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Effects of sulfide and lead nitrate addition to a gold cyanidation circuit using potentiodynamic measurements

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Abstract

Corrosion potentiodynamic polarization experiments on a gold electrode in a cyanide solution with 0–30 ppm lead addition and 0–20 ppm sulfide were carried out. Solutions containing 300 ppm NaCN, adjusted to a pH 11.1 by NaOH and bubbled with air were used at atmospheric pressure and room temperature. If the concentration of lead ions was equal or larger than the sulfide ions a change of potential towards the more negative potential (a potential drop) was observed and this was accompanied by a significant increase in the corrosion rate (up to 10 mm y^{-1} in certain circumstances). If lead nitrate was added to a solution with a gold electrode that had been previously passivated by sulfides, the corrosion rate typically rose from about 0.3 to 0.95 mm y^{-1}. The addition of lead nitrate to sulfides in cyanide solution can create a synergetic effect which results in an increase in dissolution rates of gold in cyanide solutions and this is accompanied by a drop in the corrosion potential of gold and a dramatic decline in thiocyanate and free sulfide concentrations.

1. Introduction

In the latest work from Tshilombo and Sandenbergh [1] there is a suggestion of some type of synergy between the lead and sulfides in the solution. Previous work [2, 3] has shown the accelerating effect of lead nitrate on gold cyanidation under similar conditions to those used in the experiments outlined in this paper. The addition of lead (in the mill) also shows an improvement in the cyanidation of gold especially in the presence of sulfides [4–6].

Interpreting the E_{corr}/t and potentiodynamic results will lead to a better understanding of the reactions occurring due to sulfide addition and the beneficial effects of lead nitrate in the presence of sulfides. The goal is to obtain a better understanding of the underlying reactions occurring during gold cyanidation.

The influence of sulfide ion addition to cyanide solutions with and without lead nitrate addition on the electrochemical behaviour of gold has been examined. The harmful effect of sulfide on gold cyanidation is well known but the underlying reactions and interactions between the different ions are not well understood. This study employed corrosion potential measurements and potentiodynamic techniques on a gold electrode in a cyanide solution with 0–30 ppm lead addition and 0–20 ppm sulfide.

2. Experimental details

The working electrode used was 99.99% pure gold (Aldrich) in the form of short lengths soldered to PVC insulated copper wires, cast in acrylic resin. The gold electrode had an exposed area of 0.071 cm^2. Before being introduced into the cell the gold electrode was ground with silicon carbide abrasive paper down to 600 grit (Leco Corporation) and cleaned with deionized water. A platinized platinum foil was used as the counter electrode. The reference electrode used in these experiments was mercurous sulfate (MSE); Hg, H_2SO_4/sat. K_2SO_4 (0.640 V vs NHE). All potentials in the paper are given with respect to the normal hydrogen electrode (NHE).

A pH of 11.1 (±0.1) was used in all experiments, controlled by sodium hydroxide. A concentration of 300 ppm NaCN at room temperature with continuous air bubbling was used in all experiments. The solution was always magnetically stirred.

The electrolytic cell was a one litre glass cell containing 800 ml of electrolyte prepared using doubly distilled water. Sodium cyanide, sodium hydroxide, lead nitrate and sodium sulfide were all A.C.S. reagent grade (Aldrich). The electrochemical measurements were conducted using an EG&G Princeton Applied Research 273 potentiostat/galvanostat controlled by a software called 342 SoftCorr™ III.

Potentiodynamic curves were produced by scanning from −550 to 150 mV vs NHE. Conditions for other potentiodynamic experiments ranged from −100 to 100 mV vs mixed potential and were used to calculate the corrosion rate. The corrosion rates were calculated using the polarization resistance method (R_p) in the Softcorr program. The scan rate used was either 0.1 or 1 mV s^{-1}.

3. Results and discussion

3.1. *Gold behaviour in alkaline aqueous cyanide solutions containing sulfide ions*

The solutions used in these experiments exhibited noticeable differences over time. The corrosion potential of the gold becomes more positive as the solution ages but seems to reach equilibrium after several days (Figures 1 and 2). Indeed, in some experiments the potentials become more negative in the later part of the experiments. Previous experiments showed that more negative potentials correspond generally to increasing corrosion current [1]. When fresh sulfides were added to a solution the potential returned to the expected state as if it were a fresh solution. Only a few experiments were performed and so they are not discussed in detail in this paper.

