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The effect of pyrite particle size on the electrochemical dissolution of gold during cyanidation

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ABSTRACT

Pyrite is considered as the most common sulphide mineral that carries gold in refractory gold ores. In these ores, pyrite can be found in different particle sizes. Following flotation process, the flotation tailings is sent to the cyanidation circuit for gold extraction that may contain appreciable amounts of pyrite. Until now, the effect of pyrite on gold dissolution was reported to be either positive or negative in the open literature. This current research examines the effect of particle size and amount of pyrite on gold dissolution in a packed bed leach reactor (PBLR). Electrochemical characterization as a function of pyrite particle size on gold dissolution was tested. It was found that pyrite (4 g) has positive galvanic effect on gold dissolution especially in the presence of fine particles, − 106 μm (i.e., 54% Au in the absence of pyrite vs. 95% with + 20–53 μm pyrite). On the other hand, gold dissolution showed a sharp decrease when particle size was coarser than + 106 μm. Highest gold extraction, 98%, was achieved when gold particles are in contact with + 75–106 μm pyrite particles. When the pyrite amount was doubled (8 g of + 75–106 μm), gold dissolution was decreased to 35% due to the partial passivation of gold. If the pyrite amount were reduced by half (2 g of + 75–106 μm), gold dissolution increased by 30% as compared to the case without pyrite. Different scenarios were also considered regarding to activation and passivation of gold. For instance, when gold was split and dispersed equally within the pyrite layer and within the adjacent quartz layer, gold dissolution was found to be around 35%, suggesting a negative effect of released species from pyrite. Cyclic voltammetry and potentiodynamic polarization findings are in line with the cyanide leaching results. The shift in open circuit potential in presence of pyrite is in support of observed leach kinetics. SEM-EDS results have confirmed the decrease in gold dissolution in the presence of coarse particles. These findings have revealed that pyrite particle size and its amount have significant impact on gold dissolution.

1. Introduction

Due to the rapid depletion of free-milling types of gold ores, it is accepted worldwide that there is an increasing trend in the treatment of refractory sulphidic gold ores (Adams, 2016). Refractoriness is a term generally used to express the reason(s) of poor or low gold extractions (La Brooy et al., 1994). Since the majority of gold ores are associated with sulphides, then it is critical to examine its influence on gold dissolution. Dissolution kinetics of gold may be reduced/slowed down in some conditions, and if so, passivation and galvanic interaction phenomena are considered as potentially significant factors (Lorenzen and van Deventer, 1992; Mrkusic and Paynter, 1970).

In cyanide solutions, sulphide minerals are to some extent soluble thus, there will possibly be some soluble species present in the leaching solution. It is generally accepted that the presence of such species results in high consumption of cyanide and oxygen. The influence of sulphide minerals on gold dissolution has extensively been studied in the literature (Fink and Putnam, 1950; Weichselbaum et al., 1989; Deschênes et al., 1998; Dai and Jeffrey, 2006). Weichselbaum et al. (1989) found that the addition of trace amounts of sodium sulphide to the cyanide solution dramatically reduced gold leaching. This phenomenon was attributed to the formation of a passive layer of Au_2S on the gold surface. Lorenzen and van Deventer (1992) obtained similar results on gold dissolution in the presence of reactive sulphide minerals. Liu and Yen (1995) conducted a systematic study of the kinetics of gold dissolution in the presence of various sulphide minerals in both air-saturated and oxygen-enriched systems. Their results demonstrated that the leaching behaviour of gold in the presence of sulphide minerals depended strongly on both the solubility of the sulphides and the oxygen concentration in the solution.

Gold is mainly associated with sulphide minerals, in particular with pyrite, arsenopyrite, and sphalerite (Flatt and Woods, 1995). Among

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others, pyrite is known as the most common sulphide mineral that carries significant amounts of gold, to the point where solid-solution gold may become the principal form of gold in the ore and pyrite its chief carrier (Thomas, 1997). A refractory pyritic ore typically contains different types of pyrite with various gold concentrations (Ketcham et al., 1993).

A number of studies have investigated the galvanic interaction between gold and pyrite as a function of leaching parameters such as cyanide concentration, pH, dissolved oxygen, and agitation rate (Azizi et al., 2011; Huai et al., 2017; Lorenzen and van Deventer, 1992) and the galvanic interaction between gold and pyrite occurs and enhances the dissolution of gold at the initial stage, followed by the passivation of iron oxides (Aghamirian and Yen, 2005; Azizi et al., 2010; Lorenzen and van Deventer, 1992). Aghamirian and Yen (2005) employed potentiodynamic polarization tests in one container and found that pyrite and pyrrhotite showed positive effect on the leaching of gold which is not in agreement with the previous findings (Paul, 1984; Lorenzen and van Deventer, 1992). These results show that the influence of pyrite on gold dissolution still receives much attention.

