

The effect of regrind mills on the separation of chalcopyrite from pyrite in cleaner flotation



Xumeng Chen, Yongjun Peng*

School of Chemical Engineering, The University of Queensland, St. Lucia, Brisbane, QLD 4072, Australia

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ABSTRACT

Stirred mills have been widely used for regrinding and are more energy efficient than tumbling mills. These two types of mills present different particle breakage mechanisms and redox environments during grinding. In this study, the effect of regrinding with these two types of mills on the separation of chalcopyrite from pyrite in the cleaner stage was studied. A laboratory rod mill and a laboratory stirred mill were used to regrind rougher flotation concentrates. It was found that chalcopyrite and pyrite exhibited different flotation behavior after regrinding with the rod mill and the stirred mill, resulting in different separability of chalcopyrite from pyrite. The mechanism underpinning this phenomenon was investigated by a range of techniques including dissolved oxygen demand measurements, X-ray photoelectron spectroscopy (XPS) and Time of flight secondary ion mass spectrometry (ToF-SIMS). It was found that the two mills produced different surface oxidation and pyrite activation by copper ions which determined the separation of chalcopyrite from pyrite. This study demonstrates that the selection of a regrind mill should not only depend on its energy efficiency but also the property of surfaces produced for subsequent flotation.

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1. Introduction

Regrinding rougher flotation concentrates is typically used to liberate valuable minerals from gangue prior to the cleaner stage in the processing of highly disseminated ores. For example, in Newcrest's Telfer gold mine, the regrinding of copper rougher concentrates significantly improves copper and gold recoveries in the subsequent flotation (Seaman et al., 2012). The small grain size of the valuable minerals in highly disseminated ores requires fine grinding to provide sufficient mineral liberation. In some mineral processing plants, mineral liberation can only be achieved by regrinding to finer than 10 μm (80% passing size) (Johnson, 2006) while it is becoming increasingly common to regrind to 20 μm .

Grinding is the single largest energy consuming process in mineral processing plants, and the selection of energy efficient mills is critical to fine grinding. Stirred mills, recently introduced to mineral processing, have been proved to be more energy efficient than traditional tumbling mills in terms of fine grinding, and have been widely used at the regrinding stage in many mineral processing plants (Pease et al., 2006). In addition to energy efficiency, these two types of mills also provide different particle breakage mechanisms (Kelly and Spottiswood, 1982). During the grinding in a

tumbling mill, impact breakage is predominant, while during the grinding in a stirred mill, a large proportion of attrition breakage exists especially when particles become fine (Wills and Napier-Munn, 2006; Roufai and Klein, 2010). It has been reported that breakage mechanisms can influence particle size distribution (Kelly and Spottiswood, 1982; Hogg, 1999), particle shape (Vizcarra, 2010) and mineral liberation (Roufai and Klein, 2010; Vizcarra et al., 2010) which play an important role in mineral flotation. In addition, recent studies have shown that breakage mechanisms can affect the formation and distribution of mineral surface species (e.g. collector, contamination species) (Ye et al., 2010a,b; Vizcarra et al., 2011; Chen et al., 2014a). As presented in Fig. 1, if the breakage mechanism is impact, the surface species distribute on to the surface of particles of all sizes. If attrition breakage is applied, the surface species are removed from the original particle and tend to distribute on to fine and ultra-fine particles.

Another important aspect of regrinding is the strong electrochemical reactions occurring inside regrind mills. It has been reported that the interfacial chemical reactions of sulphide minerals during grinding can be affected by different grinding forces resulting in the formation of crystal lack, dislocation and the nascent surface (Hu et al., 2009). Further, breakage mechanisms not only directly change the surface chemistry on a single particle, but also change the way of fine particles generated and then indirectly change the overall chemical environment in the mill. These

* Corresponding author.

E-mail address: yongjun.peng@uq.edu.au (Y. Peng).

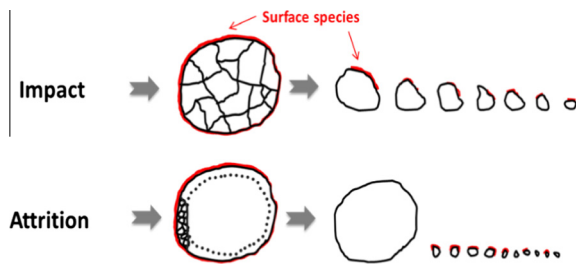


Fig. 1. Representation of the distribution of surface species during particle breaking under impact and attrition mechanisms.