The potentiodynamic scans gave three cathodic–anodic junctions, which have also been observed using E_{corr}/t techniques. These three junctions can be summed up as follows:

First level (*C*). Most positive (highest) potential junction (~0 mV), normal corrosion potential for cyanide solutions without any addition, (and with Pb^{2+} addition). Not observed in experiments with S^{2-} addition unless lead nitrate is added.

Second level (B). Middle junction, first (and only) observed corrosion potential in experiments with S^{2-} addition (~ −120 mV).

Third level (A). Most negative (lowest) potential junction, observed only when the electrode is not polished, and only in solutions with sodium sulfide and lead nitrate additions (~ −350 mV). Absent in potentiodynamics scans at 1 mV s^{-1} in cyanide solutions without any addition, and in fresh solutions with S^{2-} addition even at 0.1 mV s^{-1} scan rate.

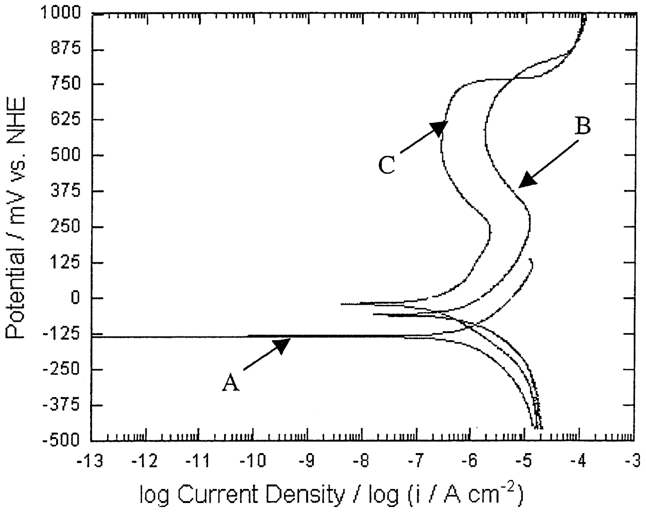

Fig. 1. Polarization curve for pure gold electrode in 300 ppm NaCN. Key: (A) 5 ppm S^{2-}, solution 20 h old, electrode not polished; (B) 20 ppm S^{2-}, solution 3 h old, electrode polished; (C) 1 ppm S^{2-} solution 43 h old, electrode polished, (0.457 mm y^{-1}). 0.1 mV s^{-1} scan rate, agitated and air bubbled, 23°C, pH 11.1.

Figure 1 shows three potentiodynamic scans for different quantities of sulfide addition at different solution ages. A and C resulted in very similar scans although the solutions were very different. A is a scan for 5 ppm S^{2-}addition, 20 h after the solution was made, C is a scan for 1 ppm S^{2-}addition, 43 h after the solution was made.

In experiment A the gold electrode had not been polished and the corrosion rate was 0.305 mm y^{-1}, in experiment C the gold electrode was polished before the scan and the corrosion rate was 0.457 mm y^{-1}.

In the case of A the gold electrode had been in solution for 20 h, and was 50% more passive than solution C, the same effect was seen for solutions with the same concentration of sulfide addition [1]. In the case of experiment B the solution was only 3 h old, 20 ppm S^{2-} was added, the gold electrode was polished and the corrosion rate was 0.254 mm y^{-1}. The lowest corrosion rate observed was below 0.051 mm y^{-1} for a solution of 20 ppm S^{2-} addition, in which the gold electrode had been left in the solution for over 21 h.

Little difference (in corrosion potentials or rates) was noted in these solutions as long as the gold electrode was polished. If the electrode was left in a solution (aged or otherwise) it passivated as a function of time immersed in solution. The more sulfides the more rapid and total was the passivation.

