

# The behaviour of mild steel in aqueous cyanide solutions at high temperatures

by J.R. de Wet\* and R.F. Sandenbergh\*

## SYNOPSIS

The behaviour of mild steel in aqueous cyanide solutions similar to caustic cyanide elution solutions was investigated at high temperature in electrochemical experiments. The anodic polarization diagrams of mild steel indicated that steel may undergo active dissolution under these conditions. The rare occurrence of gold plating in practice is the result of the limiting of the anodic dissolution of the steel by the presence of a passive layer on the steel. This passive layer is stable only in a certain potential range, and the free corrosion potential attained determines whether the steel will be passive or active. For conditions typical of elution columns, several corrosion potentials are possible, depending primarily on the initial condition of the steel and the concentration of oxygen in the solution. If these conditions result in the formation of a passive layer on the steel, changes in concentration and temperature will not necessarily result in plating since the layer may exist in a metastable form.

## SAMEVATTING

Die gedrag van sagte staal in waterige sianiedoplossings soortgelyk aan hoë temperatuur elueeroplossings is met behulp van elektrochemiese tegnieke ondersoek. Anodiese polarisasiediagramme dui daarop dat aktiewe oplossing van die staal moontlik is onder hierdie toestande. Die seldsame voorkoms van goudplatering in die praktyk kan toegeskryf word aan die beperking van die anodiese oplossing van die staal deur die teenwoordigheid van 'n passiewe laag op die staal. Die passiewe laag is slegs in 'n sekere potensiaalgebied stabiel en die korrosiepotensiaal sal bepaal of die staal passief of aktief is. Vir toestande tipies van elueerkolomme is 'n aantal korrosiepotensiale moontlik, afhangend van die inisiële toestand van die staal en die suurstofkonsentrasie in die oplossing. Indien hierdie toestande lei tot die vorming van 'n passiewe laag op die staal sal die verandering van konsentrasie en temperatuur nie noodwendig tot platering lei nie aangesien die laag in 'n metastabiele toestand kan bestaan.

## INTRODUCTION

The successful use of mild steel as a construction material for gold-leaching plants can largely be attributed to its good resistance to corrosion in aerated aqueous cyanide solutions. The reason for the good performance of mild steel lies in its ability to form passive layers that effectively shield the steel substrate from attack by the solution. However, it is well known that gold will become plated onto mild steel under certain conditions, and that this may cause problems with the plating of gold onto iron-rich particles<sup>1</sup>. The carbon-in-pulp (CIP) process introduced new and potentially more aggressive processing conditions to gold-recovery circuits in the form of the acid treatment of carbon and the elution of loaded carbon with high-temperature caustic cyanide solutions. Gold cementation can indeed take place on elution columns, as has been confirmed by experience in gold-plant elution operations<sup>2,3</sup>. The work described here on the behaviour of mild steel in aqueous cyanide solutions at high temperature was initiated by Genmin, and was undertaken to more clearly define the conditions under which gold plating will occur and to evaluate the resistance of various steels to this phenomenon.

The Pourbaix diagram for the iron–water system shown in Figure 1 indicates that iron will dissolve actively over a wide range of potentials at low pH values, but only over a

small range of potentials at high pH values. At intermediate pH values, oxides of Fe(II) are formed at low potentials, and Fe(III) at higher potentials. These oxides will inhibit the kinetics of iron dissolution depending on the solubility and retention of the oxidized species on the surface. Insoluble compounds may limit the corrosion rate sufficiently for steel to become effectively corrosion-resistant, i.e. passive. Iron (III) species such as  $\alpha$ -FeOOH,  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>, and  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> have low electrical conductivities, while iron species with a greater number of Fe(II) sites have greater conductivities<sup>5</sup> and are considered to be less effective passifiers. Once a passive species is present on the surface of iron, further oxidation is slow. The good corrosion resistance of steel that is usually obtained in alkaline gold pulps indicates that very protective oxides form under these conditions.

An increase in temperature leads to a significant increase in the solubility of iron oxide at high pH values owing to the formation of soluble  $\text{HFeO}_2^-$ , as indicated in the Pourbaix diagram for this system at 90°C (Figure 2). The possibility that iron will corrode in alkaline solutions through the formation of  $\text{HFeO}_2^-$  is therefore increased at high temperatures, as has been found by a number of investigators<sup>6–9</sup>. This is in contrast to the behaviour at lower temperatures, where active dissolution seldom occurs at high pH values<sup>10</sup>.

Cyanide in aqueous solution may change the behaviour of iron by the formation of soluble iron cyanide complexes in preference to insoluble oxides, as is indicated in the Pourbaix diagram for the system Fe–CN–H<sub>2</sub>O at 25°C (Figure 3). However, little is known about the combined influence of cyanide and high temperature on the

\* Department of Materials Science and Metallurgical Engineering, University of Pretoria, Pretoria 0002.

© The South African Institute of Mining and Metallurgy, 1993. SA ISSN 0038-223X/3.00 + 0.00. Paper received September 1992; revised paper received February 1993.

