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Gold and copper leaching from gold-copper ores and concentrates using a synergistic lixiviant mixture of glycine and cyanide

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ABSTRACT

The presence of cyanide soluble copper in the cyanidation of gold-copper ores and concentrates significantly increases the cyanide consumption in order to achieve sufficient gold recovery. In addition, cyanide recovery or cyanide detoxification/destruction processes are also required which adds extra cost to the process. This research introduces a leaching approach to extract gold, silver and copper from gold-copper ores and concentrates using a synergistic lixiviant leaching process using glycine in the presence of low concentrations of cyanide. The effects of glycine and cyanide concentrations on gold, silver and copper leaching kinetics and recovery were studied. It is shown that, in the presence of glycine, gold, silver and copper extraction increase significantly in solutions containing copper-cyanide species at a very low, or zero, free cyanide concentration. It has also been shown that the gold dissolution rate in glycine-cyanide system is almost three times higher than the gold dissolution rate in the conventional cyanidation. Kinetic studies were conducted to evaluate the effects of glycine concentration, pH, and CN/Cu ratio on the dissolution of gold and silver. It has also been shown that the gold dissolution rate increases by increasing the glycine concentration up to 2.0 g/L (Gly:Cu molar ratio of 2.2:1) and any further glycine addition has no significant effect on the dissolution of gold. It is shown that the presence of glycine in solutions containing copper (I)-cyanide species can significantly enhance the dissolution of precious and base metals. The proposed leaching approach significantly reduces the cyanide consumption by at least 75% and most of the copper is present as cupric glycinate in the final leach solution. In addition, gold, silver and copper extraction was higher than the conventional cyanidation process utilising similar cyanide dosages for all the gold-copper sources studied.

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1. Introduction

To extract precious metals from gold-copper ores and concentrates, the presence of copper minerals has detrimental effects on gold extraction unless high cyanide should be added to keep CN:Cu molar ratio above 4. For every 1% of reactive copper present about 30 kg/t NaCN was reported to be consumed (Muir, 2011). Stewart and Kappes (2012) also reported cyanide consumption can reach up to 2.3 kg/kg Cu recovered. The presence of copper minerals also has a negative effect on the extraction of gold (Muir et al., 1993; Nguyen et al., 1997; Jiang et al., 2001). In addition to lower gold recovery, additional costs are incurred to either recover the copper and/or cyanide, or to destruct/detox cyanide and WAD cyanide species in the final tail solutions (Mudder and Botz, 2001; Sceresini, 2005). Table 1 shows the effect of cyanide soluble copper on cyanide consumption and gold recovery from Jiang et al. (2001) research study. High cyanide consumption and low gold recovery were observed at higher reactive copper contents of different ores. Therefore, finding an alternative process of leaching such problematic ores is essential to make these ores more feasible by decreasing the consumption of cyanide whilst maintaining gold recovery.

It is well known that cyanide soluble copper dissolves in cyanide solutions to form toxic copper-cyanide complexes such as $Cu(CN)_2^-$, $Cu(CN)_3^{2-}$, $Cu(CN)_4^{3-}$. A number of studies have been published to treat gold-copper ores by either adding ammonia to the conventional cyanidation process, or recycling cyanide after the leaching stage (La Brooy et al., 1991; Muir, et al., 1991 and 1993; Costello et al., 1992; Jeffrey et al., 2002; Gonen et al., 2004; Adams et al., 2008; Xie and Dreisinger, 2009a and b; Alonso-González et al., 2009 and 2013). However, there are some issues regarding the environmental considerations of toxic and volatile ammonia which need attention. Threshold limit values (TLV's) established by the American Conference of Governmental Industrial Hygienists for ammonia is 25 ppm (ACGIH, 1994). In addition, there are also increasing public and environmental concerns and restrictions on the discharge of cyanide and copper-cyanide complexes to tailings dams. Moreover, destruction of the WAD cyanide after leaching is sometimes uneconomical especially in the presence of high

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Table 1
Gold recovery and cyanide consumption by cyanidation at different cyanide soluble copper contents (Jiang et al., 2001).

Sample	Au recovery, %	Cyanide consumption, kg/t	Cyanide soluble copper, %
A	93.03	5.95	0.00
B	90.23	5.99	0.06
C	71.5	11.49	0.17
D	57.21	11.3	0.2
E	89.8	7.26	0.04
F	72.25	10.59	0.11
G	44.36	14.25	0.86
H	70.75	13.48	0.22

copper concentrations (Dai and Breuer, 2009; Smith and Mudder, 1991). The formation of strong (therefore non-WAD) cyanide complexes, such as ferrocyanide, from copper-iron minerals leads to further reduction in the potential to recover cyanide.

