Active and passive behaviors of gold in cyanide solutions

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Abstract: Active and passive behaviors of pure gold (Au) and roasted gold ore (RGO) electrodes were investigated at 25 °C in de-aerated agitated cyanide media. Cyclic voltammetry and potentiodynamic polarization with agitation at 100 r/min in 0.04 mol/L NaCN solution showed different peak positions and current densities. Potentiodynamic tests illustrate that the peak current densities increase greatly with increasing the cyanide concentration. Increasing the pH value from 10 to 11 resultes in a great decrease of current density, while it increases noticeably by decreasing the agitation from 100 to 60 r/min. In the presence of oxygen, Au and RGO electrodes show different characteristics of peak positions and corrosion rates. The potentiostatic studies show that increasing the potential from 1 to 1.4 V at pH value of 11 results in an 80% decrease of current density while decreasing the pH value from 11 to 10 at 1 V gives a 1.7 fold increase of current density, possibly due to more effective passive layer. Following polarization, electrochemical noise measurements (ENM) during decay periods show that Au results in more passive states at high potentials, showing pitting corrosion. The ENM results show that this technique can be a promising tool for a better understanding of gold leaching. The XPS studies prove the presence of passive oxides.

Key words: pure gold; roasted gold ore; cyanide; passivation; electrochemical noise

1 Introduction

Due to rapid depletion of free-milling gold ores, refractory gold ore processing has become ever important [1]. In practice, the refractoriness of ore leads to low gold extractions and high cyanide consumption [2,3]. In gold ore processing, the passivation of gold surface and/or the diffusion control are the practically faced problems. During cyanidation process and under certain conditions, gold surface is protected by a surface film, which causes poor gold extractions. There are several electrochemical measurement techniques to evaluate the anodic behavior of gold.

Passivation phenomenon of gold surface can be considered as one of the challenges in practical cyanidation and then a better understanding of this phenomenon is quite important. Two recently published papers [4,5] have considered the passive phenomenon of metals including gold during dissolution. HOLMES and CRUNDWELL [4] used pyrite sample and mentioned that polysulfides did not cause passivation.

CRUNDWELL [5] claimed that each point on the surface was considered as both anodic site and cathodic site and concluded that there was no separation of anodic and cathodic sites on mineral surface. HABASHI [6] and HABASHI and BAS [7] pointed out that certain experimental results demonstrated the existence of anodic and cathodic zones during the dissolution of minerals. Moreover, AZIZI et al [8] examined the passive behavior of gold ore and concluded that all minerals directly affected the leaching of gold and pre-oxidation may be an effective option for gold dissolution. These studies show that active and passive behaviors of gold still receive high attention and need to be examined.

In the case of gold, to date, some electrochemical techniques have been used to monitor anodic behavior of gold. Cyclic voltammetry (CV) [9,10] and potentiodynamic techniques [11−13] were used by some research groups for the observation of interfacial reactions. LIN and CHEN [9] used relatively high cyanide concentration (0.2 mol/L) as compared with leaching practice when using cyclic voltammetry testing with rotating disk electrode at 500 r/min in oxygen-free

electrolyte. Three oxidation and one reduction peaks were observed. MUGHOGHO and CRUNDWELL [10] employed cyclic voltammetry of rotating disk gold electrode at 1000 r/min and scan rate of 100 mV/s using dilute cyanide solution (0.003 mol/L). Three oxidation peaks, one reduction and one small oxidation peaks in the return sweep were obtained with relatively low current density in this rarely used dilute solution in practice. In the previous potentiodynamic studies, the effects of cyanide concentration and pH value were tested and found that in most cases, gold had three oxidation peaks and certain intermediate reactions were advanced [14,15]. MACARTHUR [16] mentioned the complexity of the reaction and emphasized the difficulty to obtain a precise result. It was suggested that gold oxides and cyanide films were responsible for the passivation of gold surface [14,17]. Electrochemical noise measurement (ENM) [18] was referred as a random fluctuation of current and/or potential that has received wide attention to study the electrochemical systems. The instantaneous response to the change of surface conditions enables this method to be an online-monitoring tool. Although ENM technique has been considered for stainless steel [19], copper [20], zinc [21], aluminium [22] and other metals, there is a paucity of in-situ ENM studies for gold.

