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The leaching and adsorption of gold using low concentration amino acids and hydrogen peroxide: Effect of catalytic ions, sulphide minerals and amino acid type

J.J. Eksteen *, E.A. Oraby

Department of Mining Engineering and Metallurgical Engineering, Western Australian School of Mines, Curtin University, GPO Box U1987, Perth, WA 6845, Australia

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ABSTRACT

The leaching of gold using alkaline amino acids–hydrogen peroxide solutions at low concentrations has been studied. The application of alkaline amino acid–hydrogen peroxide system may offer an alternative and environmentally benign process for gold leaching, particularly in the context of leaching low grade gold ores in an in-situ or in heap leach processes. In the presence of an oxidant or oxidants, it was found that amino acids can dissolve gold at alkaline condition at low and moderate temperature. Heating the leach solution between 40 and 60 °C was found to enhance the gold dissolution significantly in alkaline amino acid–peroxide solutions. It was also found that gold dissolution increases by increasing amino acid concentration, peroxide and pH. Amino acids acts synergistically to dissolve gold. Although glycine showed the highest gold dissolution as a single amino acid compared to histidine and alanine, histidine was found to enhance gold dissolution when used in equimolar amounts with glycine. The presence of Cu^{2+} ion enhances gold dissolution in the glycine–peroxide solutions. The process will propose an environmentally benign process for gold treatment in order to replace the use of cyanide in heap or in-situ leaching. In the presence of pyrite, the amount of gold leached was lower due to the peroxide consumption in sulphide oxidation.

1. Introduction

The current alternative lixiviants to cyanide pose many challenges. Despite copper ammoniacal-sodium thiosulphate being the main contender by different studies (Sparrow and Woodcock, 1995; Aylmore, 2001, 2005; Jeffrey, 2001; Breuer, 2002; Fleming et al., 2003; Chandra and Jeffrey, 2004; Oraby, 2010; Oraby et al., 2010), it is expensive, it has a complex leaching chemistry leading to the formation of polysulphide intermediates, it is very pH sensitive (labile) and it is applicable to a limited number of gold ores. It cannot economically be produced at site, it requires complex downstream separation and it is not biodegradable. Despite these challenges, thiosulfate has been applied in pilot plant since the 1980s, and has been used in heap leaching processes by Newmont Gold (Wan et al., 1994). Industrially, Barrick Gold has implemented a calcium thiosulphate retrofit at their Nevada operations (Choi, 2013). A development of in situ gold leaching using ferric EDTA and ferric oxalate complexes in thiosulfate solutions has been studies by Heath et al. (2008). However, in thiosulfate-iron (III) system the operating pH must be controlled, which increases the complexity of the application of this system in heap or in situ leaching. In addition, it was found that in the presence of thiourea the gold oxidation rate increases (Chandra and Jeffrey, 2004). However, thiourea has been identified as a potential carcinogen and its use has been met with scepticism.

In the main thiosulfate–copper–ammonia system, the presence of ammonia can cause environmental safety concerns of the surrounding environment by the evaporation of ammonia (Aylmore, 2005; Aylmore and Muir, 2001). Ammonia poses environmental and toxic problems both as a gas in air and as a soluble solution. The threshold limiting value (TLV) for ammonia gas, in air, is 14 mg/m^3 (Gos and Rubo, 2000), which is a very similar to that of HCN (15 mg/m^3). In additions, the US National Institute for Occupational Safety and Health (NIOSH) recommend an airborne exposure limit of 25 ppm (18 mg/m^3) averaged over a 10-h workshift with a limit of 35 ppm (27 mg/m^3) not to be exceeded during any 15 min work period (NIOSH, 2000).

The application in situ leaching (ISL), or heap leaching, or vat leaching, of complex and low-grade ores has a significant potential because it eliminates the need for hauling/hoisting large amounts of ore from underground and open pit operations (for ISL) or it can eliminate extremely energy inefficient grinding (by rather

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* Corresponding author. Tel.: +61 (0)8 9266 4419; fax: +61 (0)8 9266 1597.
E-mail address: jacques.eksteen@curtin.edu.au (J.J. Eksteen).

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heap or vat leaching). ISL has been used in the production of uranium since the mid 1970s (Mudd, 2001).

The aim of this research is to evaluate an environmentally friendlier hydrometallurgical process to leach gold directly from different (primary and secondary) sources. The aim of this work was to investigate a potential alternative process that would not require significantly different process conditions to conventional cyanidation processes, and that would allow the gold–lixiviant complex to be stable and adsorption in a carbon-in-pulp or carbon-in-column circuit. Of the reagents proposed, only glycine is not in use by the gold industry, whereas the alkali used and the hydrogen peroxide used in the process are currently in use, either in leaching, or in cyanide destruction (Lee et al., 1989; Lorosch, 1990; Lorosch and Kappes, 1991; Guzman et al., 1999).

Glycine is an amino acid with a carboxylic group and an amine group. It is used as a levelling agent in acidic copper plating baths. Glycine has several advantages over cyanide and its alternatives such as thiosulfate, thiocyanate, thiourea, halides: it is an environmentally benign reagent, produced in large industrial quantities, and it is significantly cheaper than many alternative lixiviants and the solutions are stable over a wide pH–E_h range. Due to its complexing action, glycine can also enhance the solubility of copper ions in aqueous solutions (Aksu and Doyle, 2001, 2002).

