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A study of the effect of grinding environment on the flotation of two copper sulphide ores

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ABSTRACT

It is well known that different milling procedures may result in different flotation responses. In the present study, the effect of various grinding conditions such as wet or dry grinding and addition of lime to the mill compared to the flotation cell on the flotation of two different copper sulphide ores was investigated. The milling was carried out in a Magotteaux Mill which enables reagent addition during milling as well as the monitoring of changes in parameters such as pH, Eh and DO during milling. The paper will present grade and recovery results obtained after the different milling procedures. After wet milling, the ores yielded different concentrations of Cu and Fe in the pulp and also significantly different recoveries. Dry grinding affected the behaviour of the ores differently. Proposals are made to explain the results by reference to the mineralogical properties of the two ores.

1. Introduction

Flotation is widely applied in the mineral processing industry to recover valuable minerals from crude ores. In general, metallurgical performance of a flotation process depends mainly on the mineralogical nature of the ore being processed, the performance of the flotation cells, aeration and hydrodynamic conditions of the pulp in flotation cells, the particle size distribution and mineral liberation of the ore subsequent to the upstream grinding process, and many other factors such as pulp density, pulp chemistry and surface properties of minerals after conditioning. These factors have been well described by Klimpel (1988) and Nagaraj (2005). Fundamental studies have also shown that the electrochemical interactions occurring between thiol-collectors and sulphide-mineral surfaces play a key role in rendering surfaces of sulphide-mineral particles hydrophobic, thus promoting their floatability. Recent studies showed that the upstream grinding may also have influences on pulp chemistry, mineral surface properties and thus the flotation performance, and these influences are most likely to be ore specific (Palm et al., 2010, 2011). In particular these latter referenced studies have shown significant differences in the downstream flotation behaviour of platinum group minerals (PGMs) compared to a sphalerite ore. Dry grinding was shown to enhance the recovery of the sphalerite ore but reduced the recovery of the PGM ore compared to wet grinding. Feng and Aldrich (2000) have shown that dry ground samples had a greater relative degree of roughness compared to those obtained after wet grinding and consequently exhibited more stable, higher loaded froths and faster flotation kinetics, owing to the activated particle surfaces. Bruckard et al. (2011) have reviewed the effects of the grinding method and grinding medium upon the flotation performance of sulphide minerals. It has been shown that the pulp chemical environment, the ore composition, the properties and type of the grinding media, the size reduction method employed, pre-conditioning stages prior to flotation, and reagent interactions during grinding (and conditioning) can all influence the subsequent flotation process. Kotake et al. (2011) have shown how wet as opposed to dry grinding can affect fineness and also the shape of the particle size distribution of the ground product. Wiese et al. (2015) and Wiese and O'Connor (2016) have subsequently shown how the shape of particles can significantly affect the entrainment of gangue particles thus affecting the final grades obtained in the flotation circuit. Peng et al. (2003) have shown, using a similar grinding device as that used in the present study, that chalcopyrite separation from pyrite was affected by the activation of pyrite flotation by copper species dissolved from chalcopyrite. They proposed that grinding media had a large effect on the reduction of copper(II) to copper(I) on the pyrite surface. The reducing grinding condition generated by mild steel medium thus favoured formation of a copper(I) sulphide phase, which resulted in high pyrite activation. Thus, it was shown that chromium medium produced better chalcopyrite selectivity against pyrite than the mild steel medium.

The aim of the present study was to investigate the effect of various grinding conditions such as wet or dry grinding and addition of lime to the mill compared to the flotation cell on the flotation of two different

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Table 2-1
Mineralogical composition of the two ores.

Mineral	LJ ore, %	DX ore, %
Molybdenite	–	0.05
Chalcopyrite	1.35	1.22
Galena	–	0.04
Sphalerite	–	0.03
Chalcocite	0.37	–
Tetrahedrite		–
Covellite		0.08
Digenite		
Bornite	–	
Cuprite	0.02	–
Pyrite	4.11	5.00
Limonite	0.78	
Quartz	41.45	35.98
Mica	39.78	32.76
Feldspar	–	11.83
Chlorite	8.51	8.87
Calcite	3.03	2.53
Rutile	0.52	0.80
Apatite		0.61

copper sulphide ores. Proposals are made to explain the different behaviours observed by reference to ore mineralogy, pulp chemistry and mineral surface properties.

2. Experimental

2.1. Ore materials

The two ores used in this study were a copper ore supplied by Lujiu (LJ) Mine in north eastern China and a copper ore taken from Dexing (DX) Mine in south eastern China. Both ores contained chalcopyrite as the main copper-bearing mineral and pyrite as the most abundant other sulphide mineral. Table 2-1 shows the mineralogical composition of the two ores.