Figure 2 shows an E_{corr}/t curve of gold for two different solutions of 300 ppm NaCN with sulfide addition. The solution with 5 ppm S^{2-}(A) was fresh at the start of the experiment, while the 20 ppm S^{2-} solution (B) was 24 h old. The addition of 5–20 ppm S^{2-} resulted in the same type of curve for at least 48 h, however even small amounts of lead nitrate changed this curve. Figure 2 was selected to illustrate that the same results would occur regardless of the time elapsed or amount of sulfides used. Since 5 and 10 ppm S^{2-} addition gave the same results as 20 ppm S^{2-} addition, it was decided that 20 ppm S^{2-} would be used to illustrate the case and to compare against other experiments. The minute quantities of lead (ppb Pb^{2+}) in sodium cyanide seem to have no impact on the harmful effect of sulfide ions to the cyanidation process. At least

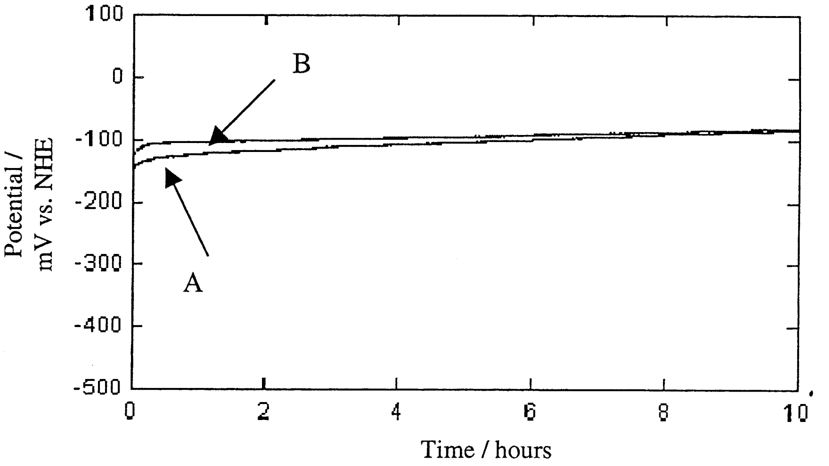

Fig. 2. Open circuit curves for gold electrode in comparison of 5 and 20 ppm S^{2-} addition to 300 ppm NaCN, electrode polished, pH 11.1, agitated, air bubbled. Key: (A) 5 ppm S^{2-}, solution fresh; (B) 20 ppm solution 24 h old.

not for 48 h after the solution is made. The conditions in Figures 1 and 2 illustrate the situation that applies to all experiments with sulfide ion addition. In a previous article [2] the addition of lead guaranteed the presence of three junctions. In this case there is only one junction at a scan rate of 0.1 mV s^{-1}. When lead nitrate was not added only one junction was present at a scan rate of 1 mV s^{-1}, at 0.1 mV s^{-1} all the junctions were present.

The sulfide eliminates the other two junctions. The electrode is passive as evidenced by the corrosion rates and the observed dullness of the gold surface. The first and third junctions, in both cases was absent from the potentiodynamic scans and the resulting corrosion rate was very low if the electrode was not polished before the potentiodynamic experiment. For 5 ppm S^{2-} addition experiment it was 0.457 mm y^{-1} (solution 43 h old, electrode polished), and 0.076 mm y^{-1} (solution 27 h, electrode immersed for 27 h). In the case of 20 ppm S^{2-} addition a reduction from 0.254 mm y^{-1} to 0.069 mm y^{-1} was observed when the gold electrode was left immersed in solution for 19 h. In a previous paper [2], used for baseline comparisons, a similar immersion without sulfide or lead addition resulted in a reduction of the corrosion rate from 0.91 mm y^{-1} (electrode polished) to 0.53 mm y^{-1} (electrode not published, left in solution for 21 h). The addition of lead nitrate counteracted this effect.

3.2. *Gold behaviour in alkaline aqueous cyanide solutions containing sulfide and lead ions*

As previously mentioned the potentiodynamic scans gave three cathodic–anodic junctions, which have also been observed using E_{corr}/t techniques. Figure 3 briefly summarizes these junctions.

Level B, passivation of gold surface by sulfide film, as has been observed when no lead ions are added. Level A, after 20–200 min the potential of the gold electrode drops to A in the presence of lead nitrate (Figure 4). The time difference is dependent, on the relative quantities of

