InLine Leach Reactor Benefits For Cu-Au Concentrates

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Abstract. This paper summarises the cyanide consumption and copper and gold leaching kinetics from the vast number of intensive leach tests that have been carried out at Gekko Systems Pty Ltd's Ballarat laboratory. It has been found that copper leaches preferentially to gold and that a sodium cyanide addition in excess of 4 moles of cyanide to 1 mole of soluble copper is required to ensure high gold leach recovery. The results of the tests also indicated that gold could be produced for less than A$100/ contained ounce (excluding the value of the copper or detoxification) for ores containing >1500 g/t gold even with up to 18% soluble copper. A process to selectively recover the gold from the copper/gold pregnant leach solution is proposed using the Gekko Resin Column and AuRIX® 100 weak base ion exchange resin.

1. INTRODUCTION

Over the past six years the staff of Gekko Systems Pty Ltd (Gekko) have undertaken numerous intensive leach tests of gravity and flotation concentrates containing varying concentrations of gold and copper. This paper collates the gold and copper leach recovery and cyanide consumption data for those tests and discusses the correlation between soluble copper concentration, cyanide consumption and gold recovery. Also, the economics of leaching gold/copper concentrates is discussed.

A process for selectively recovering gold from a gold/copper leach solution using the weak base ion exchange resin AuRIX® 100 is proposed.

1.1 Copper Leach Theory

The leaching of copper minerals in cyanide solutions has been previously described [1] as following the reactions given below:

$$Cu + 2NaCN \leftrightarrow 2NaCu(CN)_2$$

$$2NaCu(CN)_2 \leftrightarrow CuCN + Na_2Cu(CN)_3$$

$$Na_2Cu(CN)_3 + NaCN \leftrightarrow Na_3Cu(CN)_4$$

Based on the above it is possible to leach copper at CN:Cu molar ratios from 2 to 1 to 4 to 1. The amount of cyanide required to be added to ensure an excess is available for gold leaching was determined as part of the Gekko test work.

2. THE INLINE LEACH REACTOR

The Inline Leach Reactor (ILR), designed and manufactured by Gekko in Ballarat, Victoria, Australia, is used extensively throughout the gold industry for the leaching of gold concentrates with over 40 units installed worldwide. The ILR (see Figure 1) has been described by others [2] and involves the following process steps:

- Gravity and/or flotation concentrate is de-watered in the feed cone before being fed into the reactor drum.
- Fresh reagents are added to the solution cone (The volume of the solution cone can be designed to ensure the optimum solution/solids ratio can be achieved).
- The leach solution is circulated through the reactor drum and is recycled back to the solution cone.
- The solution undergoes electrowinning or absorption onto activated carbon or resin before being re-used in the leaching process.
- The solid tails are washed (either with barren solution or fresh water) and returned to the ball milling circuit or to final tails as required.

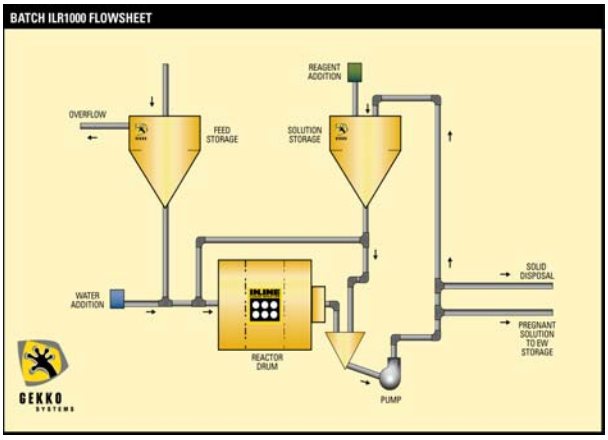

Figure 1: Gekko Inline Leach Reactor

The ILR incorporates unique mass transfer zones to ensure high rates of transfer between the solid, liquid and gas zones as shown in Figure 2.

The demonstrated benefits of the ILR include:

- No fines loss.
- Rolling drum chemistry.

- Good agitation, attrition and mixing.
- No gold plating onto steel scats due to the continuous high oxygen environment.
- Secure access to concentrate.
- Controlled inlet rate.
- High solution to solids ratio if required.
- Available fully automated.