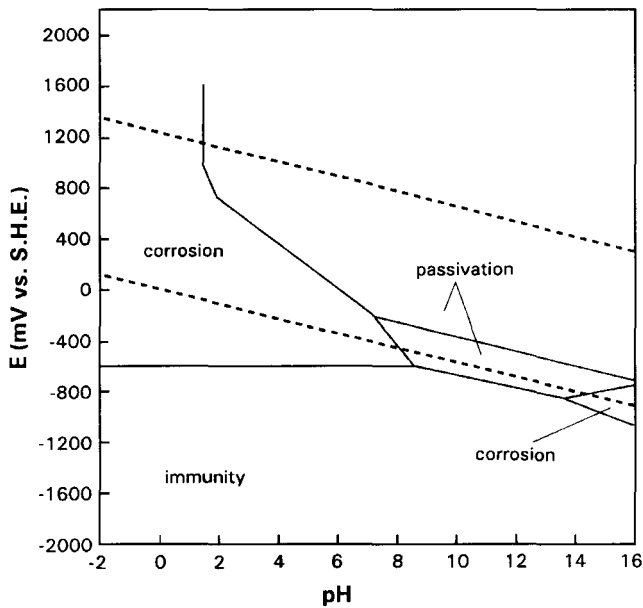


Figure 1—Pourbaix diagram<sup>4</sup> for the system Fe-H<sub>2</sub>O at 25°C

dissolution of iron, and this was one of the aspects dealt with in the present investigation. In CIP elution circuits, the presence of cyanide will favour the dissolution of iron to form a ferrous cyanide complex while also stabilizing the gold in solution as the aurocyanide complex. Temperatures of up to 75°C do not have a significant influence on the stability of the aurocyanide complex at constant cyanide levels, as shown in Figure 4. However, a decrease in the cyanide concentration, as could result from the hydrolysis of cyanide at high temperatures<sup>13</sup>, or from elution operations without cyanide additions (as is now typical for many South African operations<sup>14</sup>), will make the aurocyanide complex less stable. The driving force for gold plating is determined by the stabilities of both the aurocyanide and the soluble iron species, such as the iron cyanide complexes and hypoferrite, and will depend on

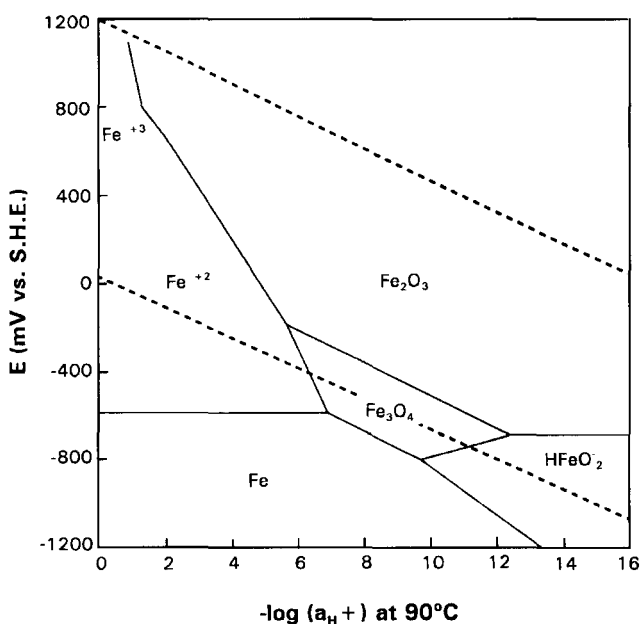


Figure 2—Pourbaix diagram<sup>6</sup> for the system Fe-H<sub>2</sub>O at 90°C

how these are influenced by changes in the solution conditions.

In the present work, the influence of hydroxide and cyanide in aqueous solution on the dissolution of iron was investigated for process conditions typical of elution. The aim was to more clearly define the conditions under which gold plating will take place so that these can be avoided in the operation of CIP elution plants. A comparison of the performance of different steels in cyanide and hydroxide solutions at high temperatures was also made.

## EXPERIMENTAL

The dissolution of iron in cyanide and hydroxide solutions at high temperatures was investigated by the use of electrochemical polarization techniques and measurements of corrosion potential. All the experiments were conducted in an autoclave made of type 316 stainless steel, as shown in Figure 5. A silver-silver chloride (SSC) reference electrode maintained at room temperature and connected to the cell through a pressure-reducing Luggin tube was used for the potential measurements. The Luggin tube was filled with saturated potassium chloride, and a thread of asbestos wool was passed through the tubing to ensure continuity of the electrolyte. A counter-electrode of platinum was used in the polarization experiments, while the working electrode consisted of the material under investigation. The temperature in the autoclave was controlled by an electrical-resistance element fitted round the outside of the autoclave, a thermocouple inside the autoclave, and a temperature controller. The polarization studies were conducted under isothermal conditions, and the gold-plating experiments were conducted while the temperature was steadily increased from room temperature to 110°C at a fixed rate. Samples of low-carbon steel, type 304 stainless steel, and 3CR12 (nominal compositions shown in Table I) were used. The samples were ground to a 600-grit finish, and were washed in de-ionized water before being immersed in the solution. The preparation was carried

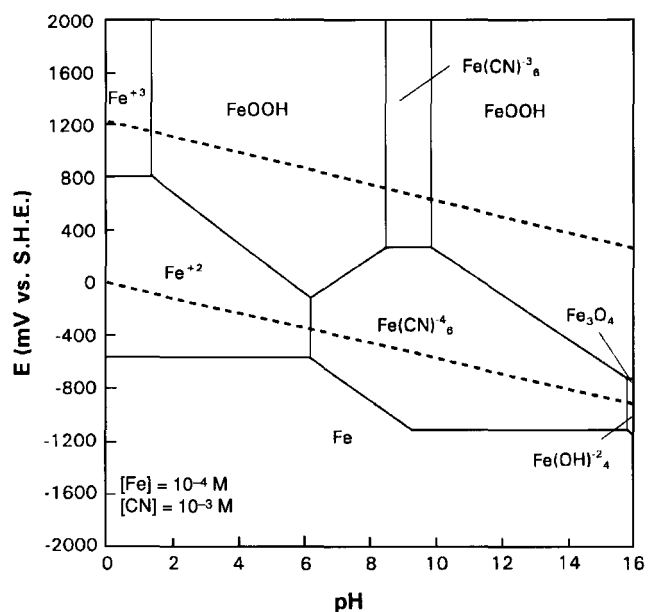


Figure 3—Pourbaix diagram<sup>11</sup> for the system Fe-CN-H<sub>2</sub>O at 25°C