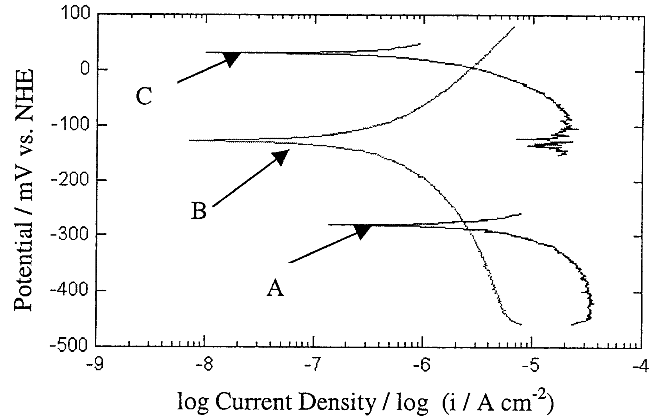

Fig. 3. Polarization curve for pure gold electrode in 300 ppm NaCN, 20 ppm S^{2-}, 20 ppm Pb^{2+}, 1 mV s^{-1} scan rate. Key: (A) solution 15.5 h old, electrode not polished (electrode in solution for 15 h), corrosion rate = 3.251 mm y^{-1}; (B) electrode polished, solution freshly made, corrosion rate = 0.142 mm y^{-1}; (C) electrode polished, solution 23 h old, corrosion rate = 0.737 mm y^{-1}.

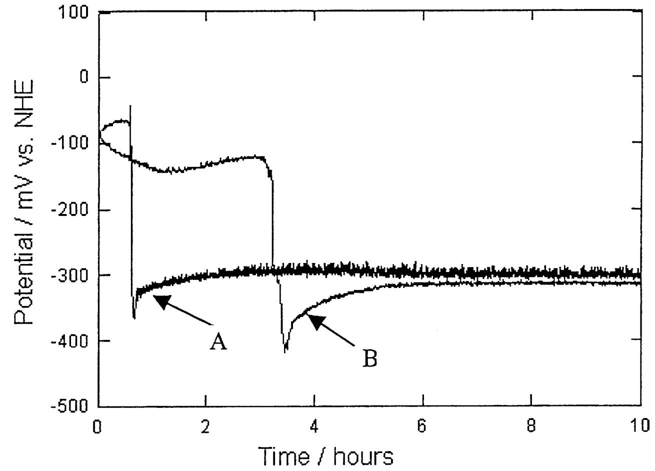

Fig. 4. Open circuit curves for gold electrode in 300 ppm NaCN, 20 ppm Pb^{2+} addition, fresh solution and varying additions of sulfides. Key: (A) 10 ppm S^{2-}, electrode polished; (B) 20 ppm S^{2-}, electrode surface polished.

lead and sulfide ions in solution, the more lead nitrate the quicker the potential drop occurs, the more sulfide present the longer the time interval before level A. The potential is stable after level A only as long as the electrode is left undisturbed in the solution. Level C occurs when the electrode is removed and polished.

When no lead nitrate was added levels A and C are eliminated and only level B is observed. If fresh sulfides are added to the solution at any stage the gold electrode potential resets to level B. If a very large quantity of sulfides are present compared to lead ions (10 to 1) the electrode remains at level A for many hours (15+) and then jumps to level C (Figure 5). The relative concentration of lead and sulfide ions was very important. Too much sulfide or lead ions prevented the improved dissolution at specific corrosion potentials. The phenomenon was observed across a broad spectrum of lead and sulfide concentrations, the ratios are the most critical factor [1].

Figure 3, shows potentiodynamic curves taken at different moments, showing all three junctions. All three junctions are always present on a polarization curve of gold in cyanide solutions with lead addition even in nitrogen bubbled solutions (deaerated), although in cyanide solutions without any additions only one junction is present (at a scan rate of 1 mV s^{-1}) [2]. However in cyanide solutions with fresh sulfides added, only the second junction is present. Addition of lead nitrate is necessary to break the sulfide film that forms on the gold surface since the single junction (level B) remained even after two days without lead nitrate addition. However, as soon as lead nitrate was added the three junctions reappeared.

The sulfides keep the corrosion potential around −70 to −160 mV but the addition of lead nitrate changes the balance of the system. A sulfide addition of 5 ppm S^{2-} with 20 ppm Pb^{2+} balances the system, sometimes the potential drop occurs, and sometimes it does not. When the concentration of lead ions is significantly higher than the concentration of sulfides, the potential stays in the 0–60 mV range (Figure 6). However, when the concentration of lead ions is not too much greater than the concentration of sulfides, the potential drop occurs. In Figure 4 the effect of sulfides (5–20 ppm S^{2-}) with 20 ppm Pb^{2+} addition to the cyanide solution are presented. If smaller quantities of lead and sulfide in the same proportions are used, the same results occur. For instance when 1 ppm S^{2-} and 2 ppm Pb^{2+} were added to a cyanide solution, the potential fell to −360 mV in 45 min. This type of curve can really be seen as composed of two part: (1) The first part of the curve from the start of the experiment until the potential drop (level B), and (2) The potential drop and the new equilibrium level (level A).