Gold solubility in different amino acids solutions has been studied by Zhang et al. (1996) and Brown and Smith (1982). Recently, Feng and Van Deventer (2011) have also found that gold extraction in thiosulfate solutions was largely improved by the addition of amino acids (L-valine, glycine, DL-a-alanine and L-histidine).

From that point, the application of solution containing glycine and peroxides on gold dissolution may achieve a promising gold dissolution rate. The authors, in another paper, (Oraby and Eksteen, 2014) have reviewed the mechanism of gold leaching in glycine–peroxide solutions.

In general, the stoichiometry of gold dissolution in alkaline glycine solutions is described in Eq. (1):

$$\begin{aligned}&4Au + 8NH_2CH_2COOH + 4NaOH + O_2\\&\rightarrow 4Na[Au(NH_2CH_2COO)_2] + 6H_2O \qquad (1)\end{aligned}$$

The presence of soluble oxidants, other than oxygen, in gold leaching using glycine is expected to enhance the gold dissolution, as their concentrations are not limited by the air/oxygen solubility, neither do they lead to significant amino acid oxidation. Table 1 summarises the advantages of the glycine–peroxide process to leach and recover gold. Table 1 summarises the advantages of glycine–peroxide system for gold leaching.

While Oraby and Eksteen (2014) have shown that the reaction rates are a 1/20th to 1/30th of the leach rate of cyanide under similar pH and E_h conditions, the lixiviant system has particular value in environmentally open, long leach time systems as implemented in ISL and heap leaches (or even vat leach modes). In these leach modes, mass transport through the particles become the rate limiting factor. The heating requirement (to 60 °C) for these modes can easily be provided using solar ponds or solar water heating in pipes, particularly in areas with much sunshine. Eksteen et al. (2014) have demonstrated that solar heating of heap leaches to heat recirculated barren solutions to moderately elevated temperatures (~to below 60 °C) can be achieved quite easily in subtropical regions. The thermal inventory of heaps or underground deposits (in the case of ISL) provides adequate buffer between day and night time temperature variations.

While Oraby and Eksteen (2014) discussed some aspects of gold leaching with glycine peroxide systems, the focus of that research was to provide a review and to evaluate the potential of glycine at higher concentrations (0.3–1.0 M Glycine solutions), as well as to evaluate the role of silver and silver-gold alloys. In the paper by Oraby and Eksteen (2014), the authors have showed that the gold and silver glycinate complexes could be successfully loaded onto activated carbon from solutions of the high concentration glycine–peroxide leach system. This paper will evaluate amino acid–peroxide systems for amino acids in lower concentrations (as would be considered for heap and in-situ leaches) and the temperature effects at these concentrations. In addition, it will evaluate the effect of oxidant concentration, the effect of catalytic ions, the role of amino acid type and synergism in amino acid mixtures, the role of pyrite gangue and finally, the adsorption onto carbon from low concentration pregnant leach solutions. While the stated amino acid concentrations may still be higher than the corresponding cyanide concentrations used in gold leaching, the amino acids (in particular glycine) have stabilities that would allow recycling and reuse in the circuit, whereas cyanide tend to be lost as hydrocyanic acid, thiocyanate, cyanate, ferricyanide and a range of Weak Acid Dissociable Cyanides, limiting reuse potential.

2. Experimental

2.1. Leaching

All experiments were carried out using solutions prepared from either analytical grade or synthesized reagents and Millipore water. Unless specified, all experiments were conducted using magnetic stirrers and Teflon coated magnetic stirrer bars. Unless specified otherwise, 400 mL of 0.1 M glycine and 1% peroxide solution was heated in a beaker to different temperatures and stirred at 300 rpm. Gold foils (20 cm^2) used in all the experiments were made from 99.99% pure gold. Prior each experiment, the surface of the each sheet was polished with Struers waterproof silicon carbide paper (FEPA P#2400). Finally the gold sheet was washed with distilled water and allowed to dry.

2.2. Adsorption

For testing the carbon activity to adsorb gold–glycine complex, unless specified, 1.5 g/L of fresh carbon (−2.36 + 2.00 mm) was added into the pregnant solutions after leaching. The adsorption experiments have been conducted at room temperature and with a roller rotation speed of 150 rpm. In order to evaluate the gold adsorption on carbon, sub-samples were taken at different time intervals and then diluted with aqueous sodium cyanide before being analysed using ICP–OES.

3. Results and discussions

3.1. Effect of temperature

Leaching reaction of gold with glycine–peroxide solution has been shown that it is a chemically controlled reaction (Oraby and Eksteen, 2014) for high concentrations (e.g. tank leach conditions). In this paper, at 0.1 M glycine concentration, the effect of temperature has been studied at 23, 30, 40, 60 and 75 °C. Fig. 1 shows the effect of temperature on the kinetics of gold leaching with dilute glycine solutions. Clearly, it can be seen that gold dissolution increases dramatically as the temperature increases. However at high temperature (75 °C) it was found that the initial gold dissolution is faster but the gold leach rate decreases rapidly.

Gold leaching is a chemically controlled process in which temperature mostly affects the reaction rate. The most interesting results shown in Fig. 1 that after 264 h of leaching at room temperature, gold dissolution rate increased dramatically once the temperature has been raised to 60 °C.

Fig. 2 illustrates the gold dissolution rates over leaching time at different temperatures. It can be seen that at elevated temperature,