Minerals Engineering 126 (2018) 9–15

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Mitigating the negative effects of clay minerals on gold flotation by a lignosulfonate-based biopolymer

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ARTICLE INFO

Keywords:
High-clay-content ore
Gold flotation
Entrainment
Slime coating
Pulp rheology
Biopolymer

ABSTRACT

The objective of this study was to identify various mechanisms responsible for the poor flotation of a high-clay-content gold ore and then develop a remedial solution. Compared to the flotation of a clean gold ore with a low clay content, obtained from the same flotation plant, the flotation of the high-clay-content gold ore produced much lower gold grade and gold recovery. The degree of entrainment (ENT) was calculated and it was found that a high mechanical entrainment of gangue minerals occurred in the flotation of the high-clay-content gold ore, contributing to the low gold grade in flotation. Electrochemical impedance spectroscopic (EIS) measurements were conducted to detect a possible clay slime coating on gold surface during flotation. It was observed that a clay slime coating did not occur on gold surface in the flotation of the high-clay-content gold ore, and therefore slime coating was not the reason for the poor gold flotation performance. Rheological measurements show that the high-clay-content gold ore slurry exhibited a non-Newtonian behaviour with a high apparent viscosity, contributing to the low gold recovery in flotation. Based on the previous studies, a lignosulfonate-based biopolymer (DP-1777) was used to mitigate the negative effects of clay minerals in the flotation of the high-clay-content gold ore. It was found that DP-1777 improved both gold grade and gold recovery significantly through the reduction of mechanical entrainment and pulp viscosity, respectively.

1. Introduction

With the depletion of high grade gold deposits, an increasing amount of low grade gold ores with a high content of clay minerals are being processed (Seaman et al., 2012; Dunne, 2016). However, processing these high-clay-content ores poses widespread problems due to the fine grain size, layer structure and anisotropic charge of clay minerals (Cruz et al., 2013, 2015a, 2015b, 2015c; Wei et al., 2013; Zhang and Peng, 2015a; Zhang et al., 2015b; Basnayaka et al., 2017; Chen and Peng, 2018). The fine grain size and anisotropic charge of clay minerals may make them coat the surface of a range of valuable minerals through electrostatic attraction, which prevents the adsorption of collectors on these minerals resulting in a deteriorated flotation performance (Yu et al., 2017a). In a recent study by Zhao et al. (2017), the electrochemical impedance spectroscopy (EIS) was developed to detect the formation of kaolinite slime coatings on chalcocite surfaces. EIS allows an in-situ detection of the formation of surface layers on the electrode which is well correlated with the electrode capacitance. The measured impedance data can also reflect the kinetics of surface electrochemical reactions in-situ with a minimum of surface modification. This technique has a potential to be applied to measure clay coatings on gold surfaces under flotation conditions.

In addition to clay coatings, clay minerals may also affect flotation through the formation of network structures in the slurry due to their layer structures with distinctly different face and edge surfaces. Depending on the type and strength of network structures formed, clay minerals may either reduce the flotation recovery of valuable minerals or increase the mechanical entrainment of gangue minerals. A number of recent studies have reported a strong relationship between flotation recovery and pulp viscosity (Patra et al., 2012; Wang et al., 2015; Zhang and Peng, 2015a; Chen et al., 2017). The high pulp viscosity resulting from the formed network structures of clay minerals affects the hydrodynamics within flotation cells and therefore leads to the change of various flotation sub-processes including reduced gas dispersion and gas hold-up, decreased mobility of particles and bubbles, and reduced particle-bubble collision and attachment. The formation of loose network structures of clay minerals does not change pulp viscosity significantly, but promotes a high gangue entrainment accompanied by a low grade of flotation concentrates (Cruz et al., 2015b, 2015c; Zhang et al., 2015c).

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https://doi.org/10.1016/j.mineng.2018.06.021
Received 7 March 2018; Received in revised form 16 June 2018; Accepted 21 June 2018
0892-6875/

Although the mechanisms responsible for the deleterious effects of clay minerals on the flotation have been identified, the previous studies only focused on an individual mechanism in each case. Clay minerals may affect the flotation through several mechanisms simultaneously. Recently, Chen et al. (2017) investigated the flotation of copper minerals in the presence of amorphous silica which has similar properties to clay minerals. They found that the presence of amorphous silica might increase gangue entrainment while decreasing flotation recovery.

Both physical and chemical methods have been developed to mitigate the negative effects of clay minerals on flotation. The physical methods are mainly the application of strong agitation, desliming and ultrasonic treatments to remove clay coatings (Yu et al., 2017b, 2017c). Although these physical methods have been proved effective in laboratory, their application in flotation plants is still rare due to the high cost required. Chemical dispersants have also been developed to remove clay coatings or modify clay mineral network structures to reduce pulp viscosity (Seaman et al., 2012; Wei et al., 2013; Liu and Peng, 2015). Wang et al. (2016) examined the effect of three lignosulfonate-based biopolymers with different compositions in copper flotation in the presence of kaolinite. They found that these biopolymers dispersed the kaolinite aggregates with increased copper flotation recovery. Newcrest's Telfer Operation also tested a lignosulfonate-based polymer, F-100, in the flotation of a high-clay-content gold ore (Seaman et al., 2012). It was found that F-100 improved both gold recovery and gold grade significantly. In the study by Seaman et al. (2012), the mechanisms responsible for the poor flotation of the high-clay-content gold ore and how F-100 improved the gold flotation were not reported.