The LJ ore had a copper content of 0.62%. The main gangue minerals in the LJ ore were quartz, mica, illite, chlorite and calcite. Most of chalcopyrite in the ore was closely associated with pyrite and gangue minerals, occurring mainly in the grain size range of 0.02–0.6 mm. The mass ratio of pyrite to chalcopyrite was about 3 to 1. The DX ore had a copper content of 0.36%. The main gangue minerals in the DX ore were quartz, mica, feldspar, calcite and chlorite. As in the case of the LJ ore most of chalcopyrite in the ore was closely associated with pyrite and gangue minerals, occurring mainly in the grain size range of 0.02–0.3 mm. The mass ratio of pyrite to chalcopyrite was about 4 to 1. Both ores were prepared by crushing and screening of the samples to 100% passing a 3.35 mm (6 mesh) sieve.

2.2. Equipment

Grinding was carried out in a Magotteaux mill at the University of Cape Town. The mill design and its operation have been described elsewhere (Greet et al., 2004; Magotteaux Australia Pty Ltd, 2009). Flotation tests on the grinding product were carried out in a 4.5-litre Magotteaux flotation cell, which has a bottom-driven stainless-steel impeller enabling the entire surface of the froth to be scraped with a scrapper at a constant depth during the test.

2.3. Water and reagents

Synthetic plant water (SPW) was used in all wet grinding and batch flotation operations carried out in this study (Wiese et al., 2005; Shackleton et al., 2007). The synthetic plant water was made up by adding various chemical salts into distilled water to achieve specific ionic strength and total dissolved solids (TDS) content. The contents of ions present in the synthetic plant water used in this study are shown in Table 2-2.

Table 2-2
The concentration of ions in the synthetic plant water used.

Ion	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	NO_3^{-}	CO_3^{2-}	TDS
Concentration (ppm)	80	70	153	287	240	176	17	1023

Lime was used as pH-regulator and as a pyrite depressant. In the flotation tests the collector was sodium isobutyl xanthate (SIBX) and the frother was DOW 200. All chemicals used for making synthetic plant water were of AR (analytical reagent) grade.

2.4. Test procedure

For each milling test, 2 kg ore material was added to the Magotteaux mill, together with 20 kg grinding media made up of mild-steel balls in the size range of 30–35 mm. In the cases of wet grinding, 2 L SPW was added into the mill. During wet grinding the pH, Eh and DO of the pulp were continuously measured. During dry grinding, the circular holes of the separator plate in the mill were blocked with plastic adhesive tapes and all pulp-chemistry probes were removed from the measuring chamber. Each milling process consisted of a mixing phase at the beginning to homogenize the mill charge at a rotation speed of 10 rpm for 5 min followed by the grinding phase at the rotation speed of 60 rpm for a pre-set period.

The time for wet grinding was determined by conducting a series of milling tests with LJ ore at different grinding times (30, 15 and 7 min) in order to establish a milling curve and then interpolating to obtain the grinding time required to achieve the product fineness of 60% passing 75 μm. This was found to be 10.5 min and this time was used for wet grinding of both the LJ ore and the DX ore. The time required for dry grinding was estimated to be the wet grinding time multiplied by a factor of 1.3, which has been suggested by Bond (1961) to consider the relative inefficiency of dry grinding compared to wet grinding.

A complete test procedure consisted of grinding in the Magotteaux mill followed by conditioning and flotation of the ground product in the Magotteaux cell. The ground product (slurry from wet grinding or powder from dry grinding) was transferred to the flotation cell to make a slurry body of 4.5-litre volume by adding SPW before conditioning and flotation. The time of this transfer was kept within 30 min. For all test sets the same flotation reagent suite was used, viz. lime 1000 g/t, SIBX 40 g/t and DOW 200 frother 30 g/t. During flotation, the impeller speed was set at 1200 rpm, the air flow rate at 10 L/min, and the froth height kept constant at 2 cm. Four concentrates were collected at 2, 6, 12 and 20 min of flotation time (i.e. in the time intervals of 2, 4, 6, and 8 min respectively) by scraping the froth into the collecting pan every 15 s.

Three different procedures were studied for each ore. These were:

- Procedure 1: Wet milling followed by lime addition in the flotation cell
- Procedure 2: Wet milling with lime addition in the mill
- Procedure 3: Dry milling followed by lime addition in the flotation cell

These procedures are shown in Figs. 2-1, 2-2 and 2-3 respectively. For Procedure 1, levels of pH, Eh and DO of the pulp were measured during grinding and before as well as after lime addition. For Procedure 2, levels of pH, Eh and DO of the pulp were measured during grinding and before adding collector. For Procedure 3, levels of pH, Eh and DO of the pulp were measured before and after lime addition to the flotation cell.

During each test, slurry samples were extracted from the flotation cell to determine the amount of EDTA-extractable Fe and Cu content of