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Short communication

Effect of using different grinding media on the flotation of a base metal sulphide ore

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ABSTRACT

In the present investigation flotation was used as a diagnostic to understand the effects of changes to the media during the grinding stage. A Base Metal Sulphide (BMS) ore was ground under media of different shapes and compositions to determine the effect of different rod/ball material on the flotation performance of the ore. The observations from flotation for different media are discussed in terms of water recovery, solid recovery and valuable mineral recovery. The chemical parameters; pH, redox potential (Eh) and dissolved oxygen (DO) levels were measured. For a given grind (D_{80} = 75 µm), media shape had no effect on flotation performance of a BMS ore. Different grinding media had significant effects on slurry chemical properties and flotation performance. Mild steel rods (RMMS) produced the highest solids recovery, nickel and pyrrhotite (Po) recovery, with the highest ethylenediaminetetraacetic acid (EDTA) extractable iron and the lowest DO level. Chrome steel balls and stainless steel rods produced the lowest metal recovery, EDTA extractable iron and the highest DO level. Ferric ions were seen to depress talc.

1. Introduction

The main purpose of crushing and grinding of ores in mineral processing is to prepare the ore particles for downstream processing. One of the most important such downstream processes is flotation and hence in many respects flotation performance represents an excellent diagnostic of the efficiency of the comminution process. Among many of the different variables involved in the comminution of ores, the shape and composition of milling media can have a significant impact on the nature of the particles produced. Specifically the use of mild or stainless steel or inert/ceramic media can influence the surfaces of the particles. Wet or dry milling has also been shown to significantly affect the flotation of ores and this has also been found to be mineral specific (Chapman et al., 2011). The use of mild or forged steel media can result in the generation of oxyhydroxide species in the pulp. The gaseous atmosphere used in the grinding, such as having a relatively inert low dissolved oxygen (DO) concentration, can affect the chemical nature of the particle surfaces. Changing the chemical conditions, such as pH, or adding flotation reagents, such as collectors, into the mill may also affect the ultimate floatability of the particles. Previous studies have investigated the use of balls or rods made from mild steel, ceramic, stainless steel or chrome steel to investigate the effects of different media on flotation. Stainless steel or chrome media have been found to improve the flotation of sulphides compared to mild or forged steel media (Rey and Formanek, 1960; Peng et al., 2003a, 2003b; Huang and Grano, 2006; Bruckard, 2011). Miettunen et al. (2012), in a study of a low sulphur containing platinum group mineral (PGM) ore found that forged media grinding in a CO_2 atmosphere led to the highest Pt and Pd grades and recoveries whereas the high chrome grinding media gave lower flotation recoveries. Studies carried out using autogenous grinding have indicated that sulphide minerals produced in the non-reducing, low iron grinding environment of the autogenous mill exhibited enhanced flotation properties compared with conventional grinding (Bruckard, 2011). Khonthu (2012) found that stirred milling improved the flotation performance of the fine fraction of a PGM ore. Chapman et al. (2011) found that dry milling improved the flotation performance of a base metal sulphide but produced the opposite effect when applied to a PGM ore thus emphasizing the importance of using at least two quite different ore types when carrying out such investigations since the results obtained may be ore specific. Conventional milling methods make use of either steel rods or balls as media and the use of these media types may result in the production of particles with different characteristics due to different breakage mechanisms. While the shape of the mill product is considered a valuable characteristic, this was not within the scope of this study.

In the present investigation, the effect of using rods or balls of

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different composition during milling in a tumbling mill on the flotation behaviour of a base metal sulphide (BMS) has been investigated. In this study, apart from investigating the effect of media shape and composition on flotation behaviour, the effect on factors such as the chemical properties (pH, Eh and DO) of the mill product were also determined.

2. Experimental procedures

2.1. Milling procedures

The ore samples were received from a Cu-Ni base metal operation located in South Africa containing approximately 5% total sulphide (Cu 0.36 wt%, Ni 0.67 wt%, S 5.67 wt%) and 7% talc. 3 kg representative samples were used for each test. Grinding was performed in the absence of reagents at 67% solids. The media used were, respectively, stainless steel rods (RMSS), mild steel rods (RMMS), 21% chrome steel balls (BMCS) and forged steel balls (BMFS). The particle size distributions of the feed and product after grinding were determined using wet sieving. The grinding time was determined to obtain a product with a d_{80} of 75 µm. Vickers Hardness Test ASTM C1237 were conducted by an external laboratory. Talc samples obtained from Wards were chopped into small chunks before being pulverized to +38–75 µm.