In this study, flotation tests were conducted on two gold ore samples, one with a low clay content and one with a high clay content. The mechanisms responsible for the effects of clay minerals on the flotation of the high-clay-content ore were identified by a range of techniques to determine the degree of gangue entrainment, clay slime coating and pulp rheology. A lignosulfonate-based polymer was examined to improve the flotation of the high-clay-content ore with the underpinning mechanisms determined.

2. Experimental details

2.1. Materials and reagents

A high-clay-content gold ore and a clean gold ore with a low clay content were supplied by a gold flotation plant. The key mineral and elemental compositions of the two ores are listed in Tables 1 and 2, respectively. The analysis by quantitative X-ray Diffraction (XRD) indicates that the major gangue minerals in the high-clay-content ore are kaolinite and quartz with minor albite and amorphous minerals, while the major gangue minerals in the clean ore are quartz and albite with a significantly lower content of kaolinite. In terms of elemental composition, the clean ore has a copper grade and a gold grade of 0.31% and 1.09 g/t, respectively, which are higher than 0.16% copper and 0.73 g/t gold in the high-clay-content ore.

Plant collector, an industrial grade IPETC (isopropyl ethyl thionocarbamate), was used in laboratory tests. Frother DSF004, an aliphatic alcohol based mixture, used in the gold flotation plant was used as received in laboratory tests without further purification. A lignosulfonate-based biopolymer, DP-1777, supplied by Pionera, Norway, was used to improve the flotation of the high-clay-content ore. DP-1777 has a structure similar to F-100 examined at Newcrest's Telfer Operation (Seaman et al., 2012), but has a more hydrophilic character. It has a molecular weight of 13,700 with 8.5 wt% sulfonic group, 9.8 wt% carboxylic group and special counter-ion Na^+. During grinding and flotation, lime was used to adjust the pH. Brisbane tap water was used in the whole process.

Table 2
Elemental compositions of the high-clay-content ore and the clean ore.

	Cu (%)	Au (ppm)	Fe (%)	S (%)
High clay ore	0.16	0.73	0.64	0.31
Clean ore	0.31	1.09	3.15	2.36

2.2. Ore grinding and flotation

The two ores were crushed to a size of −2.36 mm through a jaw crusher and a roll crusher. Then 1 kg batch of the −2.36 mm ore sample was ground in a laboratory rod mill with stainless steel rods at 66% solids to obtain an 80% passing size of 106 μm (P_{80} = 106 μm). The ground slurry was then transferred to a 3.0 dm^3 J.K. flotation cell with an Agitair impeller/stator arrangement. The agitation speed during flotation was kept at 900 rpm. The slurry pH was adjusted to 9.0 with lime at the beginning of flotation, and then conditioned with or without the addition of DP-1777 for 3 min. Collector (10 g/t) and frother (20 g/t) were added before flotation. After the addition of each reagent, the pulp was conditioned for 2 min. Another 5 g/t collector and 10 g/t frother were added after 4 min flotation and conditioned for 2 min. In total, four flotation concentrates were collected after cumulative times of 1, 3, 6 and 10 min. Flotation froth was scraped every 10 s.

2.3. Electrochemical impedance spectroscopic (EIS) measurements

A gold sheet (20 × 10 × 2 mm) with a high purity of 99.9% gold, obtained from XRF Labware, was used as a working electrode. One end of the electrode was connected with a copper wire using silver-loaded conducting epoxy, and then sealed in a glass tube using a non-conducting epoxy resin. Both sides of the gold sheet were immersed into the slurry during the measurement, so the total geometric surface of exposed gold was approximately 4.0 cm^2. Before each test, a fresh gold surface was prepared by abrading with 2000, 1200 and 800 grit silicon carbide papers and then rinsed with deionized water.

The gold electrode was immersed into 400 mL slurry sample which was taken from the flotation cell after the addition of all the reagents. The electrode was conditioned at 200 rpm stirring speed for 5 min, and then rinsed with DI water. The electrode was then immediately transferred into the electrochemical cell as a stationary working electrode.

EIS was performed in a double-wall glass reactor with an effective volume of 200 mL filled with pH 9 buffer solution as the background electrolyte (prepared by 0.025 M sodium tetraborate decahydrate and 0.1 M hydrochloric acid) at room temperature. A conventional three electrode electrochemical cell with a platinum counter electrode and an Ag/AgCl reference electrode was employed to conduct the measurement. The reference Ag/AgCl electrode, filled with 3 M KCl, had a potential of +0.220 V against a standard hydrogen electrode (SHE) (Mu et al., 2015). Open circuit potential was taken as the direct current (DC) voltage (starting potential) of EIS measurements. The alternating current (AC) voltage (amplitude) was 10 mV. Typically, the working electrode surface was allowed to react in the solution for 5 min to

Table 1
Mineral compositions of the high-clay-content ore and the clean ore analysed by quantitative XRD.

	Quartz (%)	Kaolinite (%)	Albite (%)	Ankerite (%)	Amorphous (%)
High clay ore	44.4	36.1	5.3	0	7.8
Clean ore	28.8	1.9	37.4	14.3	5.6