.18 mS/cm), medium (5.40 mS/cm) or maximum conductivity (12.24 mS/cm) was mixed with deionized water to obtain the required water conductivity for CCRD experiments. Details are shown in Table 3.

2.2. Experimental methods and procedures

2.2.1. Experimental design

The statistical design was conducted in a way to investigate the effect of 3 factors (frother dosage, collector dosage and water conductivity) on 3 responses (air recovery, combustible matter content of flotation concentrate, combustible matter recovery) using the minimum required number of experiments detecting any curvature. In the previous study, air recovery was found to be the best indicator of froth stability for fine coal flotation using saline water with an over-frothing issue. Combustible matter content of flotation concentrate and combustible matter recovery are indicators of the coal flotation performance. A full factorial design requires a minimum of three levels per variable to obtain the prediction of quadratic terms in the response model (Box and Wilson, 1951). Central composite design (CCRD) was developed by Box and Wilson (1951) and improved by Box and Hunter (1957). It uses fewer tests than traditional full factorial designs and has desirable properties for fitting polynomial models. The CCRD was selected for the design method in this study as it provides similar information as a three-level factorial design while requiring fewer tests and allowing the sufficient detection of curvature relationship between the factors (Obeng et al., 2005). The total number of tests for CCRD includes the standard 2^k factorial points with the origin at the center, $2k$ points that are of equal distant away from the fixed center with a distance, α and center point tests which are the replicates of baseline center conditions. k is the number of factors. The axial points are determined to

Table 1
Compositions of the simulated process water used in this study.

Characteristics	pH	Conductivity ($\mu\text{S}/\text{cm}$)	Na + mg/l	K ⁺ mg/l	Ca ²⁺ mg/l	Mg ²⁺ mg/l	Cl ⁻ mg/l	SO ₄ ²⁻ mg/l
Minimum	7.2	180.0	19.2	2.1	6.6	6.4	11.6	10.6
Average	8.1	5400.0	1177.4	18.2	87.8	127.1	1018.0	1179.6
Maximum	8.1	12,240.0	3050.8	58.1	360.5	470.7	2101.0	4505.8

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