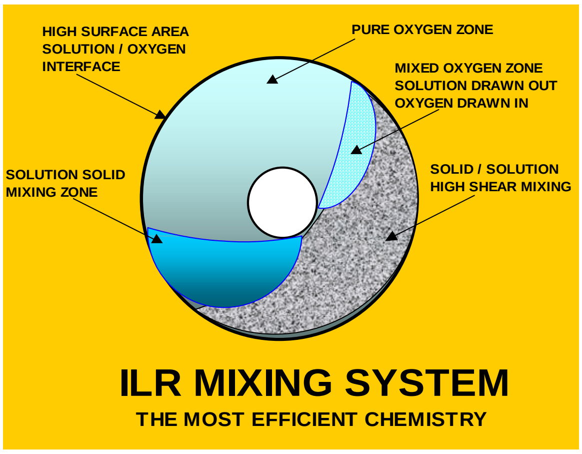

Figure 2: ILR mass transfer zones within the reactor drum

3. COPPER/GOLD LEACH TESTWORK

Gekko has performed extensive intensive cyanidation leach tests on ores and concentrates from all over the world. This has produced a large database of leach data. This section summarises the results of leach test work on samples containing concentrations of copper up to 30% and gold up to 35,000 g/t.

3.1 Methods Used

As mentioned in section 2.0, the ILR has the ability to operate at low % solids, which enables high cyanide and oxygen addition rates. The agitation and mixing characteristics are similar to a conventional rolling bottle test. Some of the following leach tests were carried out in rolling bottles whilst others were carried out in either a lab-scale unit (Figure 3) or an 1 tonne industrial batch unit, the ILR100 (Figure 4).

Figure 3: Lab-scale ILR

Figure 4: ILR100 Industrial Unit

3.2 Case Studies

The results from a select number of leach tests are discussed in this section.

Case Study 1 - Very High Gold Grade Gravity Concentrate

This concentrate, grading 35,000 g/t gold and 7% copper, was leached in the Lab-scale ILR. Figure 5 shows the gold and copper leach kinetics and reveals fast copper leach kinetics and slow gold leach kinetics though overall gold leach recovery was excellent at 98%.

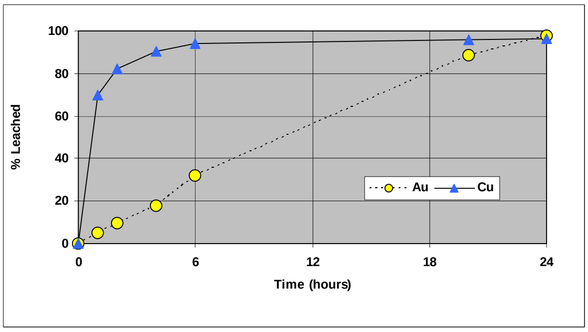

Figure 5: Case Study 1 copper and gold leach kinetics

The target sodium cyanide concentration was 3.5% but in most cases the cyanide added was totally consumed between readings which limited the gold leach rate. Cyanide consumption was high at 300 kg/t.

Case Study 2 – Copper Flotation Concentrate

Four hundred kilograms of this concentrate, grading 70 g/t gold and 30% copper, was leached in the ILR100. Figure 6 shows the gold and copper leach kinetics and in this case, gold leaching (94%) was a lot faster than copper leaching (45%) due to the presence of some slow leaching copper minerals (eg. Chalcopyrite).

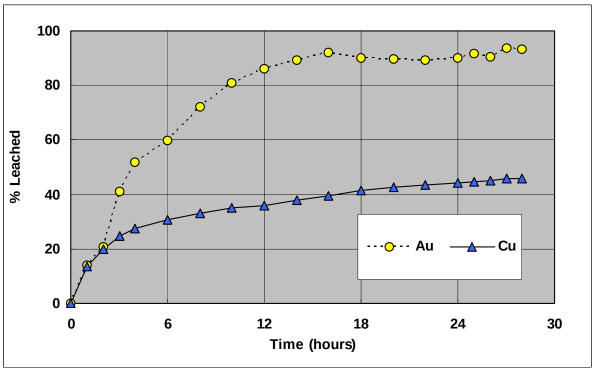

Figure 6: Case Study 2 copper and gold leach kinetics

The target sodium cyanide concentration was 2% and 518 kg/t was consumed by the concentrate.