Following the base-metal flotation of gold-bearing ores, such as in sulphur/silicate bearing minerals, the flotation tailings are sent to cyanidation circuit to extract gold. This flotation residue could contain some amounts of pyrite with a particle sizes defined for the flotation circuit, and this may play an important role on the cyanidation process. Until now, the effect of pyrite with different size fractions on gold dissolution with regard to activation and passivation during cyanidation has not received much attention. Hence, the objectives of this study are: (i) to examine the influence of particle size of pyrite on gold dissolution; (ii) to test the quantitative effect of pyrite on the leaching of gold which represents the practical conditions of some of the gold with base metal ore deposit; (iii) to characterise its electrochemical behaviour; and (iv) to provide an alternative explanation for the slowdown in the gold leach rate supported by surface characterization studies. These tests have been carried out in packed-bed leach reactor (PBLR) to decouple and quantify the individual contributions of passivation phenomena and galvanic interactions on gold dissolution (Table 1). It is important to underline the fact that liquid-solid mass transfer coefficients with similar-size particles, whether being present in a fixed bed –such as the present mini-reactor cell– or in a conventional slurry reactor –as in actual cyanidation slurry agitated tanks or sparged bubble columns–, must behave in a qualitatively similar fashion by virtue of the convective flows in action in both reactor geometries. In addition, should the imposed flow rates in the PBLR correspond, hydrodynamically speaking, to liquid interstitial velocities matching the particle-liquid slip velocities in slurry configuration then similar figures must prevail for both mass transfer coefficients. Another worth reminding feature of this PBLR is its ability to "artificially" emulate large ensembles of microscopic contacts which stem from partially liberated gold inclusions within pyrite granular environments. This is rendered possible with the PBLR tool without recourse to microscopic/nanoscopic costly instrumentation to assess microscopic solid-state phenomena while being representative of the industrial bulk leach conditions.

2. Experimental

2.1. Materials

Sodium cyanide (NaCN) with a purity of > 98% was obtained from Sigma-Aldrich Canada. The solution medium (100 mL) was prepared using distilled water. Leaching tests were conducted in 30 mM NaCN electrolyte solutions saturated with oxygen at 0.1 MPa, and NaOH (Fisher Scientific Canada) adjusted pH to 11 ± 0.01.

Pure gold powder (P_{80} = 39 µm, 99.998%) was purchased from Alfa Aesar USA. Pyrite was obtained from Wards Minerals and was reduced in COREM Research Centre down to the following size fractions: +20–53 µm, +53–75 µm, +75–106 µm, +106–150 µm, +150–212 µm and +212 µm. X-ray fluorescence (XRF) analyses showed that the sample contains 44.8% Fe, 51.4% S, and 0.45% SiO_2. Unless otherwise reported, 50 mg Au and 4 g pyrite (Py) were used in leaching tests, and the rest of the reactor volume was segregated (//) by quartz (Qtz). Different scenarios such as half Au + Pyrite // half Au + Quartz were also considered. Sintered glass filtered disc that has 20 mm diameter, and 3 mm thickness was purchased from VWR. This was used to have two compartments, i.e., segregating Au from pyrite.

2.2. Cyanidation test procedure

Leaching tests were performed in a 250 mL glass container by a continuous circulation of 100 mL of leach solution with a peristaltic pump through PBLR (cylindrical working section 25 mm H, 15 mm I.D.) with a constant flow rate of 10.4 mL/min. The solution was agitated at 300 rpm with a magnetic bar (4 cm long and 1 cm in diameter) during tests. Leach solution was fed upwardly from the bottom in order to avoid the channeling of the feed solution in the reactor and to maximize residence time of the cyanide solution in the mineral layer (Fig. 1). Instead of air, pure oxygen gas was sparged through the container to maintain a constant dissolved oxygen level ($DO_2 \sim 0.45$ mM at 25 °C), which was monitored by means of a dissolved oxygen probe (FOXY-AL300 model from Ocean Optics), while pH of the feed solution was maintained at 11 ± 0.01 using an Oakton 1000 series pH-meter. The concentration of CN^- in solution was monitored using Thermo Scientific Orion 9606BNWP Cyanide Ion-Selective Electrode. Sodium cyanide was added to maintain the concentration of free cyanide at the predetermined level over the leaching period. Leach solution was sampled at predetermined intervals over 24 h.

At the termination of cyanidation, leach residues were collected and dried in oven at 105 °C for characterization studies (explained in

Table 1
Strategy adapted to examine the effect of pyrite regarding the activation and passivation of gold.

Tests	Objectives & explanation
• Au + Qtz (No Pyr)	✓ Dissolution profile of Au in absence of pyrite. ✓ Packed-bed leach reactor (PBLR) was entirely filled with mix of Au (50 mg) and quartz (Qtz).
• Au + Pyr (+20–53 µm) // Qtz	Objective: investigate the effect of pyrite particle size on gold dissolution and the galvanic interactions between gold and pyrite.
• Au + Pyr (+53–75 µm) // Qtz	
• Au + Pyr (+75–106 µm) // Qtz	✓ Mix of Au and Pyrite (Pyr) samples placed in lower part of PBLR, and Qtz was in upper part. Tests with 4 g of Pyr.
• Au + Pyr (+106–150 µm) // Qtz	✓ According to results, pyrite particle size of +75–106 µm was considered for further investigation as it yielded maximum gold dissolution.
• Au + Pyr (+150–212 µm) // Qtz	
• Au + Pyr (+150–212 µm) // Qtz	
• Au + excess Pyr (8 g) // Qtz	Objective: test the effect of pyrite amount on gold dissolution.
• Au + Pyr (2 g) // Qtz	
• half Au + Pyr (4 g) // half Au + Qtz	✓ Amount of pyrite (8 g) doubled and halved (2 g). ✓ Amount of Au split and dispersed equally with Pyr and Qtz powders in segregated parts of PBLR.
• Pyr (4 g) // Au + Qtz	Objective: examine passivation effect during gold leaching.