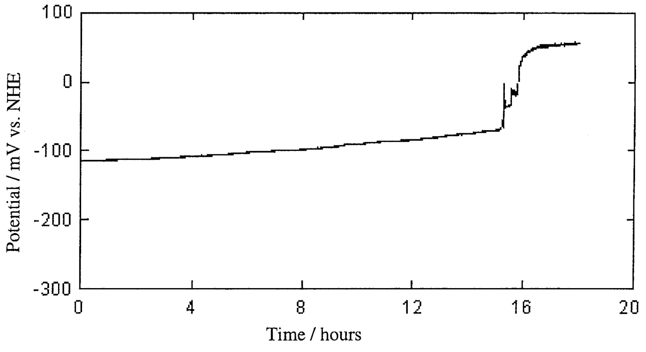

Fig. 5. Open circuit curve for gold electrode in 300 ppm NaCN, 1 ppm Pb^{2+} addition with 20 ppm S^{2-} addition. Agitated and air bubbled, pH 11.1, 23°C, electrode polished before experiments. Corrosion rate at start 0. 229 mm y^{-1}, at the end of the experiment 0.965 mm y^{-1}.

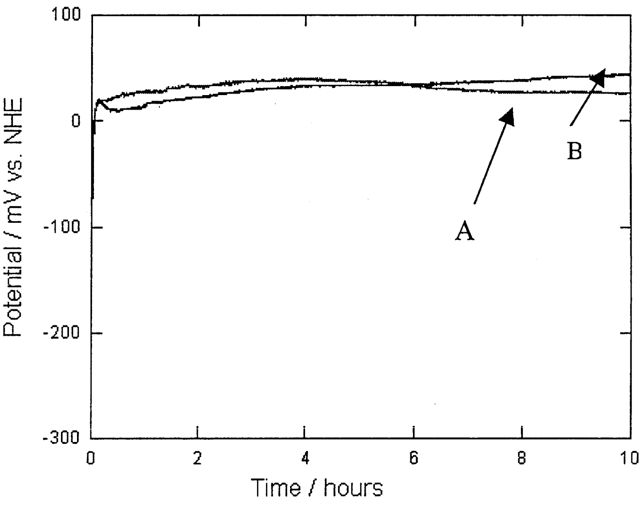

Fig. 6. Open circuit curves for gold electrode in 300 ppm NaCN, 20 ppm Pb^{2+} addition, fresh solution and varying additions of sulfides. Key: (A) 20 ppm Pb^{2+} addition and 1 ppm S^{2-} addition; (B) 20 ppm Pb^{2+} addition and 4 ppm S^{2-} addition.

In Table 1 the effect of sulfide and lead nitrate additions to a cyanide solution are shown and the changes that occur to thiocyanate (SCN^-) and free sulfide (S^{2-}) levels in solution. The results show a dramatic decline in thiocyanate and free sulfides when lead nitrate is added to cyanide solutions with sulfides added [7–9]. The free sulfides form a passive layer on the surface of gold, thus preventing the leaching of gold by cyanide.

However, when lead nitrate is added the concentration of free sulfides was reduced by a factor of 10. The concentration of free cyanide was also reduced, so some sulfides reduce the amount of free cyanide available for

Table 1. Analysis of cyanide samples (300 ppm NaCN) at pH 11.1

Sample	Concentration of Pb^{2+} /S^{2-}	SCN^- /ppm	S^{2-} /ppm	Titration for NaCN /ppm	Quality of end pt.
A	20 ppm S^{2-}	17	4.0	Not calculable	None
B	5 ppm S^{2-}	2	4.5	305	Good
C	1 ppm S^{2-}	< 1	0.9	280	Good
D	1 ppm S^{2-} 20 ppm Pb^{2+}	1	0.15	265	Excellent
E	10 ppm S^{2-} 20 ppm Pb^{2+}	10	0.1	270	Excellent

leaching. Thus adding more cyanide may solve the problems caused by sulfides. It is also noticeable that adding more lead nitrate does not seem to reduce the free sulfide concentration, 20 ppm Pb^{2+} counteracted 1 and 10 ppm S^{2-} equally effectively, as seen in sample D and E in Table 1. The free sulfides are almost identical but the thiocyanate is 10 times higher for sample E. The SCN^- concentration changes as a function of sulfide addition, so it is reasonable to say that the lead nitrate addition catalyses the formation of thiocyanate and the removal of harmful free sulfides. Indeed in the absence of lead ions, 1 ppm S^{2-} (C) resulted in 9 times more free sulfides than 10 ppm S^{2-} with lead nitrate addition (E).