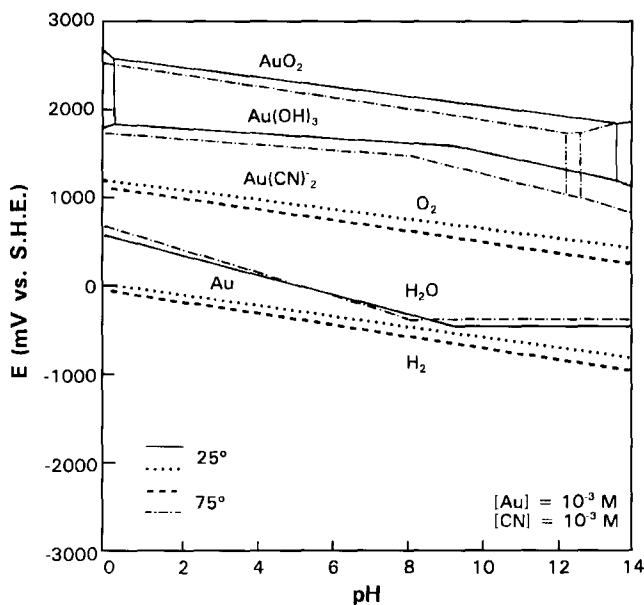


Figure 4—Pourbaix diagram for the system Au-CN-H<sub>2</sub>O, indicating the influence of temperature on the stability of the aurocyanide species<sup>12</sup>

out just prior to the experiments to avoid variations due to the formation of different oxide layers on the surfaces of the samples. The solutions were made up from reagent-grade chemicals and distilled water. The solutions typically used in Zadra elution circuits contain about 0,5 mass per cent NaCN (0,1M NaCN) and 1 to 2 mass per cent NaOH (0,25 to 0,5M NaOH), and the concentrations of 0 M, 0,1 M, and 0,2 M NaCN and 0,05 M and 0,5 M NaOH used in the experiments were chosen to approximate these conditions and possible excursions. The two hydroxide concentrations yield theoretical pH values of 12,7 and 13,7 respectively at 25°C. Potassium sulphate was added to a concentration of 0,1 M K<sub>2</sub>SO<sub>4</sub> to enhance the conductivity of the solution. The volume of the solution used was 300 ml, which gave a ratio of volume to sample area of approximately 50 ml/cm<sup>2</sup> for all the experiments.

In the polarization experiments, the autoclave was filled with the solution and was then de-aerated by the bubbling of purified nitrogen through it to give an oxygen concentration in the solution of less than 1 mg/l as measured with an Oxi-92 oxygen meter. The electrodes were then immersed in the solution, and the working electrode was cleaned by being polarized to a potential of -1 V (SSC) for 5 minutes, after which the potential was allowed to move freely. The reproducibility obtained with

Table I  
Nominal compositions of the materials used (in percentages)

Material	C	Mn	P	S	Si	Cr	Ni	Al	Ti	Mo
Type 304 stainless steel	≤ 0,08	≤ 2,00	≤ 0,045	≤ 0,03	≤ 1,00	18,00–20,00	8,00–10,50	–	–	–
Mild steel	0,08–0,16	1,75–2,25	≤ 0,025	≤ 0,025	0,05–0,25	≤ 0,015	≤ 0,15	≤ 0,03	–	–
3CR12	≤ 0,03	≤ 1,5	≤ 0,04	≤ 0,03	≤ 1,0	11–12	≤ 1,5	–	≤ 0,6	–

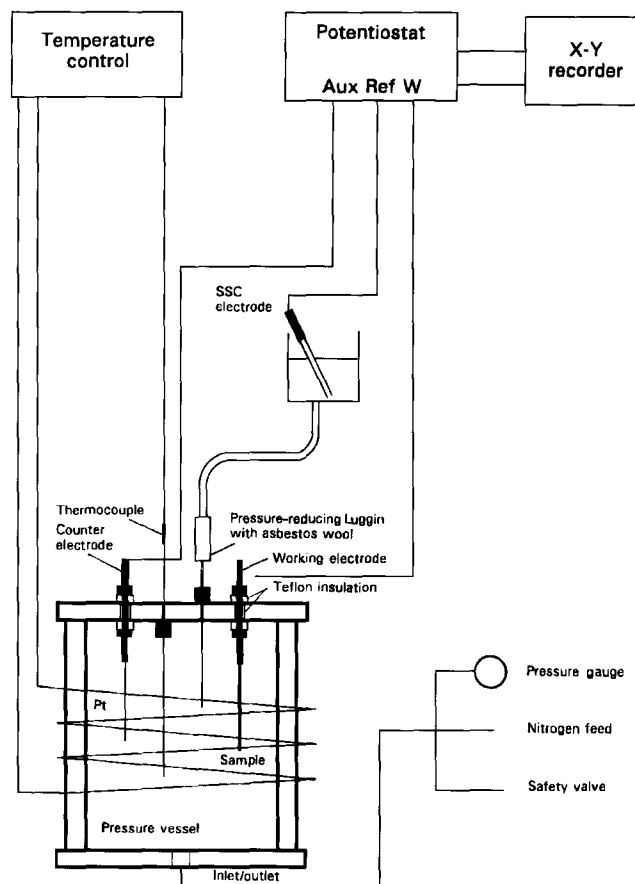
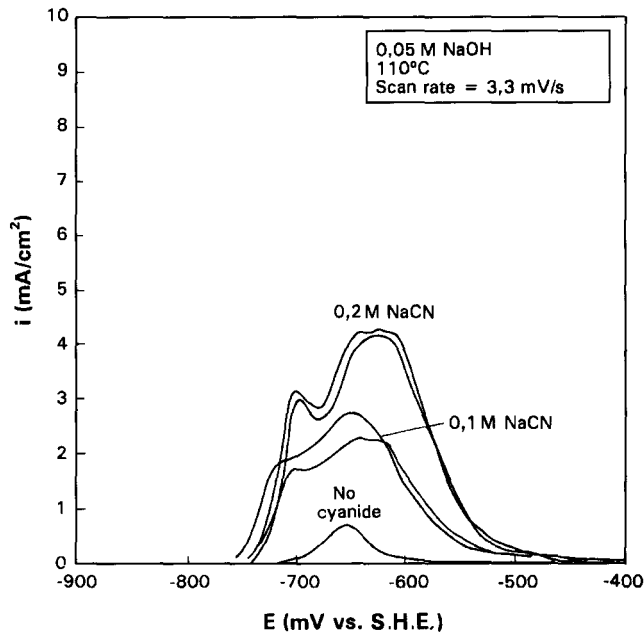


Figure 5—Schematic diagram of the experimental set up for the polarization studies

this treatment was found to be relatively good, as shown in Figure 6. The autoclave was heated immediately after this treatment, a heating rate of approximately 10°C per minute being achieved. The experiments were started after the temperature had stabilized to within 1°C of the set value, which took approximately 15 minutes from the time that the heating started. A model 176 Princeton potentiostat was used for the polarization experiments, which started at the corrosion potential, the potential then being scanned at a rate of 3,3 mV/s in the positive direction. The current-voltage curves were recorded continuously.