Case Study 3 – Gravity Concentrate

100 g of concentrate, grading 1,800 g/t gold and 4% copper, was leached in a rolling bottle. Figure 7 shows the gold and copper leach kinetics. Gold leaching was again slower than copper but both reached high levels (95% gold and 96% copper).

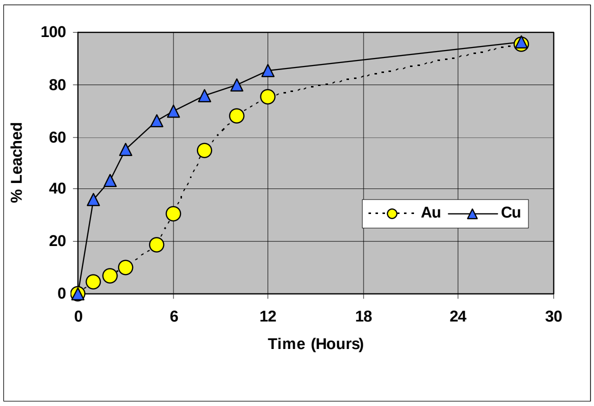

Figure 7: Case Study 3 copper and gold leach kinetics

The sodium cyanide concentration target was 1% whilst consumption was 160 kg/t, which is in line with the lower copper concentration.

Case Study 4 – Medium Grade Flotation Concentrate

400 kg of this concentrate, grading 200 g/t gold and 32% copper, was leached in the ILR100. Leach kinetics are shown in Figure 8 and reveal high recoveries for both gold and copper (98% and 99% respectively) but the copper leach kinetics were significantly faster than the gold kinetics.

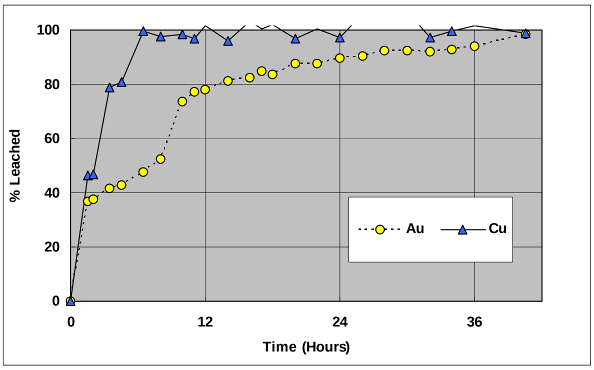

Figure 8: Case Study 4 copper and gold leach kinetics

The copper was predominantly found as free copper and chalcocite both of which are readily leachable [1]. Sodium cyanide consumption was very high at 800 kg/t from a target concentration of 5%.

Case Study 5 – "Low Grade" Flotation Concentrate

400 kg of flotation concentrate, grading 90 g/t gold and 2% copper, was leached in the ILR100. Leach and copper kinetics are shown in Figure 9.

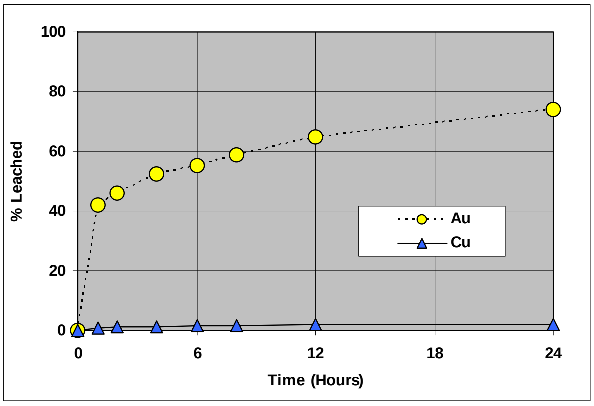

Figure 9: Case Study 5 copper and gold leach kinetics

In this case there was very little copper leached due to it all being associated with chalcopyrite. Gold recovery was limited to 74% due to poor liberation (The sample was leached "as received").

Sodium cyanide target concentration was 1% and consumption was only 15 kg/t which is a reflection of the low soluble copper levels in the concentrate.

4. RESULTS

Generally the tests that have been undertaken have shown that copper is leached preferentially to the gold. Other conclusions regarding the amount of cyanide required to ensure high gold recovery and the economics of leaching copper/gold concentrates are discussed below.

