



Importance of oxidation during regrinding of rougher flotation concentrates with a high content of sulfides



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ARTICLE INFO

Article history:

Received 21 December 2013

Revised 17 March 2014

Accepted 12 April 2014

Available online 3 May 2014

Keywords:

Regrinding chemistry

Pyrite concentrates

Copper–gold flotation

Oxidizing condition

ABSTRACT

The objective of this study is to understand the flotation behavior of copper and gold minerals after regrinding the rougher flotation concentrate with a high pyrite content. It was found that low Eh and dissolved oxygen (DO) were produced after regrinding due to the quick consumption of oxygen by the large amount of fresh pyrite surfaces created, resulting in poor flotation of copper and gold and their selectivity against pyrite. A number of methods were used to provide an oxidizing condition, including pre-aeration before flotation, regrinding in an oxidizing condition, and addition of different oxidizing agents during regrinding. It was found that all the oxidizing methods improved the flotation of copper and gold, however, the effectiveness of these methods varied from case to case. This study demonstrates the importance of oxidation during or after regrinding for the flotation of rougher flotation concentrates with high sulfide contents.

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1. Introduction

As more and more low grade and complex ores are processed, regrinding rougher flotation concentrate to improve the liberation of valuable minerals from gangue minerals followed by a cleaner flotation stage to reject gangue minerals has become a common practice. For example, in Newcrest's Telfer gold mine, in order to increase copper and gold recovery, regrinding of pyrite rougher flotation concentrates followed by cleaner flotation of copper and gold minerals was commissioned in 2012 (Burns et al., 2012; Seaman et al., 2012). The regrinding process liberates the locked copper and gold minerals from pyrite which are then recovered in the cleaner flotation. However, even though the valuable minerals are well liberated after regrinding, the subsequent flotation of these fine particles is not always straightforward due to a high sulfide content which changes the pulp chemistry of the regrind product dramatically.

It has been reported that the pyrite content and reactivity in copper flotation significantly influence the flotation behavior of both pyrite and copper minerals (Owusu et al., 2013,2014).

Moreover, when regrinding rougher flotation concentrates with a high sulfide content to fine particles, much stronger electrochemical reactions occur compared to primary grinding that produces coarser particles (Chen et al., 2012; 2014). These reactions have a critical effect on subsequent flotation. Firstly, sulfide minerals can be easily oxidized, and the oxidation affects their surface hydrophobicity. Mild oxidation may increase the flotation by forming hydrophobic metal-deficient sulfide, polysulfide, or elemental sulfur on the surface (Gardner and Woods, 1979; Buckley and Woods, 1984; Zachwieja et al., 1989). For example, chalcopyrite can be recovered by flotation in the absence of collectors under mild oxidizing conditions due to the sulfur-rich surfaces produced (Heyes and Trahar, 1977). However, extensive oxidation produces hydrophilic iron oxide/hydroxide or sulfate species on minerals, and reduces their floatability (Senior and Trahar, 1991; Smart, 1991). It has been found that the oxidation of pyrite can strongly depress its flotation due to the formation of hydrophilic species prohibiting the collector adsorption on mineral surfaces (Houot and Duhamet, 1990; Kuopanportti et al., 2000). These hydrophilic species may also form on copper mineral surfaces upon contact with pyrite due to the galvanic interaction (Owusu et al., 2014). The addition of more collectors may partially recover its floatability by removing the hydrophilic species (Smart, 1991). However, it has been reported that some collectors, such as thionocarbamate types, are not capable of removing the oxidation species from pyrite surfaces or preventing their formation (Leppinen et al., 1988).

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Furthermore, hydrogen peroxide may form on fresh pyrite surfaces in contacting with water, which is an oxidizing agent stronger than oxygen (Borda et al., 2003). It has been proposed that hydrogen peroxide forms on fresh pyrite surfaces during fine grinding and plays a role in pyrite surface oxidation and collector adsorption (Javadi Nooshabadi et al., 2013; Javadi Nooshabadi and Hanumantha Rao, 2014).

In addition to the formation of oxidation species, the pulp potential and dissolved oxygen have a significant influence on sulfide flotation, because the adsorption of thiol collectors, such as xanthate, thionocarbamate, on sulfide minerals is dependent on pulp potential and dissolved oxygen (Leppinen et al., 1988; Leppinen, 1990). It was found by Mielczarski et al. (1998) that only under oxidizing conditions, was the uptake of xanthate collector by chalcopyrite possible, by forming dixanthogen or copper(I)-xanthate on chalcopyrite surfaces. Under reducing conditions, the uptake of xanthate on chalcopyrite was minimal. The oxygen, as the main oxidant of this electrochemical reaction, is essential in collector adsorption. As studied by Kuopanportti et al. (2000), the number of collector adsorption layers on pyrite and chalcopyrite is reduced as the oxygen concentration decreases, and no collector adsorption occurs without oxygen. It has also been reported that the adsorption of collector on gold and its floatability can be considerably improved by the presence of oxygen (Srdjan, 2010).