As the validity of the results would be affected if a significant loss of cyanide occurred due to hydrolysis, the loss of cyanide was determined during the experiments. To do this, a solution containing 0,2 M NaCN and 0,05 M NaOH was heated to a temperature of 130°C and maintained at that temperature for the duration of a normal experiment, which was approximately 5 minutes; after cooling, the solution was analysed. The loss of cyanide was found to be about 18 mass per cent. Because the conditions in these experiments were considered to be favourable for the hydrolysis of cyanide (high cyanide and low hydroxide concentrations), and because the normal polarization experiments needed shorter times at temperature, the loss of cyanide during the experiments was not considered to have seriously affected the results.

The activation behaviour of mild steel and the plating of gold from solutions made up in the laboratory and from Zadra eluate were evaluated with the steel in different initial conditions, and with and without oxygen in the



**Figure 6—Polarization diagrams for mild steel in cyanide solutions containing 0,05 M NaOH at a temperature of 110°C. The samples were pre-polarized at -1 V (SSC) for 5 minutes, and potential scanning was started from the open-circuit potential at a rate of 3,3 mV/s**

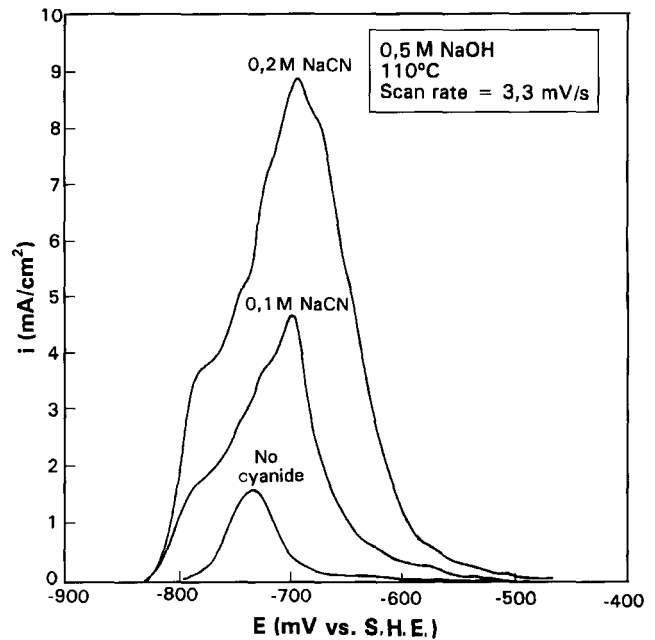
solution. Gold was added to all the solutions, including the Zadra eluate, to a concentration of 100 p.p.m of potassium aurocyanide. After the sample had been immersed in the solution, heating was started at a rate of 12,5°C per minute while the corrosion potential was recorded continuously.

## RESULTS AND DISCUSSION

### Influence of Sodium Cyanide and Hydroxide on the Dissolution of Mild Steel

The influence of cyanide and sodium hydroxide on the anodic polarization characteristics of mild steel at a temperature of 110°C are shown in Figures 6 and 7. In all cases, higher concentrations of either hydroxide or cyanide gave rise to an increase in the active peak current densities. In the case of the hydroxide, the lower potential boundary of the active peak is most probably due to the hydrogen reaction, while the upper boundary is defined by the hypoferrite-magnetite or hypoferrite-hematite boundaries, as indicated in Figure 2. The low current densities measured at higher potentials are due to the passivation of the mild steel by the formation of  $\text{Fe}_3\text{O}_4$ ,  $\text{FeOOH}$ , or  $\text{Fe}_2\text{O}_3$ . Consequently, no gold cementation would be expected at these potentials. At the higher concentrations of hydroxide, the active region moved down to lower potentials, as would be expected in view of the lower reversible potential for the hydrogen reaction at increased pH values. The anodic peak current also increased, probably due to the increased stability of the hypoferrite species (Figure 2) but, in view of this, it is surprising that the potential region was not expanded.

Cyanide additions caused the active potential region to expand, and increased the peak current densities significantly. This effect was more pronounced at higher hydroxide concentrations, but increased current densities were also noted at lower pH values. This is in contrast to



**Figure 7—Polarization diagrams for mild steel in cyanide solutions containing 0,5 M NaOH at a temperature of 110°C. The samples were pre-polarized at -1 V (SSC) for 5 minutes, and potential scanning was started from the open-circuit potential at a rate of 3,3 mV/s**

the results of Kenna *et al.*<sup>3</sup>, who found that cyanide inhibited the corrosion of steel at a pH value of 9. This discrepancy may have been due to the presence of potassium sulphate in the solution, which was used in the present tests to enhance the conductivity of the electrolyte. To investigate this, some experiments were conducted in cyanide-free solutions at pH 9 and 110°C with and without additions of  $\text{K}_2\text{SO}_4$ . The results are shown in Figure 8, from which the considerable anodic activity of mild steel in the solution containing potassium sulphate is immediately apparent, while the passivity was maintained in the absence of potassium sulphate. The potassium sulphate may facilitate other reactions on the surface of the steel, and the anodic activity may be due not to iron dissolution but to the decomposition of the electrolyte. However, the inactivity observed for the type 304 stainless steel (Figure 8) makes this less probable and strongly suggests that the anodic behaviour observed at pH 9 by Kenna *et al.*<sup>3</sup> can be ascribed to the dissolution of the mild steel facilitated by the potassium sulphate background electrolyte. At the higher hydroxide concentrations used in this study, there was no influence of sulphate on the results.