As Figures 4 and 6 show, there is a difference in the starting reaction of solutions D and E (Table 1). With solution D (Figure 6) there is no potential drop, but also no passivation of the gold electrode, which occurred at the start of experiments using solution E (Figure 4). The lead ions (20 ppm Pb^{2+}) counteract the free sulfide in 40 min for 10 ppm $S^{2-}$and in 3.5 h for 20 ppm S^{2-} additions to 300 ppm NaCN at pH 11.1.

A good example of the above behaviour is the curve for 20 ppm S^{2-} with 20 ppm Pb^{2+} addition, which starts with an initial E_{corr} of −90 mV. The potential very quickly drops to about −140 mV, then after about three hours (since the start of the experiment) drops to −400 mV before reaching an equilibrium potential of −320 mV (Figure 4).

When a small amount of sulfides (less than 10 ppm) are added to a cyanide solution in the presence of small amounts of lead nitrate a sudden drop in potential is seen during the first five hours after the solution is made. After the potential drop has occurred the potential is at equilibrium at this highly active level (−300 to −360 mV) (Figures 4 and 7). However, when the experiment is terminated and a second run begins (with a polished electrode), the potential is at level C (0 to 60 mV) and does not exhibit the potential drop again without the addition of fresh sulfides. Potentiodynamic studies have shown that the addition of fresh sulfides reduces the corrosion rate to around 0.305 mm y^{-1}, a reduction of at least one-third compared with a corrosion potential around −80 mV. However, when it reaches the final equilibrium state, the corrosion potential is shifted to around −330 mV with a corrosion rate of 3.05 mm y^{-1} or more.

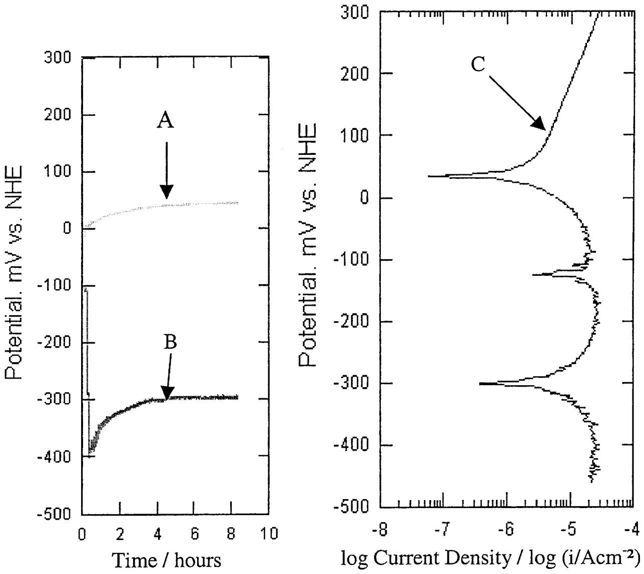

Fig. 7. Open circuit curves for gold electrode in 300 ppm NaCN, 10 ppm S^{2-} addition, 20 ppm Pb^{2+} addition. Key: (A) old solution (35 h); (B) fresh solution, and compared to (C) polarization curve for pure gold electrode with the same conditions as the open circuit experiments, solution old (21 h).

The starting potential in Figures 5 and 6 is the most interesting aspect, in that the corrosion rate analysis shows it to be a passive region in Figure 5. The jump in potential after 10 h or longer (about 15 h in Figure 5) is due to the presence of lead nitrate that was added to the solution. What is interesting is that although all three junctions are present at the end of the experiment the potential drop does not occur. The passivity has been countered by the lead. It is probably not due to the breakdown of the sulfides by the cyanide solution into thiocyanate (CNS^-). According to Weichselbaum et al. [7] some gold plants operate successfully in solutions with up to 15 mg L^{-1} sulfide without adding lead. Two possibilities: (i) lead and/or other heavy metals are present in the ore or cyanide solution; or (ii) under certain conditions sulfides do not passivate the gold [1].

