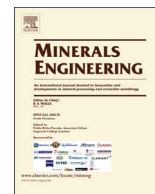




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Galvanic interaction of grinding media with arsenopyrite and pyrite and its effect on gold cyanide leaching

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ABSTRACT

Galvanic interactions between different types of grinding media and arsenopyrite and pyrite, during the grinding was quantified and the effect of galvanic interactions on gold cyanide leaching was investigated. The synthetic ores were prepared by mixing arsenopyrite or pyrite with clean gravity gold concentrate and quartz. In the presence of arsenopyrite, the results showed that when the grinding of the ore was performed using the 30% chromium or ceramic grinding media, the gold leaching was more efficient than that when the forged steel media was used. Based upon the measurement, it was suggested that the galvanic interactions between the forged steel grinding media and sulfide minerals resulted in the formation of more iron hydroxide than that when the 30% chromium or ceramic grinding media was used. As a result, free cyanide was converted to ferrocyanide thereby lowering the cyanide available for the gold leaching. Additionally, the galvanic interactions also reduced the dissolved oxygen content and thus cyanide gold leaching was more difficult particularly at the early stages of the leaching process because the dissolved oxygen is required to dissolve gold. In contrast, when the grinding was performed with the 30% chromium or ceramic media, a very small amount of free cyanide was converted into by-products. Cyanide gold leaching was the most efficient when the 30% chromium media was used during the grinding of the ore for both pyrite and arsenopyrite. In addition, in the presence of pyrite, due to the lower galvanic current between pyrite and grinding media in comparison with arsenopyrite, the amount of iron hydroxide was lower, and thus more free cyanide was available for the gold extraction. These results indicated that more gold was extracted in the presence of pyrite rather than the arsenopyrite for a given media type used. More precisely, in the presence of pyrite, when the 21% chromium grinding media was used, 70% of gold was extracted while it was 60% in the case of arsenopyrite in 24 h. The selection of grinding media appears to be significant when cyanide reagent consumption is evaluated.

1. Introduction

Galvanic interactions between grinding media and sulfide minerals during grinding not only increase the corrosion of grinding media but also can have a negative effect on downstream operations such as flotation of galena (Cullinan et al., 1999; Peng et al., 2003), pyrrhotite (Adam and Iwasaki, 1984; Natarajan et al., 1984; Hodgson and Agar, 1988; Pozzo et al., 1990), sphalerite (Vathsala and Natarajan, 1989) and chalcopyrite (Ahn and Gebhardt, 1991; Grano et al., 1994; Yuan et al., 1996; Peng et al., 2003). The driving force for these interactions is the difference in open circuit potential of grinding media and sulfide minerals. Sulfide minerals electrochemically interact with steel grinding media which can increase the corrosion of steel grinding media. It was found that the higher the electrochemically active grinding media, the less the flotation recovery of sulfide minerals (Adam and Iwasaki, 1984; Martin et al., 1991; Subrahmanyam and

Forssberg, 1993; Peng et al., 2003; Greet et al., 2004). Furthermore, it was observed that the grinding media with less electrochemically activity such as stainless steel and chromium grinding media may produce higher flotation recoveries of sulfide minerals (Forssberg et al., 1988; Cullinan et al., 1999). However, Rabieh et al. (2016 and 2017a) showed that the improved response with high chromium media is not guaranteed in all cases, as forged steel can perform marginally better prior to flotation as known for orogenic gold-bearing pyrite ores such as Kanoona Belle in Western Australia. Meanwhile, the flotation response is seen as dependant on a number of factors, such as ore mineralogy, process water chemistry, and grinding media metallurgy.

Although the influence of grinding media on flotation performance of sulfide minerals have been studied, the literature does not provide any information about the influence of galvanic interactions during grinding on the cyanide gold leaching for the common gold associated minerals such as pyrite and arsenopyrite. The objectives of this research

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are: (i) to quantify the galvanic interactions between grinding media and arsenopyrite and pyrite based on their electrochemical behaviour during grinding, (ii) to investigate the influence of grinding media type on cyanide gold leaching in the presence of arsenopyrite and pyrite and (iii) to propose a model which can explain the correlation between oxidized iron and galvanic currents. Conversely, it would also be important to investigate to which extent post-grind cyanidation can serve as a diagnostic tool to infer the extent of galvanic interactions during the grind. This work extends previous research by the authors (Rabieh et al. (2017b)), which investigated the interactions between grinding media and pyrrhotite on cyanide leaching of gold from ores containing 2% gold-bearing pyrrhotite. As pyrrhotite is a highly reactive iron sulfide it significantly amplified the grinding media-ore interaction and the effects on cyanide leaching of gold was highly significant. This paper investigates, using a similar approach as followed by Rabieh et al. (2017b), the interactions of grinding media with the less reactive arsenopyrite and least reactive (of the iron sulfide minerals) pyrite, both of which are common gold-bearing, or gold-associated minerals.