The increased anodic activity with an increase in cyanide concentration is probably due to the formation of a soluble iron cyanide complex that is stable in this potential region if the 25°C diagram (Figure 3) is taken as a guideline. It was considered that the anodic peak could also have been due to the oxidation of cyanide to cyanate, for which the equilibrium potential is close to that of hydrogen, and should therefore be thermodynamically possible at these potentials. However, the decrease in the rate at higher potentials is difficult to explain on this premise, as is the lack of activity found for the stainless steel (Figure 9). Another apparent feature of the anodic curves is the split in the curve that develops at higher cyanide concentrations. There is no obvious explanation for this and, in the view of the limited practical implications, it was not pursued.

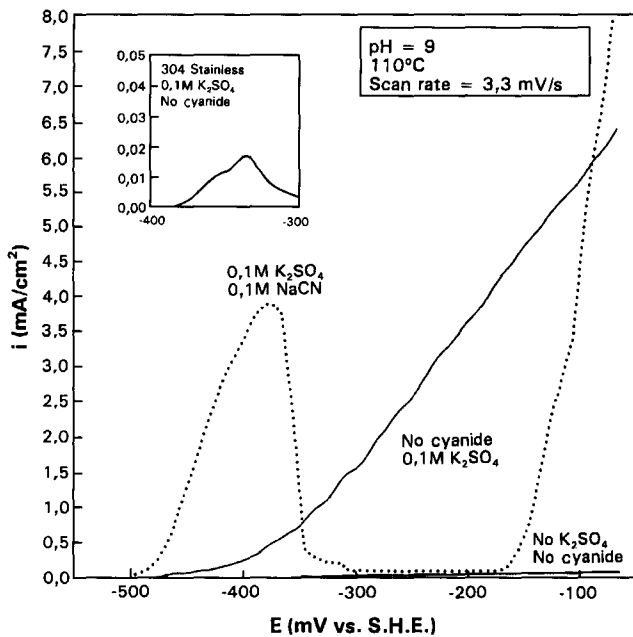


Figure 8—Polarization diagrams for mild steel in cyanide solutions at 110°C and a pH of 9 (measured at 25°C). The samples were pre-polarized at -1 V (SSC) for 5 minutes, and potential scanning was started from the open-circuit potential at a rate of 3,3 mV/s

An increase in temperature increased the active peak and expanded the active potential region to more negative values, as shown in Figure 10. The split in the anodic peak noted at the lower temperatures became more pronounced at higher temperatures. The small increase in the anodic peak with temperature indicates that the process is probably under diffusion control, as confirmed by the

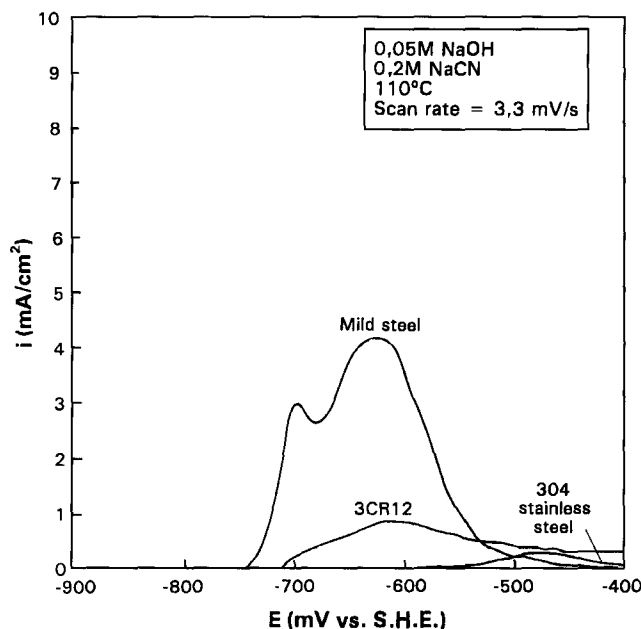


Figure 9—Polarization diagrams for mild steel, type 304 stainless steel, and 3CR12 in a solution containing 0,05 M NaOH and 0,2 M NaCN at a temperature of 110°C. The samples were pre-polarized at -1 V (SSC) for 5 minutes, and potential scanning was started from the open-circuit potential at a rate of 3,3 mV/s

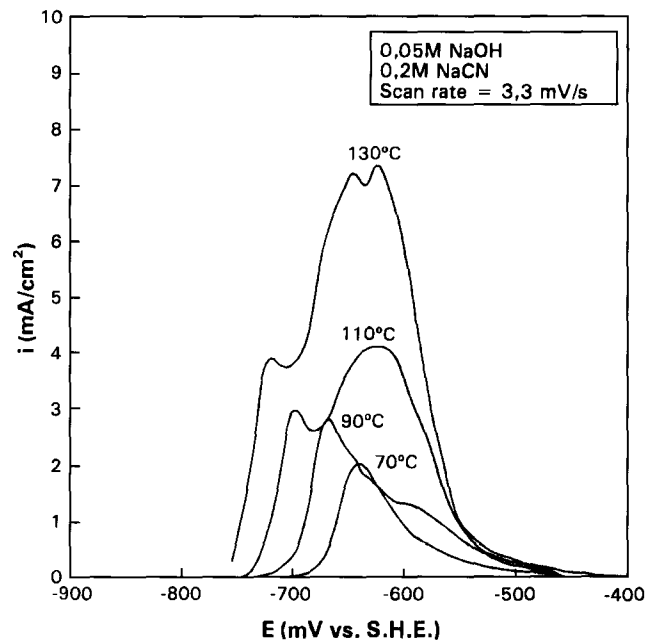


Figure 10—Polarization diagrams for mild steel in a solution containing 0,05 M NaOH and 0,2 M NaCN at various temperatures. The samples were pre-polarized at -1 V (SSC) for 5 minutes, and potential scanning was started from the open-circuit potential at a rate of 3,3 mV/s

relatively low activation energy of 25 kJ/mol calculated from the peak heights.

