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Behaviour of swelling clays versus non-swelling clays in flotation

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ABSTRACT

The deleterious effects of clays on flotation performance are widely acknowledged but the mechanisms involved are not clearly established. Moreover, the concentrations beyond which clay minerals become problematic are not clearly defined. One major parameter is the difference between swelling and non-swelling clays which is evaluated in this study. The ore slurry pulp rheology and froth stability were monitored in the absence and presence of different clay minerals. It was found that swelling clays can adversely affect the flotation performance mainly via adsorbing water which changes the rheology and froth stability, reducing both flotation grade and recovery. Non-swelling clays had a lower effect on the rheology. Kaolinite increases the froth stability and reduces the flotation grade but illite showed the least effect on the flotation performance in this study. The potential mechanisms and critical concentrations are discussed.

1. Introduction

The mineral processing industries are facing finely disseminated and low grade ores. The processing of these ores is hindered by the presence of clay minerals. A comprehensive review on the effect of clays on mineral processing has been published recently (Ndlovu et al., 2013). It revealed that clays have the potential to significantly affect the planning, operation and economics of mineral processing projects. The various deleterious roles of clays in froth flotation have been investigated by a number of authors (Bulatovic et al., 1999; Farrokhpay et al., 2013; Forbes et al., 2014; Zhang and Peng, 2015). These effects include coating of the mineral surfaces, increasing reagent consumption due to the high surface area, transferring large quantities of clay minerals into the concentrate during the flotation process by entrainment, increasing pulp viscosity, and changing froth stability (Arnold and Aplan, 1986; Bulatovic, 2007; Tao et al., 2010; Cruz et al., 2013; Farrokhpay and Ndlovu, 2013). It has been reported that bentonite and kaolin cause different issues in flotation (Wang et al., 2015).

Clay minerals are phyllosilicates which are made up of various combinations of sheets stacked on each other and bonded together. A tetrahedral sheet is made up of silicon-oxygen tetrahedrons with shared basal oxygen molecules (T layer). An octahedral sheet is made up of aluminium-oxygen octahedrons with shared apical and basal oxygen (O layer). These tetrahedral or octahedral sheets bond together through hydrogen bonding. The 1:1 clay minerals are formed by bonding of one tetrahedral and one octahedral sheet. They are electrically neutral therefore they will not attract positively or negatively charged species, and they do not swell in water. On the other hand, 2:1 clay minerals are formed by bonding of two tetrahedral and one octahedral sheet. Due to ion substitution in the layers, some of these clay minerals have a negative charge on the surface and will attract water or hydrated cations. The negatively charged surfaces of 2:1 clays attract positively charged water molecules, allowing the water molecules to enter between the layers.

It should be noted that swelling is related to the hydration of clays but not all clays swell when hydrated. For example, while kaolinite shows little or no swelling on hydration, montmorillonite considerably swells when presents in water (up to 1500%, Taylor and Smith, 1986). Kaolinite and illite are both non-swelling, albeit with different structures. Kaolinite has 1:1 structure but illite has 2:1 structure (Fig. 1), but they can be easily dispersed and transported to the concentrates (i.e. entrainment). These differences in the swelling characteristics of different clays are related to their chemical composition and structure. There can also be changes in the degree of isomorphous replacements in their structures as well as in the amount and nature of their associated exchangeable cations. It has been shown that different crystalline forms of kaolinite exist and can affect flotation differently (Ndlovu et al., 2015).

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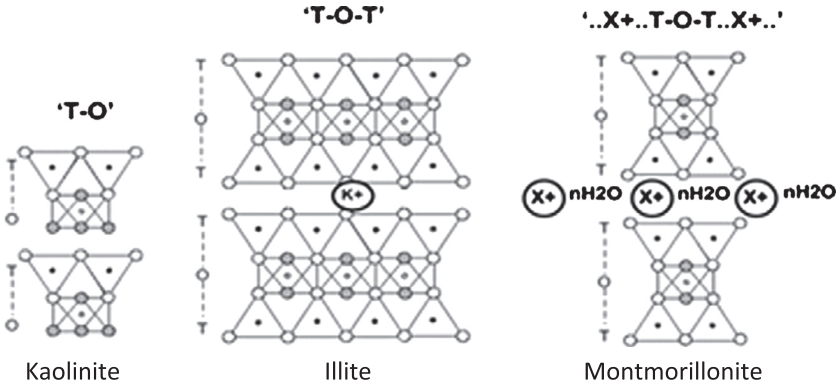

Fig. 1. Schematic of clay structures showing the T and O layers and potential adsorption of water (adapted from Ndlovu et al., 2014).