In Figure 6, with a low concentration of sulfides (< 5 ppm) and a much higher concentration of lead ions (20 ppm, or 30 ppm Pb^{2+} with 5 ppm S^{2-}), the corrosion potential rises quickly before changing very little over ten hours, the corrosion rate seems to improve over time. Only level C (around 0 to 60 mV) is observed, as seen in Figure 6. It would seem that the lead overwhelms the sulfide and prevents a drop in the corrosion potential but also prevents the passivation that occurs at the level B (−70 to −160 mV). A synergy between the lead and sulfide must be causing the drop and attendant increased activation of the gold electrode.

The corrosion rates in these experiments were comparable to solutions of 20 ppm Pb^{2+} without sulfide addition.

In experiments with S^{2-} addition to a much larger amount of lead nitrate addition, as in Figure 6, E_{corr}/t graphs are shown which have only the level C cathodic–anodic junction. This junction did not appear in other experiments (with S^{2-} addition) with fresh solutions. The corrosion potential at 0 mV was stable and the weight ratio of Pb^{2+} to S^{2-} had to be greater than 4. Thus 30 ppm Pb^{2+} and 5 ppm S^{2-} resulted in the same curve as Figure 6. Twenty ppm Pb^{2+} and 5 ppm S^{2-}, however, produced two profiles: either the potential drop shown in Figure 4 or as in Figure 6 without the potential drop. However, with a more equal lead nitrate and sulfide addition the corrosion potential started at the level B potential and dropped to the level A potential within 5 h (Figures 4 and 7), for a fresh solution. This is an indication that the additions to the cyanide solution are interacting and giving rise to different concentrations of free ions.

In Figure 7, the E_{corr}/t results can be seen beside the results of a potentiodynamic experiment. Here it is clearly shown that there are two cathodic–anodic junctions one anodic–cathodic junction in the potentiodynamic experiment, while in the E_{corr}/t experiment there are three distinct corrosion potentials which correspond to the three junctions observed in the potentiodynamic curves.

Results for corrosion rates were calculated only when the corrosion potential was in the specific junction, that is, no forced experiments with the corrosion potential forced to a higher or lower level. These results indicate that S^{2-} addition corresponded to a higher polarization resistance than other experiments. This also became more noticeable when the gold electrode was left immersed in the solution, with very low corrosion rates resulting. Looking at the second junction (only junction that appears on a scan between −500 and 100 mV, for a fresh solution), produced an E_{corr} (calculated $I = 0$) of −110 mV and a corrosion rate of 0.229 mm y^{-1}. However with an aged solution of 20 ppm S^{2-} addition and with 1 ppm Pb^{2+} addition, the corrosion rate was around 0.965 mm y^{-1} with an E_{corr} around +70 mV (Figure 6).

In Figure 7, the sudden drop in potential is see more. It was possible to run potentiodynamic experiments with respect to E_{corr} (−100 mV to 100 mV vs NHE), after the potential drop had occurred but without polishing the electrode. Surprisingly, these experiments gave corrosion rates of around 3.43 mm y^{-1}, with an E_{corr} of −320 mV. This is clearly a very active corrosion region. The combination of lead nitrate and sulfides are clearly the cause, since no such potential drop was observed in experiments with only sulfide addition or only lead nitrate addition in air bubbled solutions. The addition of too much sulfide or lead nitrate avoided or prevented the potential drop. The combination had to be within a narrow band of values to cause the potential drop.

The more active potential region between −440 and −210 mV resulted in a much higher corrosion rate, and correspondingly a lower polarization resistance in all experiments with or without lead nitrate or S^{2-} addition. When just sulfides were present this active region was not present.

It was possible to apply an imposed potential (potentiodynamic sweep from −440 to −210 mV) to calculate corrosion current on a gold electrode in most solutions (i.e., all solutions except solutions with only the addition of sulfides). When this was done, the results gave a high corrosion rate.

In Figure 8, a potentiodynamic scan that produced only one corrosion potential (fresh solution with sulfide addition) is compared to a potentiodynamic scan with three cathodic–anodic junctions. The comparison indicates that the single corrosion potential produced by the addition of sulfides is similar to the middle junction produced by a fresh solution with lead nitrate addition (no sulfide addition). This junction represents the passage from an anodic area to a cathodic area, as opposed to the two other junctions, which represent corrosion potentials.