### Comparison of Mild Steel, Stainless Steel, and 3CR12

The polarization characteristics of type 304 stainless steel and 3CR12 in 0,2 M NaCN and 0,05 M NaOH are compared with that of mild steel in Figure 9. Type 304 shows much lower anodic current densities than mild steel under these conditions, which will facilitate passivation and make gold plating less likely. The 3CR12 appears to be more active than type 304, but less so than the mild steel and, while the lower potential boundary was close to that of type 304, the measured peak currents were significantly lower.

### The Plating of Gold

Since gold is readily available in an oxidized form as aurocyanide throughout the extraction process, the determining factor in the plating of gold is the active dissolution of iron. For steel in cyanide and hydroxide solutions at high temperature, the active state is stable for a wide range of conditions coinciding with normal elution conditions. The peak currents measured for mild steel are also relatively high, which makes the active dissolution of mild steel likely from a kinetic point of view. However, the isolated reports of gold plating found in practice does not support this, and it appears that steel may be protected by some or other coating of metastable oxide. The removal of this oxide, at least in part, appears to be necessary for activation of the mild steel.

To investigate this, the behaviour of mild steel and the plating of gold from solutions made up in the laboratory and from Zadra eluates were evaluated for the steel in different initial conditions with and without oxygen in the solution. Gold was added to all the solutions, including the Zadra eluate, to a concentration of 100 p.p.m. of potassium aurocyanide.

The variations in the potential of the samples with temperature are indicated in Figure 11. For the sample in the wet abraded condition that was exposed to a de-aerated solution containing 100 p.p.m. of potassium aurocyanide, the potential was initially at relatively positive values but decreased as the solution was heated. The sample was activated at approximately 90°C, and the potential decreased sharply to a value of -750 mV(SHE) and stayed at that potential for the duration of the experiment. The sample was gold in colour after the experiment, and EDAX analysis of the surface of the sample indicated that gold had indeed been plated on its surface. The steel sample etched in hydrochloric acid was active right from the beginning of the experiment before the heating started, even though the solution was not de-aerated prior to the experiment. Again, gold plating was noted at the end of the experiment. In the case of wet abraded specimens exposed to aerated solutions, the potential remained at noble values, and no gold plating was noted on the steel at the end of the experiments. In the case of the Zadra eluate, the potential moved to a positive value and no gold plating was observed even though the solution had been de-aerated. As the concentration of hydroxide in the solution was fairly high (4,2 mass per cent), the observed behaviour must have been due to the low concentration of cyanide (0,015 mass per cent), and this tentatively indicates that gold plating should not be a problem in these eluates.

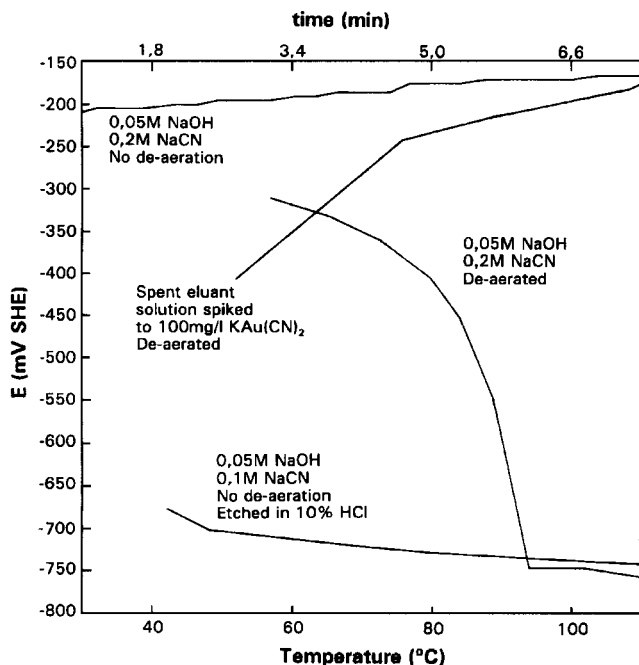
These results can be explained by a consideration of the polarization characteristics of gold and steel together. For gold plating on iron, the active region of the iron must coincide with the stability region of metallic gold, as was pointed out in the Introduction. If the data of Girardi *et al.*<sup>12</sup> are taken as a guideline, the transition from the cyanide complex to metallic gold occurs at approximately

-500 mV(SHE), which means that gold plating is possible at the lower potentials measured for steel in this investigation. The kinetics of gold precipitation onto metals has been investigated in the past, and data are available for reagent concentrations similar to those investigated here, although only at lower temperatures. If it is assumed that significant gold plating will occur when the current density for the gold cathodic reaction is 0,1 mA/cm<sup>2</sup>, the data of Oo and Tran<sup>15</sup> (500 p.p.m. of gold, 40°C) indicate that this current density will be achieved at approximately -660 mV(SHE), which is close to the anodic peak for the dissolution of iron. The precipitation of gold is thus highly likely, although the gold reaction may be depolarized to such an extent at the higher temperatures that it may passify the iron surface.

This is certainly a possibility if the decrease in the activation polarization found by Oo and Tran<sup>15</sup> between 10 and 40°C is taken as a guideline, but passivation is possible only if the anodic peak current density of the iron is lower than the cathodic current density for the gold-reduction reaction that is likely to occur at low concentrations of hydroxide and cyanide and at lower temperatures. At higher concentrations and temperatures, the active peak for iron will be so high that depolarization of the cathodic reaction will result only in higher rates of gold deposition. This last statement must be qualified in the sense that some degree of metastability may exist in the system, and that the free potential or corrosion potential attained by the steel will depend very much on the initial conditions, as has already been pointed out. For example, when the sample was etched in acid or heated in oxygen-free water, the potential stayed fairly negative for the duration of the experiment. If the heating was done in the presence of oxygen, the potential moved in a positive direction and stayed there. For these passified specimens, the current density of the cathodic gold-plating reaction is likely to be higher than the anodic current density, and the positive shift in the corrosion potential with an increase in temperature may be a result of the depolarization of the cathodic reaction at higher temperatures.

