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Research paper

Influence of clays on fine particle filtration

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A R T I C L E I N F O

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A B S T R A C T

Filtration of fine particle slurries is known to be inefficient in most plant operations and the problem is exacerbated by the presence of even small quantities of clay minerals. This paper discusses the influence of the commonly encountered clay types, bentonite and kaolin, in the filtration of a pyritic gold ore and how the adverse effects can be mitigated by the addition of Ca^{2+} ions and a hydrophobic reagent respectively, depending on the clay type. The presence of both kaolin and bentonite clays resulted in increasing specific cake resistance, filter medium resistance and final cake moisture content while effects of bentonite clay being more detrimental. The addition of hydrophobic reagent DAH (dodecylamine hydrochloride) improved the filtration rate of kaolin-containing ore. The moisture content of the filter cake was also reduced. By contrast, in the case of the bentonite-containing ore, the presence of DAH did not affect the filtration rate and the moisture content. Filtration of the bentonite-containing ore was significantly improved with the addition of Ca^{2+} ions.

1. Introduction

The presence of fine particles significantly reduces the filtration efficiency of slurries. Fine particles reduce the capillary diameter of flow channels in filter cakes built up during the filtration process (Besra et al., 1999). In large scale operations such as in the iron ore industry, filtration of fines is an inhibiting factor to increasing throughput. Also, the amount of moisture retained in the final filtered concentrates tend to be higher which reduces capacity, particularly when shipping them over long distances. The filtration performance can potentially be improved by the addition of filter-aids in the form of surfactants or flocculants. The addition of anionic polyacrylamide flocculant reduced the moisture content of the filter cake containing iron ore, resulting in the increase in porosity of the filter cake (Amarante et al., 2002). The rate of filtration can also be enhanced by the addition of the hydrophobic reagents which increase the hydrophobicity of the walls of flow channels in a filter cake (Huang et al., 2017).

The reduction in filtration rates is particularly exacerbated by the presence of even small quantities of various clays in the slurries. It is well known that the presence of clays increases viscosity of slurries which in turn affect the rheological characteristics and adversely affect various ore preparation and downstream separation processes such as flotation, crushing (Connelly, 2011), dewatering (Kozicki et al., 1968; Mpofu et al., 2005) and etc. For example, in the case of the pyritic gold ores, the presence of 5% of bentonite-containing clay reduced the flotation recovery of pyrite by 18% (Basnayaka et al., 2017). However, in the case of kaolin-containing ores, the presence of 10% of kaolin did not reduce the flotation recovery of pyrite.

Although the influence of clays on flotation of some minerals have been investigated (Zhang and Peng, 2015), the literature provides only limited information on filtration of clay-containing ores. Previous studies have shown that the presence of Ca^{2+} ions reduces the negative effect of bentonite on flotation recovery of pyrite from its gold ore (Basnayaka et al., 2017). Furthermore, the addition of the polyacrylamide polymer reduced the adverse effect of bentonite clay due to the aggregation of bentonite particles (Hocini et al., 2017). However, the mechanisms by which the clay-containing ores are adversely affected during filtration and the mitigating effects in the presence of hydrophobic reagents have not yet been studied.

The focus of this paper is to investigate the influence of commonly encountered clays on the filtration performance. In this study, the most commonly found clays in the gold ores (i.e. kaolin and bentonite) are selected. The influence of adding hydrophobic reagent, DAH (i.e. dodecylamin hydrochloride) and Ca^{2+} ions have also been studied.

1.1. Clay mineralogy

Clay minerals have particle sizes generally less than 2 μm. These minerals are commonly identified as fine-grained phyllosilicates which comprise silicate tetrahedral “T” layers and alumina octahedral “O” layers as basic building blocks (Ndlovu et al., 2014). Various combinations of “T” and “O” layers result in the formation of different types of clay minerals with similar structure, and different physical and chemical properties. However, most of the clay minerals have either 1:1

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"T" to "O" i.e. kaolinite or 2:1 "T" to "O" layer arrangement i.e. montmorillonite. Kaolinite is the most dominant mineral in kaolin clay while montmorillonite is the main mineral in bentonite clay. Kaolin and bentonite have different swelling characteristics when suspended in water. Bentonite has significantly higher swelling capacity in water solutions than kaolin.

1.2. Filtration modelling

Filtration has been modelled assuming the flow of filtrate takes place through the void spaces between the solid particles in contact with each other under laminar flow conditions with a parabolic velocity profile (Pan et al., 2016). The filtration rate can be expressed in terms of two resistances which are specific cake resistance and filter medium resistance. The resulting filtration equation derived using Poisseuille's equation is given in Eq. (1).

$$\frac{dV}{dt} = \frac{\Delta PA^2}{\mu(r_c wV + Ar_m)} \tag{1}$$

where ΔP is the pressure drop, V is the filtrate volume, A is the cross-sectional area of the filter cake, w is the volume of filter cake deposited by the passage of a unit volume of filtrate, μ is the dynamic viscosity of liquid, r_c is the specific cake resistance and r_m is the filter medium resistance.

