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Pyrite activation in amyl xanthate flotation with nitrogen

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Abstract

The low potential hydrophobic state of pyrite in amyl xanthate (PAX) flotation with nitrogen is of particular interest with regard to the N_2TEC flotation technology currently being used for the recovery of auriferous pyrite at Newmont's Lone Tree Plant in Nevada. Initially, the N_2TEC system had been found to operate satisfactorily, but cyanide in the flotation mill water appeared to be responsible for a loss in pyrite recovery. This supposition was confirmed with laboratory experiments, and a program was initiated to study flotation chemistry variables by electrochemically controlled contact angle measurements. Experimental results show that activation of pyrite in such cyanide solutions can be achieved more effectively with lead than with copper. Subsequently, based on these fundamental studies, significant improvement at the Lone Tree Plant was achieved by lead activation, in which case the recovery increased to expected levels.

The effect of activator is particularly significant not only with respect to pyrite depression by residual cyanide, but also with respect to collector (PAX) consumption and the initial state of the pyrite surface. Experimental results show the importance of the pyrite surface state and the rather interesting features of the activation process.

Keywords: Gold ores; Sulfide ores; Flotation activators; Froth flotation; Oxidation

1. Introduction

Newmont Mining Corporation has used the patented N_2TEC technology (Gathje and Simmons, 1997; Simmons and Gathje, 1998) for auriferous pyrite recovery at its Lone Tree Mine Complex, since March 1997. The Lone Tree Mine Complex, owned and operated by Newmont Mining Corporation, was originally developed as a high-grade oxide heap leach. With the addition of the whole-ore autoclave, refractory sulfide ores containing gold grades as low as 3.1 g/t could be processed economically. However, a significant portion of the sulfide resource (<3.1 g/t Au) could not be economically processed. Investigation of processing options for this low-grade sulfide resource eventually led to the development of the N_2TEC flotation process. Application of this technology led to improvements in both gold recovery and selectivity for auriferous sulfide ores (Simmons, 1997; Gathje and Simmons, 1997; Simmons and Gathje, 1998; Simmons et al., 1999).

In the N_2TEC process, processing (grinding through flotation) takes place in an inert atmosphere. The process operates in a potential range between −0.1 and −0.5 V vs. Ag/AgCl (Simmons, 1997) and uses potassium amyl xanthate (PAX) as the collector. Shortly after the plant was commissioned at Lone Tree in March 1997, the auriferous pyrite recovery decreased substantially. This decrease in pyrite recovery was thought to be the result of cyanide in the flotation mill water. To overcome the pyrite depression an investigation was initiated to evaluate different activators in order to alleviate or solve this problem. This paper reviews results from previous studies (Miller et al., 2002) regarding the low potential hydrophobic pyrite surface state and looks at the effect of activation on the pyrite surface state in the absence and presence of cyanide.

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2. Background

The conventional theory of xanthate flotation of pyrite considers xanthate adsorption an electrochemical process that involves the formation of the xanthate dimer (dixanthogen) (Fuerstenau et al., 1985; King, 1982). Dixanthogen is formed by the anodic oxidation of the xanthate ion at the pyrite surface, coupled with the cathodic reduction of adsorbed oxygen:

$$2X^- \leftrightarrow X_2 + 2e^- \tag{1}$$

$$\frac{1}{2}O_2(\text{ads}) + H_2O + 2e^- \leftrightarrow 2OH^- \tag{2}$$

Electrochemical measurements for the amyl xanthate/diamyl dixanthogen couple, has shown the standard half-cell potential to be $E^0 = -0.158$ V vs. SHE (Winter and Woods, 1973). From the Nernst equation, with dixanthogen referenced to the liquid state, $E = E^0 - 0.059 \cdot \log\lfloor X^- \rfloor$. Thus, in 1×10^{-3} M PAX solutions, a hydrophobic pyrite surface state should not be observed at potentials less than 0.019 V vs. SHE or −0.223 V vs. SCE, if dixanthogen is responsible for hydrophobicity at the pyrite surface. Earlier studies utilizing electrochemically controlled contact angle measurements, have shown that a hydrophobic pyrite surface state could be established at low potentials and low pH in a nitrogen atmosphere, as is shown in Fig. 1 (Miller et al., 2002).