4.1 Cyanide Addition Versus Gold Recovery

The results from all the tests discussed above and other tests undertaken by Gekko were analysed. The amount of cyanide soluble copper in the sample and the amount of cyanide consumed were compared to determine if a relationship exists between these two factors and gold recovery.

As mentioned in the Introduction, $Cu(CN)_x^{(x-1)-}$ can exist as $Cu(CN)_2^-$, $Cu(CN)_3^{2-}$ and $Cu(CN)_4^{3-}$. As the leaching of copper gold concentrates is typically carried out at high pH (+12) due to the pH modifying affect of the added NaCN, and in excess cyanide, it is expected that the copper will be present as $Cu(CN)_4^{3-}$ [3].

The theoretical cyanide consumption of the samples tested was assumed to be based on four moles of CN^- per mole of Cu and can be calculated from the formula:

Theo CN Cons = Wt Cu in Soln / MWt Cu * MWt NaCN * 4

= Wt Cu in Soln/63.5*49*4

where MWt = molecular weight.

The ratio of actual cyanide consumption to theoretical consumption was then plotted against gold recovery in Figure 10.

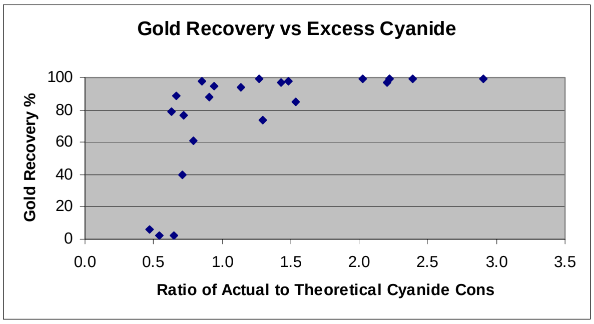

Figure 10: Gold recovery versus excess cyanide

As revealed in Figure 10, to ensure a high recovery of gold, a ratio of actual Cyanide Consumption to Theoretical Cyanide Consumption greater than 1.0 is required. The data also indicates that in a number of tests excess cyanide was required which is most likely due to the presence of other cyanicides (eg. S) in the sample.

4.2 Economics of Intensive Leaching Copper/Gold Concentrates

For a number of the leaches with high gold recovery, the financial benefits of leaching the concentrate are given in Table 1. The critical assumptions used to determine the operating costs were:

Gold Price = A$550/ounce

Copper Price = US$1.50/lb = A$4.35/kg

NaCN cost = A$2.00/kg

No detoxification costs.

Table 1: Financial analysis of leaching copper/gold concentrates

Sample #	Head Grade			Leached		Cyanide	Op Cost
	Au g/t	Cu %	CN Sol Cu%	Au%	Cu%	Act kg/t	$/cont. oz
1	35000	7	6.6	98	90	302	12
2	70	30	15	94	45	518	793
3	134	4	3	99	99	187	131
4	1547	18	17	95	96	503	63
5	1663	5	4.6	99	90	314	21
6	93	20	0.4	74	2	15	159

The operating cost has been calculated from the equation:

Op Cost = (oz gold leached/t*$550/oz – kg NaCN consumed/t*$2/kg - kg Cu leached/t*$4.35/kg) / (Gold head grade g/t * 31.1035 g/oz)

It was assumed that the copper leached was not recovered. The recovered value of the leached copper and the possible detoxification costs need to be taken into account in any rigorous financial analysis.

As can be seen from Table 1, +95% of the gold can be leached at an operating cost of less than A$100/contained oz at gold grades >1,500 g/t despite high soluble copper levels and cyanide consumptions. Even for concentrates as low as 150 g/t gold, it is possible to recover the gold for <A$150/oz if the soluble copper concentration is less than 3%.

These $/contained oz operating costs need to be compared to the treatment costs and smelter returns from copper smelters and the time delay in being paid for the gold content to see if this is a viable treatment route.

The costs associated with detoxification and loss of leached copper could be overcome with some of the newer cyanide detoxification/recovery technologies such as copper electrowinning [3] or MNR/SART but requires further investigation on a site by site basis.

5. USING AURIX® 100 RESIN

Once the gold and copper have been leached, the first priority is to recover the most valuable component, gold, from the mixture. At the cyanide concentrations and pH's used for intensive leaching (+12), AuRIX 100® (AuRIX), a weak base ion exchange resin, is ideally suited as described below.

