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The different effects of bentonite and kaolin on copper flotation

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ABSTRACT

Clay minerals impose deleterious impacts on mineral processing. In this study, bentonite consisting primarily of montmorillonite and kaolin consisting primarily of kaolinite, were used to characterise the effect of clay minerals on copper flotation. It was found that bentonite and kaolin caused different issues in the process of flotation. Increasing the proportion of bentonite reduced the amount of froth on the top of slurry and decreased the copper recovery. On the other hand, increasing the kaolin content mainly decreased the copper grade with little effect on copper recovery and the bubbles on the top of froth became smaller with higher froth stability. The different roles of bentonite and kaolin in the flotation were associated with their unique properties. The findings in this study suggest that to mitigate the negative effect of clay minerals, different approaches might be applied according to specific problems caused by different clay minerals.

1. Introduction

In the mineral processing industry, an increasing volume of low grade ores containing different types and amounts of clay and other gangue minerals are currently being processed with the depletion of high quality ores. Different operations are characterised by the presence of different clay minerals. The Chilean porphyry copper ores operated at Disputada plants contain mainly illite and chlinochlore as clay minerals (Bulatovic et al., 1998); Kimberlite ores located in the vicinity of the South Africa–Zimbabwe border chiefly contain smectite and mica; and Norseman–Wiluna gold ores in Western Australia are composed of serpentine minerals (Burdukova et al., 2008). In coal mine, kaolinite and illite are the major clay minerals in high-clay-content coal mines at Central Queensland in Australia (Wang and Peng, 2014), while bentonite is the predominant clay in Xstrata Coal Mines at Central Queensland (Wang and Peng, 2013). However, processing the high clayey ores has raised new challenges as the clay minerals have deleterious effects on the flotation of valuable minerals, such as high slurry viscosity, no froth generated, and few valuable minerals loaded on the top of froth (Burdukova et al., 2008; Ndlovu et al., 2011). Currently, no reliable and effective ways are available to reduce these deleterious effects of clay minerals, especially in copper and gold flotation.

Most investigators attribute the negative effect of clay minerals in flotation to slime coating (Edwards et al., 1980; Arnold and Aplan, 1986; Peng and Zhao, 2011), slurry viscosity (Merve Genc et al., 2012; Patra et al., 2012; Zhang and Peng, 2015), or entrainment (Wang and Peng, 2013; Liu and Peng, 2014). However, in a single study, they usually compared the negative effects of different clay minerals from one aspect. The problem underlying these studies is that some clay minerals may not cause that specific problem at all. During the flotation process different clay minerals might mainly cause different corresponding problems, due to their unique properties. Mineral flotation is a complex process that takes place in both the slurry and froth, and the changes in slurry rheology may influence the subsequent bubble–particle collision and mobility of bubble–particle aggregates, which is further associated with the froth generated. Even if little variation occurs in slurry, it is entirely possible that the froth performance turns out to be completely different, because of the presence of different clay minerals.

Clay minerals are phyllosilicate and non-phyllosilicate minerals comprising silica tetrahedral (T) sheets and octahedral (O) sheets joining together in certain proportions, based on which two structural units are classified for most clay minerals: 1:1 (T–O) and 2:1 (T–O–T) layer structures (Theng, 2012). The objective of this study is to evaluate the deleterious effects of different clay minerals on copper flotation and specify the underpinning mechanism. Swelling bentonite with a 2:1 structure and non-swelling kaolin Q38 with a 1:1 structure, were chosen in this study to represent two typical kinds of clays occurring in industry ore deposits. The influence of bentonite and kaolin on copper flotation was investigated by studying how they modified properties of both slurry and froth and caused different flotation behaviour.

2. Experimental

2.1. Material and reagents

The copper–gold ore from Newcrest Telfer mine with 0.43 wt.% Cu, Telfer clean ore, was used as a reference system. The mineral composition

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of this ore was analysed by quantitative X-ray Diffraction (XRD) using Bruker D4 Endeavor diffractometer with Co Kα radiation (1.7903 Å) generated using 35 kV and 40 mA. The scan rate and step size were 1 s/step and 0.02° 2θ, respectively. The diffraction patterns were acquired from 5 to 85° 2θ. Phase quantification was carried out using the DiffracPlus EVA software (Bruker) with the ICDD-PDF2 database (International Center for Diffraction Data, 2000). Bruker-AXS's TOPAS V4.2 software was then used to quantify each phase. Crystal structure information for all the minerals was obtained from the Bruker Structure Database. The analysis results in Fig. 1 indicated that the major valuable mineral is chalcopyrite, with pyrite, quartz, albite, muscovite, dolomite and amorphous as gangue minerals. Clay minerals may not coat chalcopyrite surface in flotation due to electrostatic repulsion between them (Peng and Zhao, 2011).

A bentonite sample and a kaolin sample were purchased from Sibelco Group, Australia. The bentonite sample contains 63% montmorillonite, 25% albite and 12% quartz, while the kaolin sample contains 85% kaolinite Q38 with 4% quartz and 11% muscovite. The previous study has shown that the variation in the purities of bentonite and kaolin samples does not affect the experimental interpretations (Zhang and Peng, 2015). The presence of muscovite in the kaolin sample will not affect the flotation of Telfer clean ore when they are mixed since Telfer clean ore itself consists of 6.8 wt.% muscovite as shown in Fig. 1. Particle size distributions of these clay samples are similar with 70% of particles smaller than 10 μm.