2.2. Batch flotation tests

Batch flotation tests were performed at 30% solids, in an 8 L laboratory bottom driven batch flotation cell. The impeller speed was set at 1200 rpm and the air flow rate was maintained at 7 L/min throughout the test. 50 g/t sodium isobutyl xanthate (SIBX) was used as a collector and 20 g/t DOW 200 as a frother. Two feed samples were taken before and a tails sample after each flotation test. Four concentrates were collected by scraping the froth into a collecting pan at 15 s intervals for 2, 4, 6 and 8 min, with a total flotation time of 20 min. The batch flotation tests of talc were performed in a flotation cell with a capacity of 500 ml with the impeller speed set at 200 rpm, and air flow rate at 1 L/min, using 50 g talc. One feed, all concentrate and tailings samples were analyzed for copper and nickel using a Bruker S4 Explorer XRF Spectrophotometer. A Leco S632 sulphur analyzer was used to determine the total sulphur content of the samples. A sulphur balance calculation enabled the pyrrhotite (FeS) content to be determined (Corin et al., 2011). pH, Eh and DO values were measured inside the flotation cell using a 556 Multi-Probe System. The measurements were made after the ore had been transferred to the flotation cell, the pulp conditioned for 5 min and before any reagents were added. All tests were performed in duplicate. Assuming the stoichiometries for chalcopyrite and pentlandite to be $CuFeS_2$ and (FeNi)S respectively, the recoveries of total copper and total nickel can be used to estimate the recoveries of chalcopyrite and pentlandite respectively. The recovery of pyrrhotite can be estimated by balance from the copper, nickel and sulphur values determined.

2.3. EDTA extraction method

The second feed sample underwent EDTA extraction for iron. (Rumball and Richmond, 1996) The 25 ml aliquot was injected into a 400 ml beaker containing 250 ml of a 3% (w/v) solution of EDTA, pH modified to 7.5 with sodium hydroxide (NaOH). This EDTA / slurry solution was stirred for 5 min before being filtered; the filtrate was submitted for analysis by Atomic Absorption Spectroscopy (AAS).

3. Results and discussion

3.1. Effect of different milling conditions on the chemical condition of the flotation pulp

Table 1 presents data describing the chemical condition of the mill product prior to flotation. The pH is the natural pH of the ore and hardly changed during the grinding stage. As expected, in general, as the DO concentrations increased the Eh of the pulp also increased. A number of oxidation-reduction reactions would be occurring in the mill. The mild steel media would undergo oxidation (Eq. (1)

$$Fe_x(s) \rightarrow Fe_{(1-x)}\ (s) + Fe^{2+}\ (aq) + 2e \quad (1)$$

The corresponding reaction is the reduction of oxygen in the pulp according to Eqn. (2) which results in a decrease in the DO concentration.

$$1/2\ O_2 + H_2O + 2e \rightarrow 2OH^- \quad (2)$$

Moreover chalcopyrite is anodic relative to pyrite and pyrrhotite and hence will undergo oxidation thus also providing electrons for the reduction of the oxygen. The very low DO levels and Eh values observed in the case of using mild steel for the BMS is expected as this reactive media may have enhanced the inter-mineral galvanic interactions and promoted the reduction of the pulp oxygen. Table 1 also illustrates well that DO concentrations are useful indicators of the chemical condition in the mill since, irrespective of the pH levels, the Eh is relatively strongly related to the DO concentrations.

3.2. Flotation results for the BMS ore

Chalcopyrite is seldom a strong indicator of a change in conditions since it is so readily floatable and as can be seen there is little difference between chalcopyrite recoveries for the different milling conditions, Table 1. On the other hand there is a very significant increase in the recovery of pentlandite when mild or forged steel media are used. Interestingly this is also accompanied by a significant increase in grade indicating that this effect is not merely a result of an increase in mass pull. There is also an increase in recovery and grade in the case of pyrrhotite when mild or forged steel media are used.

Table 1 also shows the amounts of EDTA extractable Fe, Cu and Ni. Of special interest is the amount of Fe. As can be seen the mild and, to a lesser extent, forged steel media resulted not surprisingly in the highest concentrations of Fe ions. As shown in Table 1 these conditions also resulted in significant increases in the recoveries and grades of pentlandite and to a lesser extent of pyrrhotite. The concentrations of EDTA extractable Cu and Ni were very low.

These results indicated a strong correlation between the amount of EDTA extractable Fe ions present in the pulp and the recoveries of pentlandite and pyrrhotite. In order to investigate this further, tests were carried out to investigate whether the addition of ferrous or ferric ions could result in a similar outcome. In the first instance the presence of these ions on the solids and water recoveries was investigated. It was decided to use chloride salts of iron since this would ensure that the effect of just the Fe ions would be investigated. For both divalent and trivalent Fe under the pH conditions found in this study, the dominant species would be iron hydroxides (Rao and Leja, 2004). The base case used was the result obtained when the ore was milled with chrome steel balls (BMCS) since this had resulted in the lowest Fe concentration viz. 0.57 mg/g and the effect of Fe ions would be minimal. The DO concentrations in the case of the rod mill mild steel (RMMS) was the lowest and for BMCS was the highest (cf. Table 1).

As can be seen in Fig. 1(a) the addition of Fe ions (using $FeCl_2$ or $FeCl_3$) significantly increased the solids and water recovery. However, the flotation results had indicated an increase in grades and hence this increase in mass pull was selective towards the recovery of pentlandite and particularly pyrrhotite, thus diluting the grade of chalcopyrite. Fig. 1(b), (c) and (d) show the grade-recovery results obtained using the same conditions as those used in Fig. 1(a). As can be seen there was a significant increase in both grades and recoveries of pentlandite and pyrrhotite after the addition of Fe ions relative to the results obtained in the case of BMCS.