



The effect of grinding chemistry on cyanide leaching of gold in the presence of pyrrhotite



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ABSTRACT

In this paper, the role of grinding media type on cyanide-based gold leaching in the presence of pyrrhotite was investigated. Pyrrhotite commonly occurs in many gold ores together with pyrite and/or arsenopyrite. A synthetic ore was prepared by mixing pyrrhotite with gravity gold concentrate and quartz. Pyrrhotite is of interest to grinding and leaching chemistry because this sulfide mineral is the highest cyanide- and oxygen-consuming iron sulfide and, contrary to pyrite, tends to behave as a reactive anode. The results showed that when the grinding of the ore was performed using the ceramic media, the gold extraction process was up to three times more efficient than that when the forged steel media was used. The reason is that the galvanic interactions between the forged steel media and pyrrhotite resulted in the formation of iron hydroxide; the formed iron hydroxide converted free cyanide to ferrocyanide that cannot dissolve gold (i.e. 75% of free cyanide was converted to ferrocyanide). Additionally, the galvanic interactions also significantly reduce the dissolved oxygen content and thus cyanide gold leaching is more difficult. In contrast, when grinding was performed with the ceramic or high chromium (30%Cr) media, an insignificant amount of free cyanide was decomposed (i.e. 1% of free cyanide was converted to ferrocyanide while 2.5% of that was converted to thiocyanate). For that reason, cyanide gold leaching is very efficient when ceramic or high chromium media was used during the grinding of the ore. It can be expected that the leach behaviour would be different if leaching is preceded by pre-oxidation, as is often done for pyrrhotite bearing ores. In addition, a theoretical model was developed to describe the correlation between the galvanic current and the grinding media oxidation, as measured by using EDTA extraction technique and dissolved sulfur analysis by HPLC during grinding. The electrochemical data were correlated with the amount of the grinding media oxidation during grinding with different media type. A linear relationship between the galvanic current and grinding media oxidation was obtained. It was found that the higher the galvanic current, the higher the amount of iron hydroxide was produced during grinding. Bench scale cyanide leaching can therefore serve as a useful diagnostic to determine the extent of galvanic interactions between media and minerals in grinding mills (similar to bench scale flotation which has also been used as diagnostic tool).

1. Introduction

It is well known that grinding media type might affect downstream operations such as flotation and leaching. Specifically, during grinding with steel grinding media, mineral particles become coated with different species of iron, changing the surface properties of the minerals. For example, it was found that the higher the percentage of iron in grinding media, the lower the flotation response of sulfide minerals (Martin et al., 1991; Cullinan et al., 1999; Rabieh et al., 2016). The decrease in flotation response was probably due to the presence of a hydrophilic layer of oxidised iron species on the surface of sulfide minerals.

Furthermore, during grinding of sulfide ores due to the galvanic current between forged steel grinding media and sulfide minerals,

electrons are transferred from the anode (i.e. grinding media) to the cathode (i.e. cathodic mineral), causing the change of the potential of both materials from their rest potential to the mixed potential (Adam et al., 1984; Martin et al., 1991). As a result, the corrosion of the less cathodic steel grinding media (low rest potential) increases and the corrosion of the more cathodic material (high rest potential) decreases (Fontana, 1987). Therefore, grinding media oxidation increases.

While gold-bearing sulfide ore cyanidation can be challenging there is a great variation in the extent to which sulfide minerals affect the leaching process. Deschenes et al. (2003) suggested that all sulfide minerals could be divided into three groups depending on their effect on gold leaching:

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- A group that reduces gold leaching (stibnite > orpiment > pyrrhotite > chalcocite > arsenopyrite > chalcopyrite);
- A group has little impact on gold leaching (pyrite and sphalerite);
- And a group that improves gold leaching (galena).