2. Materials and methods

2.1. Synthetic ore

Two synthetic ores were obtained by mixing 12 g of arsenopyrite (99% FeAsS and 1% SiO₂) or pyrite (98% FeS₂ and 2% SiO₂), 0.5 g of the gravity gold concentrate (6% gold from Knelson concentrator analysed by fire assay), and 587.5 g of quartz (99.5 % purity). Therefore, the synthetic gold ores had 2% arsenopyrite or 2% pyrite and 50 ppm gold. Table 1 shows the XRD analysis of the gold concentrate.

2.2. Grinding system

The feed ore was ground to a 80% pass size (P₈₀) of 75 µm by wet grinding at 34% w/w solids in the grinding system as explained in our previous work (Rabieh et al., 2017b). The grinding time to achieve the desired particle size distribution was 80 min for all type of grinding media, and the only difference was the speed of the mill which was 42, 38, 38 and 46 RPM for forged steel, 21% chromium, 30% chromium and ceramic, respectively. The pulp chemical conditions (pH, E_h, and dissolved oxygen) during the grinding of the ore samples was recorded for each minute. Additionally, every 20 min around 35 mL of the slurry was collected for the EDTA iron extraction and dissolved sulfur measurements. The dissolved sulfur measurements were performed using high performance liquid chromatography (HPLC); SO₄²⁻ ions were the only detected sulfur species.

2.3. Cyanide leaching procedure

After the grinding, the mill discharge was transferred into a 3 L glass

reactor, mechanically agitated along with a sufficient quantity of Perth tap water to generate slurry samples at 22% (w/w) pulp solid ratio. Around 12 mL of caustic soda solution (1 M NaOH) was added into the slurry in order to maintain a pH of approximately 10.5, and then mixed for another 5 min; then the solid sodium cyanide was added to the slurry in order to keep cyanide solution concentrate at 500 ppm. During the leaching process, approximately 20 mL of the slurry samples were collected after 2, 4, 6, and 24 h. These samples were filtered to analyse the solution for gold content by atomic absorption (AAS) technique, cyanide speciation by high performance liquid chromatography (HPLC), and solution cyanide strength by silver nitrate titration.

2.4. Determination of iron hydroxide content by EDTA

The amount of extractable iron in the samples taken from the mill slurry (every 20 min) was analysed by an ethylene diamine tetra acetic acid (EDTA) extraction method. In this method, a 250 mL of 3 wt% of EDTA solution at pH of 7.5 was prepared and transferred into a laboratory leaching vessel with a magnetic stirrer and purged with nitrogen for 5 min to remove the dissolved oxygen. The mill slurry samples (25 ml) were then added to the leaching vessel. The experiments were carried out for 5 min by purging with nitrogen. The slurry was then filtered through a 0.2 µm millipore membrane, and the solution was analysed by inductively-coupled plasma optical emission spectrometry (ICP-OES) for iron content, and then the amount of iron in the aqueous phase was calculated.

2.5. Electrodes preparation and voltammetry apparatus

2.5.1. Grinding media electrodes preparation

Two types of grinding media (i.e. forged steel and 30% chromium) were used to make the working electrodes. A grinding media sample was cut to the size of 15 × 15 × 3 mm to fill a Teflon tube. The electrode was connected to a screw by a conductive epoxy resin, and non-conductive epoxy was used to fill in between the Teflon tube and electrodes for isolation. Before each experiment, the electrode surface was gently polished by a set of polishing discs and alumina slurries. The chemical composition of different grinding media types used in this project explained in our previous research (Rabieh et al., 2017b).

2.5.2. Sulfide mineral electrodes preparation

The carbon paste-pyrite or arsenopyrite electrodes were prepared by thoroughly mixing 4 g of graphite powder with 3 g of pure arsenopyrite or pyrite mineral and 3 g of paraffin oil. The carbon paste-minerals was packed into the hole of the electrode body and polished. The exposed surface area of the mineral electrode was 0.071 cm². It should be noted that the carbon paste electrode was used for the electrochemistry study of sulfide minerals by a number of researchers such as Gerlach and Kuezeci (1983), Lu et al. (2000), Cruz et al. (2005), and Urbano et al. (2007). For further details about the carbon paste electrochemistry the reader is referred to work published by Lazaro et al. (1995) and Sauber and Dixon (2011).

2.5.3. In-situ mill electrochemistry

All in-situ mill electrochemistry measurements were performed using a WaveNow Potentiostat/Galvanostat system (Model number: AFTP1) provided by Pine Research Instrumentation. It should be noted that the potentiostat electrodes were placed inside the mill. The three-electrode setup consisted of the grinding media electrode or carbon paste-mineral electrode as the working electrode, an Ag/AgCl in 3 mol/L KCl as a reference electrode and a platinum wire as a counter electrode.

Table 1
Mineralogical analysis of the gold concentrate.

Mineral	Mass (%)
Clinocllore	6
Talk	< 1
Biotite	27
Muscovite	25
Amphibole	1
Clinopyroxene	3
Rutile	1
Albite	3
Alpha quartz	22
Calcite	< 1
Dolomite - ankerite	4
Malachite	4
Magnetite	3

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