The effect of sea water on copper and gold flotation in the presence of bentonite

Ming Zhang [a], Yongjun Peng [a,b,*], Ning Xu [c]

[a] School of Chemical Engineering, University of Queensland, St. Lucia, Brisbane, QLD 4072, Australia
[b] Julius Kruttschnitt Mineral Research Centre, University of Queensland, Isles Road, Indooroopilly, Brisbane, QLD 4068, Australia
[c] Minerals and Materials Science & Technology, University of South Australia, Mawson Lakes, SA 5095, Australia

A B S T R A C T

In this study, the flotation of a copper–gold ore in the presence of 10% bentonite in tap water and sea water was investigated. It was found that bentonite had a deleterious effect on copper and gold flotation in tap water, but this deleterious effect was mitigated in sea water. Rheology measurements, settling tests and Cryo-SEM analyses were conducted to understand the underpinning mechanism. It appears that the high viscosity produced by bentonite due to its swelling capacity and cross-linked network structures negatively affected flotation hydrodynamics and therefore copper and gold flotation in tap water. It is interesting that sea water reduced the swelling capacity of bentonite and modified the association modes of bentonite platelets in flotation pulp, resulting in the breakup of links between the structures with relatively large pores, which contributed to the improvement of copper and gold flotation.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Clay minerals are associated with a number of minerals and can present a variety of problems in mineral flotation such as slime coating, high gangue entrainment and high pulp viscosity resulting in low mineral flotation recovery and/or low concentrate grade. Due to anisotropic charges on edges and faces of clay minerals, clay slime coatings may occur on positively and negatively charged minerals, depressing mineral flotation (Peng and Zhao, 2011). In flotation, clay minerals may also be floated through high mechanical entrainment as a result of their colloid sizes significantly reducing the concentrate grade (Wang et al., 2013). Also due to their anisotropic charges on edges and faces, clay minerals can form a range of different aggregate structures increasing the viscosity of flotation pulp. Zhang and Peng (2015) found that copper and gold flotation was well correlated with pulp viscosity in the presence of kaolinite and bentonite. Kaolinite increased the pulp viscosity slightly and had a minor effect on copper and gold flotation recovery, while bentonite increased pulp viscosity significantly decreasing copper and gold flotation recovery.

On the other hand, with the depletion of fresh water, the use of water with a high concentration of inorganic electrolytes in

mineral processing industry has been increased. A number of flotation plants in Australia, Canada, Chile and Indonesia are operated with sea water (Philippe et al., 2011). It is documented that saline water has a negative or positive effect on mineral flotation. Flotation improvement in the presence of electrolytes as observed in coal flotation is explained by the compression of the electrical double layer by electrolytes, thus reducing electrical repulsion between valuable minerals and bubbles (Kurniawan et al., 2011). Another factor in improving mineral flotation in saline water is the formation of smaller stable bubbles due to the influence of the electrolytes on surface tension and gas solubility (Pugh et al., 1997). Both factors are favourable for the particle-bubble attachment process. It is also documented that an increase in ionic strength can cause a negative effect on mineral flotation by enhancing frothability and therefore increasing the recovery of gangue minerals (Wang et al., 2013; Manono et al., 2012, 2013).

In clay science, it is well established that particle association between clay mineral platelets determines the rheological behaviour of concentrated clay suspensions. Due to their anisotropic structure and charge properties, clay platelets can form three different modes of association, edge-to-face (E–F), edge-to-edge (E–E) and face-to-face (F–F) (Van Olphen, 1977). The E–F and E–E contacts lead to voluminous three-dimensional 'house-of-cards' structures, accompanied by the increased viscosity. The F–F contact refers to the formation of aggregates of paralleled clay platelets and leads to thicker and larger flakes. It decreases the viscosity of suspensions by reducing the number of units available

* Corresponding author at: School of Chemical Engineering, University of Queensland, St. Lucia, Brisbane, QLD 4072, Australia. Tel.: +61 7 3365 7156; fax: +61 7 3365 3888.
    E-mail address: yongjun.peng@uq.edu.au (Y. Peng).

to build gel structures and the surface available for particle inter-actions (Luckham and Rossi, 1999). Meanwhile, electrolyte solu-tions at different ionic strengths can modify clay aggregate structures and consequently the slurry rheology. Stawinski et al. (1990) investigated the microstructure of bentonite at different sodium concentrations via SEM imaging and found that a small addition of salts (10 mmol/L) to a bentonite slurry led to the forma-tion of edge-edge-type aggregates, whereas the highest concentra-tion of salts addition (100 mmol/L) led to the formation of compact, face-face-type aggregates. Heller and Keren (2001) stud-ied the rheology of bentonite suspensions under the same $NaCl$ concentration range (0–100 mmol/L) and the results indicated that clay association was the main mechanism that affected the slurry viscosity. Palomino and Santamarina (2005) also suggested that clay mineral particle associations were a function of electrolyte concentration as a result of the balance between the van der Waals attraction and the electrostatic repulsion. In the previous work, we found that clay mineral particle interactions in fresh water modified the pulp rheology and copper and gold flotation was affected accordingly (Zhang and Peng, 2015). The presence of different ions in sea water may further complicate clay mineral particle interactions in the flotation system and hence pulp rheol-ogy as well as mineral flotation performance. However, this aspect has not been studied, but is important since a number of clayey ores are floated in sea water.