AuRIX[1] has been introduced to the gold industry in numerous papers [4], [5], hence a quick summary only will be presented here.

AuRIX is a weak base resin using a guanidine, a quaternary amine, functional group to produce selectivity for gold over other metals. This selectivity is best demonstrated in Figure 11 which shows the pH isotherms for the organic solvent LIX79 (also produced by Cognis) which consists of the same functional group as AuRIX.

[1] AuRIX 100 is the registered trademark of Cognis Corporation and is exclusively licensed to Gekko Systems Pty Ltd.

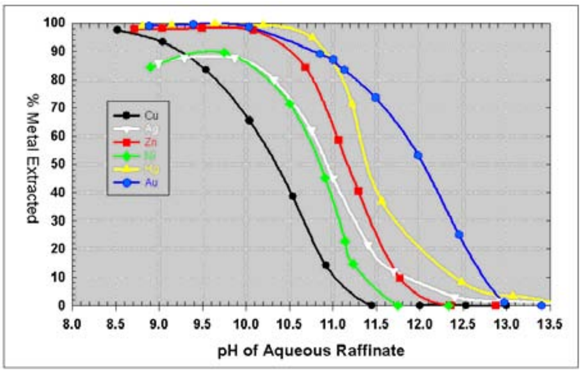

Figure 11: pH Isotherms indicating the selectivity of the Guanidine complex (LIX79) used in AuRIX resin [4]

The isotherms for AuRIX are typically not as sharp as the ones shown above and are moved approximately 0.5 pH units to the right.

By manipulating the pH of the pregnant leach solution it is possible to selectively absorb gold in a much greater proportion to the copper.

The pH isotherms also indicate the simplicity of the stripping process for AuRIX. It is one of the simplest elution methods requiring a 40 g/L NaOH (ie. pH 14), 70 g/L sodium benzoate (only required to increase the kinetics), 200 ppm NaCN solution at 60°C to recover the absorbed elements off the resin. This makes the resulting stripping circuit very simple.

No regeneration of the resin is required before re-use in the absorption circuit except for an occasional dilute acid wash to remove precipitated carbonates.

5.1 Case Study – Brown's Creek

Gray and Katsikaros [5] reported that the absorption of gold by 200 g/L AuRIX resin from a 4,000 ppm gold, 11,000 ppm copper solution at pH13.1 followed the absorption curve given in Figure 12.

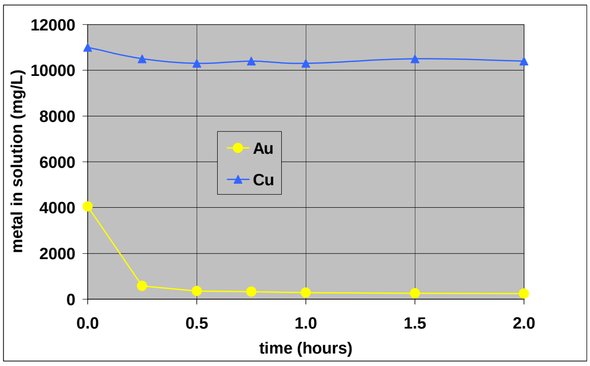

Figure 12: Copper/gold Absorption curves for Brown's Creek gold/copper solution

95% of the gold was recovered within the first hour. Some copper was initially absorbed but was displaced from the resin over time by the hydroxide ions in solution. These tests showed the high selectivity of AuRIX for gold over copper at high pH.

5.2 Gekko Resin Column

Gekko has recently developed a multi-staged pulsed reactor, called a Gekko Resin Column, to fully utilize the properties of AuRIX resin. The column has been developed specifically for solutions containing solids such as those produced by an ILR.

The Gekko Resin Column is shown in Figure 13 and consists of a series of four compartments which are loaded with AuRIX resin. The compartments in the column are separated by 400 µm wedge wire screens to contain the resin within the compartment. Pregnant leach solution flows down the column. A pulse is generated by a hydraulic ram operating on a diaphragm in the side of the column to create turbulence within the column. This ensures intimate resin/solution contact and allows near size solid particles to work through the resin beds and screens to tails.