The effect of sulfide minerals on gold cyanide leaching is governed by amount of sulfide in the ore, as well as solubility and reactivity of sulfide minerals (Deschenes et al., 2003). Although the effects of sulfide minerals and their dissolved ions on the gold leaching process have been investigated (Ntemi et al., 2013), the influence of galvanic interactions occurring between grinding media and sulfide minerals on gold cyanide leaching has not yet been systematically evaluated. For that reason, the objective of this work is to investigate the influence of pyrrhotite (highly reactive sulfide mineral) and the grinding media on cyanide gold leaching. In this paper, pyrrhotite was selected because this sulfide mineral is the highest cyanide- and oxygen-consuming iron sulfide mineral. With regards to grinding media type, the following grinding media were used: the forged steel, 21% chromium, 30% chromium and ceramic media. It should be noted that in the case of free milling gold ores, pre-treatment options are not required before cyanide gold leaching; thus, this work is relevant for free milling gold ores and not for refractory gold ores. The research in this paper is also performed to establish a baseline for comparison to other iron sulfide minerals such as arsenopyrite and pyrite at the same mass % in the ore (Rabieh et al., 2017a, 2017b). It is realised that industrial gold-bearing pyrrhotite ores may often be preoxidised which may change the outcomes of gold leaching. However, the preoxidation falls outside the scope of the research reported here.

2. Materials and methods

2.1. Synthetic ore

The synthetic ore was obtained by mixing 12 g of pyrrhotite (99% purity), 0.5 g of the gravity gold concentrate (which contains 6% gold concentrate analysed by fire assay), and 587.5 g of quartz (99.5% purity). Therefore, the synthetic gold ore had 2% pyrrhotite and 50 ppm gold. Table 1 shows the XRD analysis of the gold concentrate. The 2% level of pyrrhotite was chosen to correspond to the mass percentage used for arsenopyrite and pyrite (Rabieh et al., 2017a, 2017b).

2.2. Grinding system

The modified grinding system is designed and built to replicate plant mill performance at a laboratory scale. The feed ore was prepared to a P_{80} of 75 μm by wet grinding at 34% w/w solids in the modified grinding system as seen in Fig. 1. The four different grinding media were used: the forged steel, 21% chromium, 30% chromium and ceramic media. The surface area of the grinding chamber is 0.2 m².

Table 1
XRD analysis of the gold concentrate.

Mineral	Mass (%)
Clinocllore	6
Talc	< 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

Table 2 shows the dimension, surface area, chemical composition of different grinding media types used in this project.

The grinding system (see Fig. 2) was built not only to grind the ore but also to monitor the chemical conditions (pH, E_h , and dissolved oxygen) during grinding of the ore samples. The changes of chemical conditions during grinding of the ore were recorded every minute by the controller system. In addition, every 20 min around 35 mL of the slurry was collected for the EDTA iron extraction and sulfur measurements. The amount of dissolved sulfur was measured by high performance liquid chromatography (HPLC) method; SO_4^{2-} ions were the only detected sulfur species.

2.3. Cyanide leaching test procedure

After grinding, the mill discharge was transferred into the 3 L glass reactor (Fig. 3), mechanically agitated along with a sufficient quantity of Perth tap water to generate slurry samples at 22% (w/w) solid ratio. Around 12 mL of caustic soda solution (1 M NaOH) was added 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 the cyanide solution strength at 500 ppm. During the leaching time, approximately 20 mL of the slurry samples were collected after 2, 4, and 24 h. These samples were filtered to analyse the solution for gold content by atomic absorption (AAS) technique, the cyanide speciation by high performance liquid chromatography (HPLC), and the cyanide solution strength by silver nitrate titration. After 24 h, the leach residue solids were filtered, thoroughly washed, dried, weighed, and submitted for gold analysis by fire assay.

2.4. Determination of iron hydroxide content by EDTA

An ethylene diamine tetra acetic acid (EDTA) extraction method was employed to determine the amount of extractable iron in the samples taken from the mill slurry after every 20 min of grinding of the ore. 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. 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 electrochemistry apparatus

2.5.1. Grinding media electrodes preparation

The forged steel and 30% chromium media 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.

2.5.2. Mineral electrode preparation

The carbon paste-pyrrhotite electrode was prepared by thoroughly mixing 4 g of graphite powder with 3 g of pure pyrrhotite and 3 g of paraffin oil. The carbon paste-pyrrhotite was packed into the hole of the electrode body and smoothed on clean paper until it had a shiny surface.

2.5.3. In situ mill electrochemistry measurements

All in situ mill electrochemistry measurements were performed using a portable Potentiostat/Galvanostat system in which the Potentiostat's electrodes were placed inside the mill. The three-electrode setup consisted of the grinding media electrode or carbon paste-

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