Eq. (1) may be rearranged to yield a linear relationship:

$$\frac{t}{V/A} = \frac{\mu r_c wV}{2\Delta PA} + \frac{\mu r_m}{\Delta P} \tag{2}$$

Specific cake resistance and the filter medium resistance can be calculated from the slope and intercept of the plots of $t/(V/A)$ vs (V/A). The effects due to the presence of clays and other variables that affect the filtration process may be studied using the changes reflected in the above resistances.

2. Experimentation

2.1. Materials

All experiments were conducted on the gold pyritic ore from Western Australia. The ore was first crushed to − 2.36 mm prior to dry grinding. Crushed ore was dry ground using lab scale rod mill and a pulveriser followed by dry sieving to obtain required particle size samples for experiments. Kaolin and sodium bentonite clays were purchased from Sibelco Group, Australia. Malvern Mastersizer was used for the measuring of particle size distribution of clay samples. It was found that P_{80} of kaolin and bentonite was around 10 μm. Figs. 1 and 2 shows the particle size distribution and the XRD diffractograms of the kaolin and bentonite clays, respectively. The diffractograms were obtained using Co-Kα radiation and thus the reflections for all minerals have slightly different positions than the reflections for the same minerals obtained using Cu-Kα radiation.

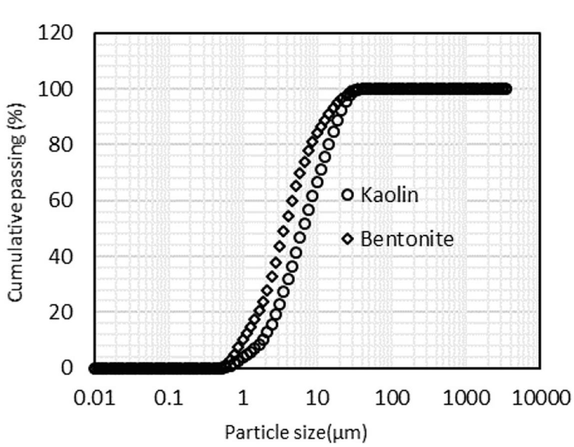

Fig. 1. Particle size distribution of kaolin and bentonite clays.

2.2. Filtration experiments

Initial filtration experiments were conducted using the gold ore containing artificially mixed bentonite and kaolin at certain solid ratios. These experiments were performed using a 20 cm diameter cylindrical pressure filter. Thoroughly mixed slurries were introduced to the filter and tests were conducted at constant pressure of 500 kPa and time was measured for collection of cumulative filtrate. Moreover, vacuum filtration experiments were conducted to identify the effect of hydrophobic reagents (DAH) on the filtration of clay containing ore. These experiments were performed using a constant vacuum pressure of 71 kPa. All the filtration experiments were conducted using Whatman grade 3 qualitative filter papers with pore size of 6 μm.

2.3. Rheological measurements

The rheological measurements were performed with an LV1 viscometer (Brookfield, USA) using a small sample of 10% kaolin or 10% bentonite pure slurries (16 mL). The slurry was introduced into the viscometer, and rheograms were generated at the shear rates from 0 to 122 s^{-1}. All rheological measurements were conducted at 20 ± 2 °C.

2.4. Zeta potential measurements

The zeta potential measurements were carried out using a zetasizer (Malvern Nano Z, UK). 0.05 g each of pure clay samples were mixed for 5 mins with deionized water. The experiments were performed in the absence and presence of DAH or Ca^{2+}. Coarse particles were allowed to settle out, and the supernatant solution containing fine particles was used for the zeta potential measurements which were repeated 4 times, and the mean value was used for further analysis. All the zeta-potential measurements were performed at 20 ± 2 °C.

2.5. Scanning electron microscopic (SEM) analysis

The SEM instrument used in this study is a ZEISS NEON 40EsB FIBSEM. The SEM analysis was performed on filter cake surface after the filtration. More specifically, two samples of filter cake containing 5% (w/w) bentonite and 10% kaolin were analysed to identify effects of clays on the microstructure of the filter cakes.

3. Results and discussion

3.1. Effects on filtration of pyritic gold ore due to the presence of clays

Batch filtration experiments were conducted to evaluate the influence of clay on the filtration performance. The typical results of filtration experiments are shown in Fig. 3. As seen in Fig. 3, there is a good agreement between the experimental and calculated data using the model given in Eq. (2) because R^2 was around 0.98.

Clay type, clay concentration, particle size, slurry density and the calcium concentration were the variables studied and were considered in designing the experiments as seen in Table 1. Specific cake resistance, the filter medium resistance were the response variables enumerated using the filtration equation given in Eq. (2). The final moisture content of the cakes were also measured after a filtration time of five minutes. Table 1 also shows the porosity data for the filter cakes; the porosities of the filter cakes (ε) were calculated using the filtration data:

$$\varepsilon = 1 - \frac{M}{AL\rho_{solid}} \tag{3}$$