In this study, bentonite was chosen as a representative of 2:1 structure clay minerals with swelling properties. Montmorillonite, the main component of bentonite, is a layered clay mineral that belongs to the smectite group. The thin sheets of montmorillonite are held together by the interlayer bridging cations (typically Na^+) (Luckham and Rossi, 1999). Bentonite slurries display a significant yield stress even at a low concentration due to the high swelling and flocculation of fine clay platelets producing a viscous gel-like structure (Goh et al., 2011). In this study, the effect of water quality (tap water versus sea water) on the modification of bentonite par-ticle association and subsequent copper and gold flotation was studied.

2. Experimental

2.1. Materials and reagents

A copper–gold ore with a low clay content was crushed to a size of −2.36 mm before grinding and flotation. The mineral composi-tions of this ore analysed by quantitative X-ray Diffraction (XRD) are shown in Table 1. The major gangue minerals are quartz, albite, muscovite with minor chlorite and kaolinite. The elemental compositions of the ore are shown in Table 2 indicating 0.70% Cu, 0.47 g/t Au, 2.87% Fe, 0.33% Zn and 0.86% S. Diagnostic leaching shows that about 80% Cu is associated with primary copper miner-als and the rest is associated with secondary copper minerals and oxides. This ore was referred to as "clean ore" in this study. Bentonite was purchased from Sibelco Group, Australia. Quantitative XRD analysis shows that the bentonite sample con-tains 63 wt.% montmorillonite, 25 wt.% albite and 12 wt.% quartz.

Particle size distribution of the bentonite sample was measured by a Laser Diffraction Malvern Mastersizer (Malvern Instrument Ltd., U.K.). The detailed procedure was described elsewhere (Zhang and Peng, 2015). The particle size distribution of mill

Table 2
Key elements of the clean ore sample.

Copper (%)	Gold (g/t)	Iron (%)	Zinc (%)	Sulphur (%)
0.70	0.47	2.87	0.33	0.86

discharge of the clean ore was measured using both wet/dry screens from 425 μm to 38 μm. The size distributions of the clay mineral sample and ground clean ore are shown in Fig. 1. The ben-tonite sample is very fine with 70% particles smaller than 10 μm, while the P80 of the ground clean ore is 212 μm.

Sodium isopropyl xanthate (SIPX) and Cytec Aero 3894A (a thionocarbamate) were used in this study as collectors. Huntsman polyfroth W22 was used as the frother. Brisbane tap water and artificial sea water were used in the study in parallel. The sea water used in this study was the same as used in the spon-sor's flotation plant. Its composition is shown in Table 3. The sea water was prepared by dissolving 35 g API Aquarium Salt pur-chased from Age of Aquariums, Australia in deionized water to make up 1 L.

2.2. Mineral grinding and flotation

1 kg crushed clean ore sample was ground in a laboratory stain-less steel rod mill with stainless steel rods at 50% solids to obtain 80% particles passing 212 μm with the addition of 8 g/t Cytec 3894A. The mill discharge was then transferred to a 3.0 L Agitair flotation cell.

In order to study the effect of bentonite on copper and gold flotation in different water, a series of artificial mixtures of the clean ore and bentonite were prepared. For each test, a calculated amount of clean ore slurry (0 or 10% of the total solid by weight) in each case was taken out from the agitating flotation cell and replaced by the same amount of a well-mixed bentonite suspen-sion so that the concentration of bentonite in the mixture was 10% while the solid density for all tests was kept constant. The mixed slurry was then conditioned with SIPX collector (6 g/t) and frother (15 g/t) before flotation. During flotation, four concentrates were collected after cumulative times of 1, 3, 7 and 17 min. After the second concentrate, SIPX collector (4 g/t) and frother (15 g/t) were added again to the pulp. Flotation was operated at an air flow rate of 8.0 L/min. The speed of the impeller was kept constant at 800 rpm. Lime was used to control the pH 9.5 at the end of grinding and during flotation.

2.3. Rheology measurement

Rheology measurements were conducted with an Ares rheome-ter (TA Instruments Ltd., U.S.) which employs a computation program so that measurement parameters such as shear stress, viscosity, and torque are directly calculated. A couette geometry with a stationary inner cylinder and a rotating outer cylinder was utilized. All rheology measurements were performed at ambient temperature around 22 °C.

The rheometer was operated in a strain-controlled mode where the shear rate was fixed and the required torque was measured. Each measurement required a sample of 15 ml which was trans-ferred by a 20 ml syringe from the agitating flotation cell before the flotation test was conducted. Rheograms were generated in

Table 1
Mineral compositions of the clean ore sample analysed by XRD (wt.%).

Quartz	Albite	Kaolinite	Muscovite	Chlorite	Chalcopyrite	Pyrite	Carbonates
27	46	5	11	6	1	2	2