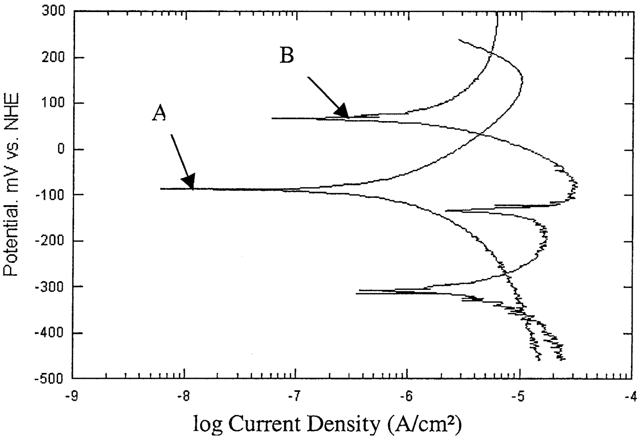

Fig. 8. Polarization curve for pure gold electrode in 300 ppm NaCN, 20 ppm S^{2-}, 1 mV s^{-1}. Key: (A) solution fresh, electrode polished; (B) solution old (37 h), 1 ppm Pb^{2+} added, electrode polished.

Sandenbergh et al. [1] showed the synergy effect occurring and this research supports it. The synergy level that was evinced from our studies was 20 ppm Pb^{2+} to 5 ppm S^{2-} or higher (up to 20 ppm). If a sulfide film does form (thus explaining the passivation of the gold electrode), it would have to be removed since the free sulfides drop to very low levels in the presence of lead nitrate. The lead would need to react with any free sulfides in the solution. In the experiments by Sandenbergh et al. [1] an increase in the dissolution rate of a gold disc was observed less than 10 min after the lead was added to a cyanide solution with sulfides. Again in their results the synergy between lead and sulfide ions is critical.

Without lead nitrate addition the passivation due to free sulfides would be expected to last days compared to hours or minutes when lead nitrate is added. As the concentration of lead ions increased, the period of passivation (low corrosion rate) is correspondingly reduced until it disappears. The potential drop to the much lower potential is due to a synergy between lead and sulfide ions. Presumably the best ratio would be one that avoids passivation instantly and completely without using too much lead nitrate. This would seem to be 4 to 1, since 20 ppm lead nitrate counteracted 5 ppm S^{2-} almost instantly. Industrially, it might be better to add a lower concentration (of lead) because one hour is not a significant delay for industry given the benefits of the synergy if it occurs. 2 to 1 is also good as this resulted in passivation for just 40 min. Equal amounts of lead and sulfide ions resulted in passivation for several hours.

4. Conclusions

If the concentration of lead ions was equal to or greater than the sulfide ions a change to a more negative potential (a potential drop) was observed. In solutions with a large amount of sulfide ions and a very small amount of lead ions the change in potential was in the opposite direction.

Before the potential drop the gold electrode is in a passive state with a corrosion rate of 0.3 mm y^{-1} or less. After the potential drop, due to the synergy between lead and sulfide ions, the gold electrode is at the most active potential with a corrosion rate of up to 10 mm y^{-1}. A ratio of 4 to 1 lead ions to sulfide ions was most effective.

For a solution with just cyanide the corrosion rate of the gold electrode fell from 0.91 mm y^{-1} (electrode polished) to 0.53 mm y^{-1} when the gold electrode was left immersed in solution for 21 h. The corrosion rate of the gold electrode was about 0.26 mm y^{-1} in a solution with 5–20 ppm S^{2-} addition, as long as the gold electrode was freshly polished before the experiment. If the gold electrode was left immersed in the solution the corrosion rate fell. For 20 ppm S^{2-} addition a reduction from 0.254 to 0.069 mm y^{-1} was observed when the gold electrode was left immersed in solution for 19 h.

The potential drop (to active values) occurs in deaerated solution with and without lead nitrate addition and in aerated solutions with both lead and sulfide ions [1, 3].

The phenomenon was observed across a broad spectrum of lead and sulfide concentrations; the ratios are the most critical factor. The CN^{-} concentration is also important.

Acknowledgements

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