Froth stability is known to play an important role in determining mineral flotation recovery and selectivity (Tang et al., 1989; Barbian et al., 2005). Over-stable froth is often difficult to handle (Farrokhpay, 2011). Therefore, optimum froth stability is of utmost importance in flotation. The presence of clay minerals in ores can dramatically affect the froth stability. When clay minerals are present as individual particles, they may adsorb a large amount of frother due to their large surface area (for example, adsorption of MIBC by coal particles as reported by Miller et al., 1983). Therefore, they may decrease the froth stability. Clay aggregates can also interact with the hydrophobic valuable minerals resulting in high froth stability.

Rheology has been recognized as an important factor in different aspects of mineral processing, including flotation (e.g. (Boger, 2009; Farrokhpay, 2012a). Rheology data can be used to understand the interactions occurring in a flotation process. For example, a higher recovery of coarse composite copper bearing particles has been reported by increasing the viscosity of the flotation medium (Farrokhpay et al., 2011). Sweet et al. (2012) have also reported that by diluting the feed slurry with water and adjusting viscosity in a Pt plant in South Africa, the flotation recovery has increased more than 10%.

The aim of this study is to understand the differing effects of swelling and non-swelling clays on the flotation of a copper ore through examining the grade and recovery, pulp rheology, and froth characteristics. The findings could be beneficial towards ongoing studies to manage high clay containing ores in flotation which has been referred as "a mineral processing nightmare" (Connelly, 2011).

2. Materials and experimental methods

2.1. Materials

A copper ore from Australia was used as the baseline in this investigation. The chemical assays of the ore sample contains 0.5% Cu, 3.8% Fe and 0.3% S. The mineralogy of the ore using XRD analysis has showed that it has 2.3% sulfides (chalcopyrite 0.7%, bornite 1.3%, and pyrite 0.3%), 39.4% quartz, 44.4% feldspar, 4.2% amphibole, 3.2% oxides, and 7.7% carbonates.

The clay minerals used in this study were illite, kaolinite and montmorillonite. Kaolinite Q38 was provided by Unimin Australia Limited. All other clay samples were obtained in a pre-ground form from Ward's Minerals.

The particle size distribution of clay samples were measured by wet size light scattering technology using a Malvern Mastersizer (Malvern, UK). In each case, 0.5 g sample was dispersed in water. Sodium hexametaphosphate (Calgon) was also used as a dispersant at a concentration of 1 wt%. The sample was sonicated for 60 s at 50% ultrasonic power for 60 s before the measurement. Pump and stirring speeds were 330 and 350 rpm, respectively. For each sample, tests were carried out in triplicate for reproducibility. The size distribution shown for each mineral is representative of the average size distribution of three individual measurements. Fig. 2 shows that the clays samples had more or less same particle size distribution. This range is the typical size of clay minerals in real ore systems.

2.2. Flotation tests

The ore was ground by wet milling at 60% solid in a laboratory rod mill to achieve the P_{80} of 90 μm. The ground sample was transferred to a 5 L bottom driven batch flotation cell (JKTech, Brisbane), and the required amount of water was added to obtain about 25% solid ratio. Brisbane tap water was used in the flotation experiments. The air flowrate and impeller speed were 15 L/min and 800 rpm, respectively. Tests were conducted on slurries comprising the copper ore and varying concentrations of each clay mineral (0–30 wt%). In each case, the pH was maintained at pH 8 using KOH and/or HCl (This is the pH condition at which most industrial flotation runs are conducted). Potassium amyl xanthate (PAX) and methyl isobutyl carbinol (MIBC) were used as collector and frother, at the dosages of 100 g/t and 40 ppm, respectively. The P_{80} and the type and amount of flotation reagents were chosen based on the

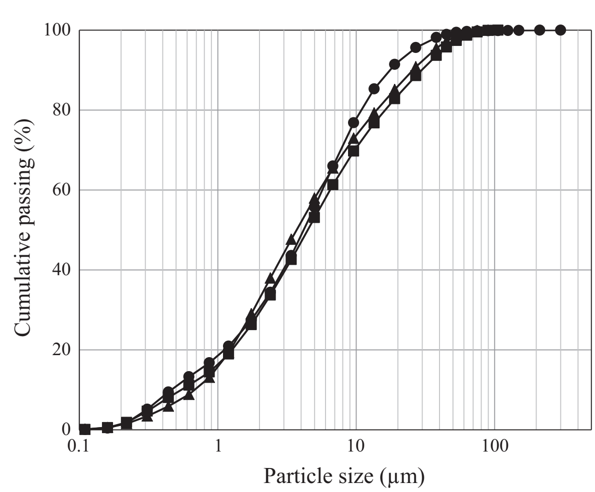

Fig. 2. Particle size distribution of the clay samples (illite ■, kaolinite ● and montmorillonite ▲) by wet size light scattering using a Malvern Mastersizer (Malvern, UK) (data are the average of 3 tests).