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Leaching of gold and copper minerals in cyanide deficient copper solutions

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Abstract

The concept of leaching copper–gold ores using leach solutions which contain $Cu(CN)_3^{2-}$ was investigated. Gold leaching occurs in air saturated $Cu(CN)_3^{2-}$ solutions at a much slower rate than in free cyanide solutions. A similar gold leach rate is observed when copper is alloyed with the gold. The dissolution of several common copper minerals in $Cu(CN)_3^{2-}$ also occurs at significantly slower rates, and in some cases not at all. This has the advantage of reducing copper dissolution and hence cyanide consumption. When leaching chalcocite (Cu_2S) in free cyanide solution, the dissolved sulfide ions significantly hinder gold leaching. However, when leaching chalcocite in $Cu(CN)_3^{2-}$ solutions, little sulfide was dissolved and gold leaching was found to be more rapid than for the free cyanide solution. Preliminary test work with gold ore samples containing CuO indicated that the initial kinetics of gold dissolution in air saturated $Cu(CN)_3^{2-}$ solutions were comparable to free cyanide. However, some gold was not leached when the leaching of the copper minerals was incomplete.

Keywords: Copper–gold ores; Leaching; Kinetics; Copper(I) cyanide; Chalcocite; Covellite; Cuprite; Tenorite

1. Introduction

For the past century, cyanidation has been the dominant means of recovering gold from its ores. Native gold is commonly found associated in ore deposits with pyrite and arsenopyrite. However, many gold ore deposits contain substantial quantities of copper minerals. Some copper minerals are readily soluble in cyanide which can have a detrimental effect on the process efficiency and economics due to high cyanide consumption, reduced gold leach rates and poor gold recovery (Coderre and Dixon, 1999; Deschenes and Prud'homme, 1997; Muir et al., 1989; Nguyen et al., 1997; Sceresini and Staunton, 1991; Tran et al., 1997). The possibility of increased cyanide losses due to catalysed oxidation of cyanide by dissolved copper, especially in the presence of

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activated carbon, has also been suggested (Muir et al., 1989).

When ores containing soluble copper minerals are leached using cyanide to recover the gold, copper also dissolves to form various copper(I) cyanide complexes: CuCN, $Cu(CN)_2^-$, $Cu(CN)_3^{2-}$ and $Cu(CN)_4^{3-}$. Their distribution in a cyanide solution is dependent mainly on the solution pH and the cyanide to copper ratios (Hsu and Tran, 1996; Lu et al., 2002). When the levels of soluble copper are low, the gold can be selectively recovered by maintaining the cyanide to copper ratio greater than 4:1 (Fleming and Nicol, 1984) which minimises the adsorption of copper onto activated carbon. Any adsorbed copper can also be pre-eluted from the activated carbon using a cold cyanide wash without desorbing gold (Muir et al., 1989).

Technologies have been proposed in order to recover gold economically from deposits that contain significant soluble copper minerals (> 0.5% Cu). The addition of ammonia to the cyanide leach has been found to improve gold recovery with reduced cyanide consumption (Costello et al., 1992; Muir and La Brooy, 1993; Muir et al., 1989). Fundamental studies recently published have shown that the addition of ammonia decreased the gold leach rate in the absence of copper, had little effect on the leaching of gold by $Cu(CN)_3^{2-}$, but does increase the leaching kinetics when the major cyanide species present is $Cu(CN)_2^-$ (Jeffrey et al., 2002). The presence of copper(II) was also shown to increase the gold leach rate, provided there is enough ammonia to stabilise it against reaction with the copper(I) cyanide complexes. Hence, this approach could be adopted where the ore contains cyanide soluble copper(II) oxide minerals. However, difficulties still remain with the stability of this system along with the environmental considerations and costs associated with using ammonia.

Another approach, which has been investigated and trialled for slimes, is leaching with deficient free cyanide where the copper cyanide complexes are also considered to contribute to gold dissolution (Nugent, 1991; Parsons et al., 1993; Sceresini and Staunton, 1991). In this case, cyanide consumption was reduced and the copper cyanide readily adsorbs onto the activated carbon along with the gold. It can then be selectively eluted with cold cyanide solution to facilitate copper recovery and importantly cyanide recycle. However, very little has been published on the dissolution of gold from ores by copper cyanide complexes.

This paper investigates the concept of leaching copper–gold ores using leach solutions which contain free cyanide or $Cu(CN)_3^{2-}$. The leaching behaviour of gold, silver, copper and their alloys, and several copper minerals have been studied. The oxidation and volatilisation of cyanide during these experiments have also been investigated.

2. Experimental methods

All experiments were carried out using solutions prepared from analytical grade reagents and Millipore water. Metal and alloy dissolution rates were measured using the rotating electrochemical quartz crystal microbalance (REQCM), which is described elsewhere (Jeffrey et al., 2000). Use of a rotating electrode as in the REQCM enables the calculation of the flux of reactants to the disc surface by using the Levich equation. The electrode mass measured by the REQCM is related to the reaction rate through Eq. (1).

$$r = \frac{1}{MA}\frac{\Delta m}{\Delta t} \qquad (1)$$

where r is the reaction rate ($mol \cdot m^{-2} \cdot s^{-1}$), A is the surface area of electrode (m^2), M is the atomic mass of the metal ($g \cdot mol^{-1}$), m is the mass of the electrode (g) and t is the time elapsed (s). This can also be converted into a calculated equivalent current density by using Faraday's law, as shown in Eq. (2).

$$I_{calc} = nFr \qquad (2)$$

where n is the number of electrons transferred per mole of metal reacted, F is Faraday's constant (96,485 $C\ mol^{-1}$) and r is the reaction rate.

Prior to each experiment, metal or alloy was electroplated onto the REQCM electrode. Gold was electroplated at 25 $A \cdot m^{-2}$ from a solution containing 0.02 M potassium dicyano-aurate, 0.23 M potassium cyanide, 0.086 M potassium carbonate and 0.5 mM silver nitrate. This resulted in a deposit containing approximately 5% silver by mass (which for simplicity will be referred to as gold), thus ensuring that the experiments more closely mimicked industrial conditions. Pure gold was electroplated from a