The way in which the reactions possibly interact to cause this behaviour can be illustrated by a schematic Evans diagram, as shown in Figure 12. The important feature is that three corrosion potentials are possible for this system, of which the most negative and the most positive potentials are likely to be fairly stable. In this type of system, the corrosion potential depends on the surface condition of the metal and on the solution conditions during the initial stages of the experiment.

Where the conditions are such that the system will be at the more positive potential initially, e.g. a stable film present on steel or conditions conducive to film formation before high temperatures are reached, the metal will tend to stay at that potential. Very little corrosion of steel and no plating of gold will take place, since the steel will be passive and the aurocyanide complex will be stable at that potential. If the conditions change so that the system is no longer stable at the positive potential, e.g. by a decrease in the oxygen concentration, the system will tend to move to more negative potentials, at which the plating of gold will be possible. Another possibility is that the steel is initially in the active state, or becomes so by the removal of its



**Figure 11—Open-circuit potentials (corrosion potentials) obtained for samples of mild steel in the conditions and solutions at the temperatures indicated. The time scale at the top gives the approximate time it took for the samples to be heated to the required temperatures**

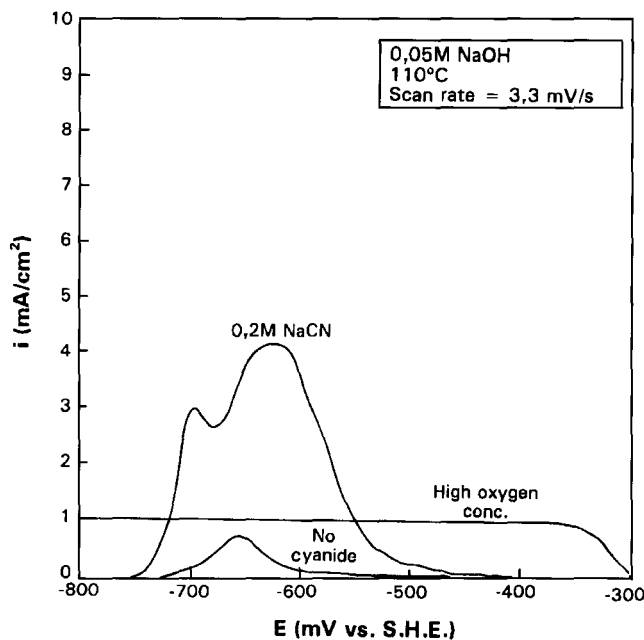


Figure 12—Evans diagram for steel in solutions containing NaOH, NaCN, and oxygen

surface layer. This will similarly result in more negative potentials and gold plating, with the difference that the potential will tend to move to more positive values once the defect is covered with gold, which will then once again dissolve. The only negative aspect of this will be that some iron will be dissolved during each of these cycles, which may result in some thinning of the wall of the vessel.

### CONCLUSIONS

The tendency of gold to be cemented onto steel is determined by the thermodynamic stabilities of both the steel and the gold. These indicate that gold cementation will be more probable if either or both the hydroxide concentration and the temperature are increased. An increase in cyanide concentration will favour the dissolution of iron, but will also stabilize the aurocyanide ion.

The kinetics of gold cementation are determined by the rate of diffusion of the aurocyanide ion to the reaction interface and/or by the anodic activity of the steel. The anodic activity of the steel increases with increasing hydroxide and cyanide concentration in the high-temperature solutions typically found under elution conditions.

In solutions at high temperature, the potential region in which the steel is in the active state is such that the plating of gold from solutions containing aurocyanide is possible. However, the steel will passify at higher potential values, where the aurocyanide complex is stable and plating will be unlikely.

The characteristics of the Au-Fe-CN-H<sub>2</sub>O system are such that the system may be metastable at various potentials, depending on the initial condition of the steel surface and the exposure conditions. The initial presence of strong oxidants, such as oxygen, in solution will move the potential into the passive region, and limited dissolution of iron and no gold plating will take place, even if the system later moves to more aggressive conditions. Consequently, the cementation of gold onto the iron will take place only if

the passive layer on the steel is removed by a reducing environment such as de-aerated solution, or by pickling in acid, or by mechanical damage.

The nature of the gold plated onto the steel during excursions to negative potentials, for example because of damage to the surface or a decrease in the concentration of oxygen, will determine whether the cementation of gold will continue, or whether the system will start to oscillate between gold plating and dissolution. Dendritic deposits that typically form at low concentrations will favour continued dissolution, while compact deposits will favour alternating plating and dissolution.

Type 304 is much less reactive than mild steel in solutions containing cyanide and caustic soda, and gold plating onto its surface is unlikely. The same can generally be expected for 3CR12, although it is slightly more reactive than type 304.

From a practical point of view, gold plating on steel can be avoided by

- keeping the solution saturated with oxygen
- avoiding damage to the passive layer on the steel as a result of contact with acid or mechanical abrasion
- avoiding high concentrations of either cyanide or caustic in the solution, or avoiding high temperatures; these factors will not give rise to plating in itself, but will favour plating in the case of damage to the passive layer on the steel.

### ACKNOWLEDGEMENTS

The financial and other assistance provided by Genmin Process Research, especially Dr D.A. Holtum, during the course of this work is gratefully acknowledged.