reactions play an important role in the formation of surface species. As demonstrated by Chen et al. (2013), there were two types of surfaces after regrinding pyrite concentrates: 16% of the total surfaces were the existing surfaces carried from the regrinding feed, and 84% of the total surfaces were the fresh surfaces generated during regrinding. The existing surfaces carried from a regrinding feed were still covered by collector and copper activation species. Both the existing surfaces and freshly produced surfaces can be oxidized during regrinding with an oxidizing environment. Oxidation species formed on surfaces can change the mineral floatability (Smart, 1991; Gonçalves et al., 2003; Bicak and Ekmekci, 2012). It is well known that chalcopyrite can be recovered by flotation in the absence of collector under oxidizing conditions, but not under reducing conditions (Heyes and Trahar, 1977). This is because mild oxidation results in the formation of a hydrophobic sulfur-rich surface due to the dissolution of iron ions (Gardner and Woods, 1979; Buckley and Woods, 1984; Zachwieja et al., 1989). In addition, pyrite surface can be activated by copper species (mainly Cu^{2+} and $\text{Cu}(\text{OH})_2$) emanating from copper bearing minerals/ores during grinding. The interaction between Cu^{2+} and pyrite is an electrochemical process involving the reduction of Cu^{2+} to Cu^+ with the subsequent oxidation of surface sulphide (Chandra and Gerson, 2009). The produced Cu-S activation species can improve the adsorption of xanthate collector by forming $\text{Cu}^+\text{-Xanthate}$. This activation process is highly dependent on the electrochemical environment. By using voltammetric techniques, Richardson et al. (1996) found that an increase in oxidizing potential inhibited copper uptake while an increase in reduction potential promoted copper uptake. Recent studies also showed that a reducing environment during grinding promoted the activation but an oxidizing environment inhibited the activation (Peng and Grano, 2010a; Peng et al., 2012; Chen et al., 2013). This phenomenon can be explained by the activation mechanism. A reducing environment favors the reduction of Cu^{2+} to Cu^+ and hence the formation of $\text{Cu}^+\text{-sulphide}$. Overall, the regrind mill can affect mineral flotation through various electrochemical reactions beyond particle breakage mechanisms.

In this study, the effect of regrind mills on the separation of chalcopyrite from pyrite in the subsequent cleaner flotation was investigated. A laboratory rod mill and a laboratory stirred mill were used to regrind the rougher flotation concentrates. The surface species, including the oxidation species, copper activation species and collector, were analyzed by a number of techniques and correlated with the flotation behavior.

2. Experimental details

2.1. Materials and reagents

Chalcopyrite and pyrite single minerals, supplied by GEO Discoveries, were crushed through a jaw crusher and a roll crusher,

and then screened to collect +0.71–3.35 mm particle size fractions. XRD analysis indicated that the pyrite sample was very pure without detecting any impurity. The purity of the chalcopyrite sample was slightly lower with about 95% chalcopyrite and 5% pyrite. The processed samples were sealed in polyethylene bags and then stored in a freezer at a temperature of $-20\text{ }^\circ\text{C}$ to reduce surface oxidation.

Potassium amyl xanthate (PAX) and Interfroth 56 were used as the collector and frother, respectively. They were of industry grade and used as received. Other chemicals were of AR grade. De-ionized water was used in all experiments. Fresh chemical solutions were prepared daily for flotation tests.

2.2. Grinding, regrinding and flotation

The mixture of chalcopyrite (50 g) and pyrite (50 g) was combined with 150 g deionized water, and ground in a stainless steel rod mill using 4 stainless steel rods (3750 g) to achieve a $P_{80} = 75\text{ }\mu\text{m}$. A 2.5% sodium hydroxide solution was added during grinding to achieve pH 9.0 in the primary grinding discharge.

After grinding, the pulp was transferred to a flotation cell (1.5 dm^3) for rougher flotation. A JKMRCLaboratory batch flotation cell with a bottom-driven agitator was used in this study. Potassium amyl xanthate (160 g/t) and Interfroth 56 (200 g/t) were added and 2 min was allowed for the conditioning of each reagent. During flotation, the pH was maintained at 9.0 by adding a sodium hydroxide solution (2.5% w/v). The froth was scraped every 10 s, and four concentrates were collected after cumulative times of 0.5, 2.0, 4.0 and 8.0 min. The air flow rate was $1.5\text{ dm}^3/\text{min}$ during the first 0.5 min, and then increased to $3.0\text{ dm}^3/\text{min}$ from the second concentrate.

The four rougher flotation concentrates were combined and mixed with additional water to achieve a pulp density of 18%, and then reground in either a rod mill or a stirred mill. The target particle size of the regrinding product was $P_{80} = 20\text{ }\mu\text{m}$. A sodium hydroxide solution (2.5%) was added in the feed to achieve pH 9.0 in the regrinding discharge. For regrinding with the rod mill, 10.3 kg stainless steel rods were used, and the particle size $P_{80} = 20\text{ }\mu\text{m}$ was achieved after grinding for 15 min. The stirred mill used in this study was a vertical bead mill with a disc-type agitator. It was made by Netzsch (model number: M1.5), and the volume of the grinding chamber was 1.5 L. 1 L ceramic beads were used as the grinding media. The diameter of the media was 2.5 mm. The regrinding time was 3.5 min at a rotational speed of 1200 RPM to achieve the particle size $P_{80} = 20\text{ }\mu\text{m}$.

The size distribution was determined by Laser Diffraction with a Malvern MasterSizer (Malvern Instrument Ltd., U.K.). For the purpose of measuring size distributions, the regrinding products were filtered and dried at $70\text{ }^\circ\text{C}$ in an oven. The dried samples were split using a micro rotary riffler to produce 0.5 g sub-sample. The sub-sample was mixed with 10 mL water and then the slurry was placed in an ultrasonic bath for 5 min to disperse the fine particles. Then the slurry was transferred to the Laser Sizer for analysis. Fig. 2 shows the size distribution of the regrinding products. More fine particles were produced by the stirred mill than by the rod mill, which was caused by different particle breakage mechanisms in these two mills (Kelly and Spottiswood, 1982).

After regrinding, the pulp was transferred to a 1.5 dm^3 flotation cell for cleaner flotation. Frother (200 g/t) was added during the conditioning time of 2 min. For some tests, more collector was added, and the specific amount was detailed in the results. The cleaner flotation procedure was the same as used in the rougher flotation after primary grinding.

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