Pyrite is normally depressed in differential flotation by adding lime because of its low floatability at alkaline conditions. However, even at high pH, the depression of pyrite can be difficult if it is activated by copper ions dissolved from copper minerals. The copper-activated pyrite can compete with copper and gold minerals for collector adsorption, resulting in decreased copper and gold flotation (Owusu et al., 2014). This activation is highly dependent on electrochemical potential. As noted by Peng et al. (2012), the reducing environment during grinding promotes the activation, while the oxidizing environment inhibits the activation. More copper ions can be released from copper minerals during regrinding, providing more opportunities to activate the exposed fresh pyrite surfaces. Chen et al. (2013) reported that pyrite was further activated during regrinding at reducing conditions provided by mild steel media, while, the activation was inhibited during regrinding at oxidizing conditions provided by stainless steel media. Therefore, it is important to control the regrinding condition to avoid the further copper activation if pyrite needs to be depressed in cleaner flotation.

In this study, the pyrite regrinding-flotation process in Newcrest's Telfer gold mine was taken as a case study to understand the effect of regrinding of rougher flotation concentrates with high sulfide contents on pulp chemistry and subsequent mineral flotation and separation. At Telfer, pyrite flotation produces a rougher concentrate having about 85% pyrite with a grade of 4.4 g/t Au, 0.44% Cu and 44.7% S and a P_{80} of 77 μm . The rougher concentrate is reground to liberate gold and copper minerals from pyrite followed by the flotation of copper and gold and the depression of pyrite.

2. Experimental details

2.1. Samples and reagents

Pyrite concentrate sample was collected from the feed of regrinding mill at Newcrest's Telfer gold mine. The concentrate

Table 1
Chemical compositions of the pyrite concentrate supplied from Telfer.

Elements			
Cu	Fe	S	Au
0.44%	39.5%	44.7%	4.38 ppm

was filtered, and then frozen immediately at $-18\text{ }^{\circ}\text{C}$. The chemical compositions of the sample are shown in Table 1.

The reagents used in this work include thionocarbamate based RTD11A collector from Tall Bennet, and DSF004A from Orica as frother. These reagents were supplied by the plant. Lime was used to adjust pH during regrinding and flotation. Three oxidizing agents, hydrogen peroxide (H_2O_2), potassium permanganate (KMnO_4), and potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) were used to change the regrinding and flotation conditions in this study. Hydrogen peroxide was a 30% (w/w) solution in H_2O , while potassium permanganate and potassium dichromate are solids with a purity $\geq 99\%$.

2.2. Pulp chemistry measurement at Telfer

The pulp chemistry, including pH, Eh, and DO, was measured in the pyrite regrinding circuit at Telfer plant. The regrind mill is an Isamill M5000 with ceramic grinding media. The particle size of the regrinding product has a P_{80} of 25 μm . Samples were collected from the discharge of the regrinding mill, cleaner flotation feed hatch where air was purged to increase the DO, the tailing of each flotation cell in the cleaner flotation bank, and the final tailing.

2.3. Regrinding and flotation in laboratory

For each test a 1 kg sample of pyrite concentrate was combined with 500 g tap water, and ground in a stainless steel rod mill to achieve a P_{80} of 25 μm . Lime was added before grinding to adjust the slurry pH to 9.5. To simulate the plant pulp chemistry after regrinding, the slurry was purged with nitrogen during regrinding to reduce the concentration of dissolved oxygen in the slurry. To adjust the regrinding atmosphere, oxidizing agents were added in the mill.

After regrinding, the slurry was transferred to a 3L JKMRC flotation cell. Collector RTD11A (60 g/t) and frother DSF004A (45 g/t) were added. 2 min of conditioning time was allowed for the conditioning of each reagent. During flotation, the pH was fixed at 10.5 by adding lime. Flotation concentrates were scraped from the cell every 10 s, and four concentrates were collected after cumulative times of 0.5, 2.0, 4.0, and 8.0 min.

Flotation rate constant k of copper mineral, pyrite and Au was calculated from the following first-order flotation model:

$$R = R_{\max}(1 - e^{-kt}) \quad (1)$$

R is the recovery at the cumulative time t , R_{\max} is the total recovery at infinite flotation time, and k is the rate constant for the floatable component. The flotation recovery of pyrite and copper mineral is calculated from the chemical assay by assuming the chalcopyrite is the main copper mineral present (Zheng and Manton, 2010). The flotation rate of Au is used in this study to indicate the overall flotation kinetics of both free Au and Au which is associated with other mineral (e.g., pyrite and copper mineral).

2.4. XPS analysis

Samples for XPS analysis were collected from mill discharges or flotation pulp. The slurry samples were frozen in liquid nitrogen immediately after collection to minimize surface oxidation. XPS measurements were carried out with a KRATOS Axis Ultra (Kratos Analytical) with a monochromatic Al X-ray source operating at 15 kV and 10 mA (150 W). The analysis spot size is $300 \times 700\text{ }\mu\text{m}$. The frozen slurry samples were defrosted just prior to the analysis. The solids were placed on the stainless steel bar and immediately loaded into the introduction chamber of the spectrometer. The samples were analyzed at a pressure of

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