These early studies suggested that the reduction of pyrite surface compounds in a nitrogen atmosphere may have created a "clean", low polarity pyrite surface, which perhaps facilitated PAX adsorption and thus account for the low potential, low pH hydrophobic pyrite surface state (Miller et al., 2002).

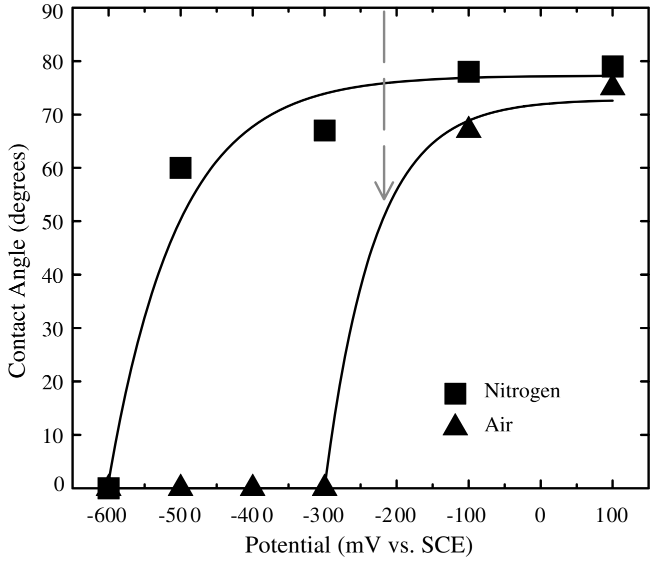

Fig. 1. Electrochemically controlled contact angle measurements for pyrite in a 1×10^{-3} M PAX solution, pH 4.68, in air and in nitrogen (Miller et al., 2002). (Dotted line indicates the standard half-cell potential for the amyl xanthate/di-amyl dixanthogen couple at an amyl xanthate concentration of 1×10^{-3} M.)

3. Experimental section

3.1. Materials

In all experimental work, Milli-Q deionized water with a resistivity of 18 MΩ cm was used. Lead nitrate and copper sulfate solutions were used for pyrite treatment. A solution of the copper cyanide complex ($K_2Cu(CN)_3$), prepared from copper sulfate and potassium cyanide, was used to study the effect of cyanide. The potassium amyl xanthate (PAX) collector used in all experiments was purified three times by dissolution in acetone and recrystallization with ethyl ether. All additional chemicals used were of analytical reagent grade quality.

The pyrite electrodes used were prepared as previously described (Miller et al., 2002), from a massive, high quality, crystalline specimen purchased from Ward's Natural Science Establishment.

For each test where a nitrogen atmosphere was required, the electrolyte was purged with nitrogen for at least 2 h prior to the experiment.

3.2. Electrochemically controlled contact angle measurements

As described in earlier work (Miller et al., 2002), electrochemically controlled contact angle measurements were made utilizing a three-compartment electrochemical cell, with a parallel plate window in the working compartment. This cell was placed on the optical bench of a Rame-Hart goniometer, which was then used to measure the contact angles (Du Plessis, 2004).

A EG&G PAR 173 Potentiostat/Galvanostat programmed with an IBM PC-XT computer, with Model 250 Electrochemical Analysis System software, was used to control the potential of the pyrite electrode at room temperature (22 °C). For a typical experiment, the voltage was set at the desired level and after 1 min at the desired potential, the activator was added. The electrode surface was then allowed to react at this potential for 10 min. Subsequently the xanthate collector was added and the electrode surface was allowed to react for a further 4 min at the desired potential. Finally, the contact angle was measured at the required potential.

3.3. Bubble attachment time measurements

A high-speed video camera was used to measure bubble attachment time. The procedure involved releasing a small bubble from the tip of a capillary glass tube next to the pyrite surface. The video camera is used to record the release of the bubble, contact against the mineral surface and bubble attachment. The bubble attachment process is then reviewed in slow motion and the bubble attachment time determined within 1–2 ms (depending on the recording speed).