Industrial grade potassium isoamyl xanthate (PAX) obtained from Orica, Australia Pty Ltd, was used as the collector. Plant frother DSF004, an aliphatic alcohol based mixture from Newcrest Operation, was used in laboratory tests. The pH value of slurry in flotation was controlled by analytical grade hydrated lime (Chem-Supply, Australia). Brisbane tap water was used throughout the flotation process.

2.2. Mineral grinding and flotation

Telfer clean ore was crushed to a size of −2.36 mm using jaw and roll crushers. Then 1 kg −2.36 mm ore sample was ground in a laboratory rod mill with stainless steel rods at 66% solids to obtain an 80% passing of 106 μm (P80 = 106 μm). The ground slurry was then transferred to a 2.5 L J·K. flotation cell. The artificial clayey ore was prepared as described in Zhang and Peng's (2015) study. Briefly, for each test a calculated amount of clean ore slurry was replaced by the same amount of a well-mixed bentonite or kaolin sample to keep the slurry density constant in the same mass fraction. The different particle sizes were found to not contribute to viscosity results.

The slurry was firstly conditioned for 3 min with 30 g/t collector, and 15 g/t frother. The agitation speed during flotation was kept at 1000 rpm. The flotation froth was scraped every 10 s. Four flotation concentrates were collected after cumulative times of 1, 3, 6 and 10 min with an air flow rate of 3.0 L/min. After the first 3 min flotation, the second conditioning was followed with 15 g/t collector, and 8 g/t frother for another 2 min. During the flotation process, the pH was maintained constant at about 9.0.

2.3. Rheology measurements

Rheology measurements were conducted by an Ares rheometer (TA Instruments Ltd., U.S.). All tests were conducted with a 42 mm diameter cup and 28 mm diameter vaned rotor geometry. Each time 40 mL of slurry sample was poured into the cup and the rotor lowered until the gap between the rotor and the bottom of cup was 4 mm. Rheograms were generated in the shearing rate ranging between 1 and 300 s^{-1} for 120 s. At least three duplications were performed for each sample. During measurements, the temperature was maintained at 25 °C with an accuracy of ± 1 °C.

2.4. Froth image and stability measurement

When flotation commenced, the froth was measured in-situ by using VisioFroth software. The camera was set up directly above the flotation cell and connected to a laptop device. The camera recorded the froth stability every 5 s automatically (Liu and Peng, 2014). The average froth stability values were calculated after each set of tests. At the same time, the froth image was recorded manually to observe the change of the amount of froth for each flotation test. The image capture area was 15.9 cm × 15.9 cm.

3. Results and discussion

3.1. Effect of clay minerals on copper flotation

The effects of various amounts of bentonite and kaolin on copper flotation are shown in Fig. 2(a) and (b), respectively. Flotation tests were performed with Telfer clean ore as a laboratory baseline in the absence of clay samples. The presence of either bentonite or kaolin affected copper flotation. In Fig. 2(a) an increase in the amount of bentonite does not affect the copper grade but it reduces the copper recovery, in particular from the first concentrate. As the proportion of bentonite increased from 0 to 20 wt.%, the copper recovery in the first concentrate decreased from 76% to 25%. When the bentonite content increased to 25 wt.%, the flotation dynamic was completely hindered, with no froth generated on the top of pulp, which normally happens in industrial operations.

In contrast to bentonite, increasing kaolin content in Telfer clean ore slightly lowered the flotation recovery, but reduced the copper grade substantially. In Fig. 2(b) with an increase in kaolin content in the ore from 0 to 25 wt.%, the copper grade decreased from 5% to 2.4% in the first concentrate. At the same time, the increase in kaolin content from 0 to 25 wt.% in the ore just slightly depressed the copper recovery of the first concentrate, from 80% to 70%.

3.2. Effect of clay minerals on slurry rheology

The increase in clay content was also associated with the increase in the slurry viscosity, in particular for bentonite. The apparent viscosity of Telfer clean ore slurry as a function of the clay concentration is shown in

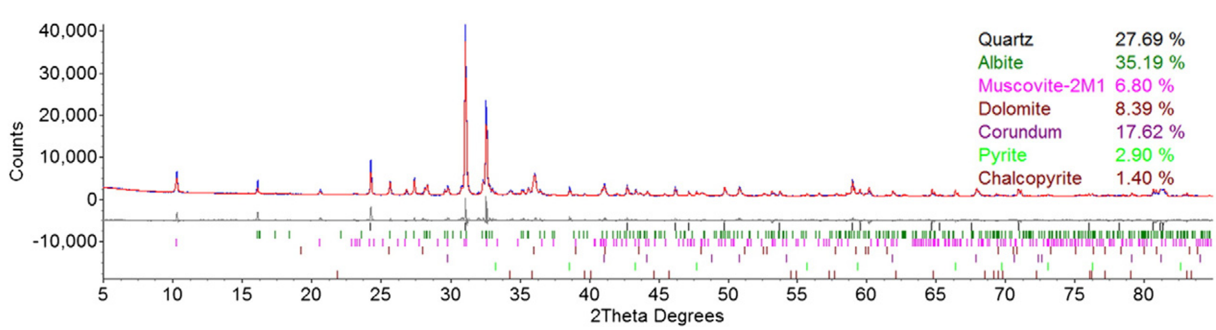

Fig. 1. X-ray diffraction of Telfer clean ore.