In this study, the cyclic voltammetry and the effects of cyanide concentration and pH value on the anodic behavior of pure gold (Au) and roasted gold ore (RGO) electrodes were tested in cyanide solutions using potentiodynamic and potentiostatic techniques in the presence of moderate agitation to simulate the practical conditions. In the potentiostatic tests, as complementary to the previous studies, the influence of imposed two anodic potentials, representing the passive region, in different electrolytes on the anodic behavior of gold and gold ore was examined. It is worth noting that, the majority of gold ore studies were conducted using sulphidic gold ores [23−26]. In this study, oxidized gold ore which predominantly consisted of iron oxides was used. Electrochemical noise measurements (ENM) technique was also applied to monitoring the anodic behavior of gold during decay periods after anodic polarization. This can give an insight for better understanding of the anodic behavior of gold in cyanide solutions. The identification of surface film of gold was carried out in parallel by XPS.

2 Experimental

2.1 Ore sample and roasted gold ore electrode preparation

The gold ore sample was obtained from Barrick Gold Corp. It was the calcinate after the roasting of refractory gold ore. The sample, which was already reduced in size with 80% passing 75 μm (d_{80}), was riffled as portions prior to use in the experiments. The mineralogical analysis of the sample indicates that the ore sample predominantly consists of hematite, magnetite and maghemite. The presence of maghemite renders the ore refractoriness in character due to the difficulties in cyanidation [27].

Roasted gold ore (RGO) with an exposed surface area of 4.9 cm^2 was used as compared with the pure gold electrode (Au) with an exposed surface area of 1 cm^2. The difference in surface areas of electrodes somewhat reflects the practice. The gold ore was mixed with graphite powder (to increase conductivity) with the mass ratio of 3:1 and around 0.5 g silicone oil for binding, till a paste was obtained. Then, it was mechanically pressed at 20 t to have uniform sample surface. After that, the roasted gold ore electrode was kept under nitrogen over a night, then connected with an insulated copper wire and cast in acrylic resin. The conductivity of the electrode was also checked.

2.2 Cyclic voltammetry, potentiodynamic and potentiostatic test procedure

The gold foil with the surface area of 1 cm^2 (99.9% purity from Sigma Aldrich) was used as a working electrode. Platinum as a counter electrode and Ag/AgCl (KCl saturated) as a reference electrode were used. The gold electrodes were first washed and polished with fine polishing paper (MicroCut® 100 grit soft) and then rinsed with distilled water. The electrodes were then introduced to aqua-regia for 10 s to clean the surface, washed with distilled water and ethanol and finally rinsed with distilled water again for reproducibility. NaCN (≥98% purity) was obtained from Thermo Fisher Scientific Company. The cyclic voltammetry of pure gold electrode without agitation was carried out in 0.04 mol/L NaCN solution at pH value of 10.5. 1 L electrolyte solution was first bubbled with argon and magnetically agitated at 250 r/min for 50 min to eliminate the oxygen. Then, typical three-electrode system was placed into the solution with slight argon bubbling on the surface of the electrolyte. The CV studies were conducted in duplicates from −1 to 1.2 V and the first two cycles were reported. The scan rate was controlled at 10 mV/s. In potentiodynamic and potentio-static tests, argon was profoundly bubbled over the test period. 1 L electrolyte medium was prepared using distilled water and the pH value was adjusted by adding 1 mol/L NaOH. The electrolyte was magnetically agitated (100 r/min) during the test. In this study, EC-Lab software obtained from a biologic company (France) was used to monitor and interpret the obtained results. The preparation procedure for EN studies included 3 steps.