### REFERENCES

1. DAVIDSON, R.J., BROWN, G.A., SCHMIDT, C.G., DUNCANSON, D., and TAYLOR, J.D. The intensive cyanidation of gold-plant gravity concentrates. *J. S. Afr. Inst. Min. Metall.*, Jan. 1978. pp. 146-165.
2. BAILEY, P.R. Application of activated carbon to gold recovery. *The extractive metallurgy of gold in South Africa*. Stanley, G.G. (ed.). Johannesburg, The South African Institute of Mining and Metallurgy, 1987. pp. 379-614.
3. KENNA, C.C., RITCHIE, I.M., and SINGH, P. The cementation of gold by iron from cyanide solutions. *Hydrometallurgy*, vol. 23. 1990. pp. 263-279.
4. POURBAIX, M. *Atlas of electrochemical equilibria in aqueous solutions*. NACE, 1974. pp. 307-321.
5. STRATMANN, M. The atmospheric corrosion of iron—a discussion of the physico-chemical fundamentals of this omnipresent corrosion process. Invited review. *Ber. Bunsenges. Phys.Chem.*, vol. 94. 1990. pp. 626-639.
6. ASHWORTH, V., and BODEN, P.J. Potential-pH diagrams at elevated temperatures. *Corrosion Science*, vol. 10. 1970. pp. 709-718.
7. BROOK, P.A. A computer method for calculating potential-pH diagrams. *Corrosion Science*, vol. 11. 1971. pp. 389-396.
8. MACDONALD, D.D. The electrochemistry of metals in aqueous systems at elevated temperatures. *Modern aspects of electrochemistry*, no. 11. Conway, B.E., and Bockris, J.O'M. (eds.). Plenum, 1974. pp. 141-197.
9. TOWNSEND, H.E. Potential-pH diagrams at elevated temperature for the system Fe-H<sub>2</sub>O. *Corrosion Science*, vol. 10. 1968. pp. 343-358.
10. UHLIG, H.H. *Corrosion handbook*. Wiley, 1948. pp. 129-135, 636-638.

11. OSSEO-ASARE, K., XUE, T., and CIMINELLI, V.S.T. Solution chemistry of cyanide leaching systems. *Precious metals, mining, extraction and processing*. Kudryk, V., Corrigan, D.A., and Liang, W.W. (eds.). TMS-AIME, 1984. pp. 173-197.
12. GIRARDI, S.C., ALRUIZ, O.M., and ANFRUNS, J.P. Pressure cyanidation: An option to treat refractory gold. *Productivity and technology in the metallurgical industries*. Koch, M., and Taylor, J.C. (eds.). The Minerals, Metals and Materials Society, 1989. pp. 627-637.
13. ADAMS, M.D. The chemical behaviour of cyanide in the extraction of gold. Part 2. Mechanisms of cyanide loss in the carbon-in-pulp process. *J. S. Afr. Inst. Min. Metall.*, vol. 90, no. 3. Mar. 1990. pp. 67-73.
14. DAVEY, L.M. Elutions without cyanide. *MMMA Circular No.2/91*, Mine Metallurgical Managers' Association of South Africa, Dec. 1991. pp. 85-93.
15. OO, M.T., and TRAN, T. The effect of lead on the cementation of gold by zinc. *Hydrometallurgy*, vol. 26. 1991. pp. 61-74.

## Estimator reduces gold losses\*

An instrument developed by Mintek for the estimation of particle size in milling and classification circuits will assist greatly in minimizing the costly losses of insoluble gold during the processing of Witwatersrand ores.

The system is centred on a microprocessor-controlled particle-size estimator (PSE) that uses the signal from Mintek's hydrocyclone-underflow meter (HUM) to calculate the particle size of the cyclone overflow in terms of the percentage passing a certain size.

Advantages of the PSE over comparable commercial instruments include its

- high accuracy and reliability
- low capital and maintenance costs
- ability to read directly the size fraction of interest.

Unlike other on-line methods for particle-size measurement, which rely on the taking of a representative sample

\* Issued by Mintek, Private Bag X3015, Randburg, 2125.

from a slurry, the PSE uses a signal taken from the entire stream. This avoids inaccurate readings caused by non-representative samples, as well as the use of complex sampling mechanisms.

The cost of the PSE is very competitive and, owing to its simplicity, the system needs very little maintenance. Once it has been set up, routine calibration can easily be done by plant personnel. Another major advantage is that the PSE can be calibrated for any particle size; for example, as most losses of insoluble gold occur in the fraction larger than 150 µm, it is advantageous to have a direct reading of this parameter.

The PSE system, which forms part of Mintek's hydrocyclone-underflow meter package, can be used as a stand-alone particle-size system, or can be incorporated in Mintek's more comprehensive multivariable-control (MVC) package for the optimization of milling circuits.

## Engineering Faculty calls for more bursaries\*

The Faculty of Engineering at the University of the Witwatersrand has expressed concern at the marked decline in the number of bursaries being offered to students by industry.


'Bursaries are generally in very short supply', says Professor Roy Adams, Dean of the Engineering Faculty. 'In particular, middle-class students whose parents cannot afford to send them to university are losing out because bursaries are no longer being offered to them'.

He adds that the shortage of bursaries is contributing towards an alarming decline in student numbers. 'Industry

should be taking a longer-term view of the engineering profession. The students we have in 1993 will be the staff you have—or do not have if numbers continue to decline—in 2001.'

Bearing in mind the cash-strapped position in which industry finds itself, Professor Adams suggests that companies need not consider the all-inclusive bursaries that were expected in the past. All that is needed is a bursary to cover fees and an allowance for books. If necessary, the bursar could then raise a loan to cover additional expenses. He adds that, although employment of the bursar by the sponsoring company on completion of his or her studies has often been obligatory in the past, there is no need for the bursary to be linked to a job.

\* Issued by Lynne Hancock Communications, P.O. Box 3712, Honeydew 2040.

	<p><b>XV CONGRESS OF THE COUNCIL OF MINING AND METALLURGICAL INSTITUTIONS</b></p> <p><b>24-29 April 1994</b></p> <p>Bill Emmett, Congress Manager, 15th CMMI Congress, P O Box 809, Johannesburg 2000, South Africa. Telephones: (27) (11) 838-8211 (office), (27) (11) 788-2518 (home) Fax: (27) (11) 834-1884.</p>
---	--