The resin is transferred into, up and out of the column with eductors using barren leach solution as the motive water.

The Gekko Resin Column and the simple elution process described previously have been combined into a simple modular system as shown in Figure 14. This system allows ILR pregnant leach solution to be processed in a relatively low cost, small footprint treatment plant.

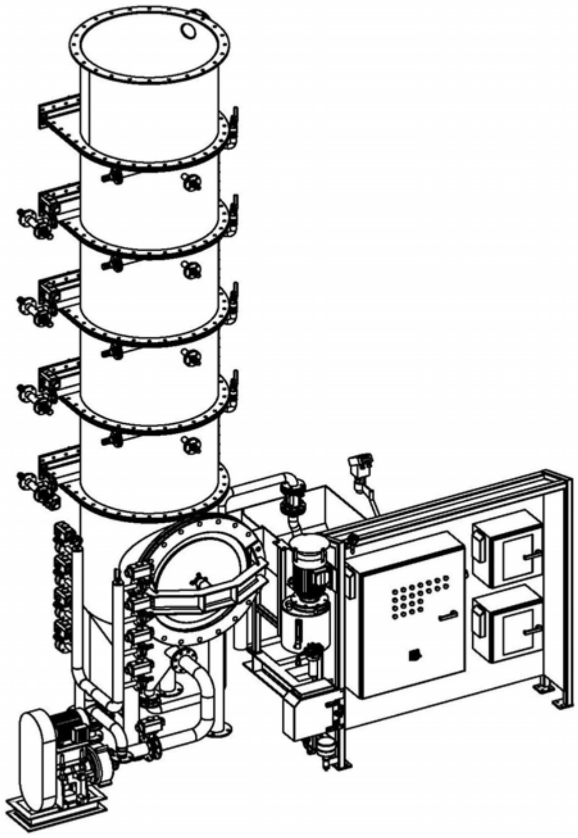

Figure 13: The Gekko Resin Column

Figure 14: A recently constructed Gekko Resin Column, resin stripping and electrowinning circuit

Figure 14 shows a plant constructed to process the solution from a continuous ILR5000 (5 tph of concentrate) and is designed to recover up to 50,000 oz gold per annum.

6. CONCLUSIONS

Test work carried out at Gekko Systems Pty Ltd's Ballarat laboratory has demonstrated that high gold leach recoveries are achievable from high copper grade copper/gold concentrates. A cyanide to soluble copper ratio in excess of 4 moles of cyanide to 1 mole of copper was found to be required to ensure high gold leach recovery during intensive leaching.

It was also found that concentrates containing greater than 1,500 g/t gold could be treated for less than A$100/contained oz (excluding detoxification costs) despite soluble copper concentrations of up to 18%.

Gekko Systems Pty Ltd has developed a multi-stage pulsed reactor, the Gekko Resin Column, for use with the weak base ion exchange resin AuRIX® 100 to selectively absorb gold from gold/copper solutions produced by an Inline Leach Reactor.

REFERENCES

1. Hedley, N. & Tabachnick, H. "Copper in Cyanidation," *Mineral Dressing Notes, Issue No. 23,* American Cyanamid, 1955.
2. Gray, A.H. & Katsikaros, N. (1999) "The Inline Leach Reactor – The New Art in Intensive Cyanidation of High Grade Centrifugal Gold concentrates.", *Randol Gold and Silver Forum,* Denver, May 1999.
3. Breuer, P.L., Jeffrey, M.I. & Dai, X. (2005) "Leaching and Recovery of Copper During the Cyanidation of Copper Containing Gold Ores.", *Treatment of Gold Ores, First International Symposium, 44th Annual Conference of Metallurgists of CIM,* Calgary, Alberta, Canada, August 2005.
4. Virnig, M.J, MacKenzie, J.M.W. & Adamson, C. (1996) "The Use of Guanidine-based Extractants for the Recovery of Gold", *Hidden*

Wealth, Johannesburg, South African Institute of Mining and Metallurgy, pp. 151 – 156.

5. Gray, A.H., Katsikaros, N. & Fallon, P. "Gold Recovery from Gold Copper Gravity Concentrates using the Inline Leach Reactor and Weak-Base Resin." *Processing of Gold-Copper and Copper-Gold Ores, Oretest Colloquium '99,* Scarborough, November 1999.