Recently the authors have developed and patented the use of amino acids and particularly glycine, as an alternative lixiviant to cyanide in the gold industry (Oraby and Eksteen, 2014a and b; Oraby and Eksteen, 2015a; Eksteen and Oraby, 2015). In addition, the authors have found that a mixture of glycine and copper-WAD cyanide has significantly improved the gold extraction from clear solutions using pure gold disc (Oraby and Eksteen, 2015b). The authors have concluded the major roles of glycine in copper-cyanide solutions to be one or more of the following roles: (i) glycine complexes with both cupric and cuprous ions (Aksu and Doyle, 2001) as shown in Eqs. (1), (2) and (3);

$$Cu^{2+} + (NH_2CH_2COO^-) \leftrightarrow Cu(NH_2CH_2COO)^+, \quad \log K = 8.6 \tag{1}$$

$$Cu^{2+} + 2(NH_2CH_2COO^-) \leftrightarrow Cu(NH_2CH_2COO)_2, \quad \log K = 15.6 \tag{2}$$

$$Cu^{+} + 2(NH_2CH_2COO^-) \leftrightarrow Cu(NH_2CH_2COO)_2{}^-, \quad \log K = 10.1 \tag{3}$$

(ii) glycine presents cupric glycinate as an additional oxidant with higher availability and solubility in leach solutions; (iii) glycine dissolves the passivation layers of CuCN, AuCN, AuCN·CuCN and $Cu(OH)_2$ on gold and copper surfaces; (iv) glycine increases the copper dissolution and breaking the copper sulfide matrixes and released fine particles of gold locked in copper sulfides; and (v) glycine acts as an additional lixiviant for gold dissolution as shown in Eq. (4) (Eksteen and Oraby, 2015).

$$4Au + 8NH_2CH_2COOH + 4NaOH + O_2 \rightarrow 4Na\left[Au(NH_2CH_2COO)_2\right] + 6H_2O \tag{4}$$

Glycine is a non-toxic, non-volatile, and low cost reagent which is produced in large industrial quantities for use in several industries. It can be easily produced industrially or derived as a by-product from different micro-organisms (González-López et al., 2005). Glycine and its copper and precious metals complexes are stable over a wide pH, Eh and temperature range. Other than losses in leach residues during solid/liquid separation, the glycine is recovered and recycled for leaching.

Therefore, the main aim of this work is to study and evaluate the application of the glycine-cyanide synergistic (GCS) process on gold extraction from gold-copper ores and concentrates. The main principle of the process is to utilise glycine to regenerate cyanide ions from copper WAD cyanide in the presence of very low or zero free cyanide in the leach solutions. The proposed process aims to introduce several advantages in treating gold-copper ores and concentrates, such as (1) low cyanide consumption compared to the conventional cyanidation; (2) high gold, silver and copper extraction; (3) leaching conducted at a very low or no free cyanide in the leach solutions; (4) most of the copper in the final leach solution present as cupric glycinate; and (5) replacing the use of high cyanide with much safer and environmentally benign reagents.

2. Experimental

2.1. Samples preparation

Three samples of different gold-copper sources have been used and tested to conduct this research and the description of these samples are:

- Cu-Au-Ag gravity concentrate with complex copper mineralogy
- Cu-Au ore (oxide Au ore with nuisance Cu)
- Cu-Au ore (porphyry sulfide ore with low grade Au and recoverable levels of Cu).

These materials are discussed below.

2.1.1. Gold-copper gravity concentrate

The concentrate was produced from a centrifugal gravity separator at a gold-copper plant in Western Australia. The gravity concentrate sample was then ground to 100% passing 75 μm. The mineralogical compositions of the gravity concentrate was analyzed by an integrated automated mineralogy technique providing quantitative analysis of minerals using quantitative evaluation of minerals by scanning electron microscopy (QEMSCAN). The concentrate was diluted using silica flour sized at 100% passing 75 μm to have average contents of 44.5 ppm Au, 4.5 ppm Ag, and 0.08% Cu. To calculate the final gold, silver and copper extractions, the final leach residues were analyzed for gold and silver by fire assay and for copper by X-ray Fluorescence (XRF).

2.1.2. Gold-copper oxides and sulfides samples

The gold-copper oxides and gold-copper sulfides samples were provided from two different Western Australian mining companies. The samples were then split and ground to 100% passing 75 μm. The mineralogical compositions of these two ores were analyzed by Quantitative X-ray Diffraction (XRD). Feed and residue samples were analyzed for gold by fire assay and for copper by X-ray Fluorescence (XRF) to calculate the final gold and copper extraction.

2.2. Leaching

All experiments were carried out using solutions prepared from analytical grade reagents and deionised water. Unless specified, all experiments are conducted using a bottle roller, and the ore or concentrate sample and glycine-cyanide solution were placed in a 2.5 L Winchester bottle. After pH adjustment to 10.5–11.0, the slurry was agitated by rolling the bottle on a bottle roll at 150 rpm. Bottles are vented through a 5 mm hole in the lid to allow for oxygen transfer. At different sampling times, solution samples of the leach solution were obtained after filtration using a 0.45 μm filter paper. The solids were returned back to the leach bottle. The filtrate were analyzed for gold, silver and copper by using atomic absorption spectrometry (AAS).

3. Results and discussions

The mineralogical analysis of the three tested samples by XRD are shown in Table 2.

Table 3 shows the elemental analysis of these samples. The gold-copper concentrate prior to 50 times silica flour dilution has 3.75% Cu distributed amongst a range of reactive copper minerals, such as chalcocite, cuprite and native copper. The gold-copper oxides ore contains 12.9 ppm Au and 0.04% copper. The gold-copper sulfides ore mainly contains chalcopyrite as a copper mineral and it contains low gold grade of 0.77 ppm gold and 0.15% copper.

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