The Use of AuRIX®100 Resin for the Selective Recovery of Gold and Silver From Copper, Gold and Silver Solutions

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ABSTRACT

The selective recovery of gold and silver from solutions containing other metals, such as copper, is possible using AuRIX®100 resin in conjunction with the Gekko Resin Column. Selectivity is driven by controlling the solution pH, which enables activities such as loading copper, gold and silver and then selectively stripping copper before gold and silver. Alternatively gold and silver can be loaded and the copper left in solution. The selective loading of gold while reducing the silver loading has also been demonstrated, opening the possibility of producing high grade gold doré from high grade silver pregnant leach solutions. This paper reviews the AuRIX®100 resin and Gekko Resin Column Technologies, discusses the uses of AuRIX®100 in the recovery of gold and silver and the chemistry relating to several projects for which AuRIX®100 is being tested.

INTRODUCTION

Gekko Systems

Gekko Systems specialises in the design, development and distribution of innovative mineral processing equipment and systems with a particular focus on gravity separation for the gold and diamond industries. The company, which has been around since 1996, has five main products: the InLine Pressure Jig, the InLine Spinner, the InLine Leach Reactor (ILR), Gekko Resin Column and Modular Systems.

The InLine Leach Reactor is an intensive cyanidation reactor that uses high cyanide (0.5 - 2 per cent NaCN) and high oxidant (20 ppm dissolved oxygen as O_2 or hydrogen peroxide) to dissolve gold from medium and high-grade gravity or flotation concentrates. The ILR, which typically replaces a shaking table in the gold room, is available in both batch and continuous models. There are 42 installations worldwide. Further details on this technology can be found in papers written by Gray *et al* (2003) and Longley, McCallum and Katsikaros (2003). By replacing a shaking table with an ILR, the overall gravity and plant recoveries can be increased significantly. Other advantages include reduced security risks, lower operating costs, reduced operator involvement due to the automatic process and increased safety for gold room operators.

A large number of gold deposits contain high concentrations of copper or other base metals. In many cases it is economical to leach the material. Leach conditions in the ILR can be modified to minimise the solubility of these metals; however, the dissolution of unwanted species cannot be stopped altogether. Copper, in particular, can be quite troublesome as it can significantly increase the amount of cyanide consumed during the leaching process and will affect the efficiency of the electrowinning process as well as the quality of the doré bar produced. Research has shown that copper generally leaches first and then gold and that the cyanide addition must be greater than 3 kg NaCN:kg Cu to ensure high gold dissolution (Hughes and Gray, 2005).

Selective absorption with AuRIX®100 resin can be used to reduce the amount of copper going into the electrowinning circuit.

AuRIX®100 Resin†

AuRIX®100 resin is a cross-linked polystyrene alkaline resin functionalised with an active guanidine group. The general chemical structure is provided in Figure 1. The resin beads are tan in colour and spherical in shape with a nominal size of 100 per cent +600 µm (Figure 2). Extensive testwork by Cognis Corporation (Virnig and Mackenzie, 1998) has shown that the beads are resistant to breakdown and fouling and do not require thermal regeneration. Other advantages include rapid absorption kinetics and competitive capital and operating costs (Virnig and Mackenzie, 1998).

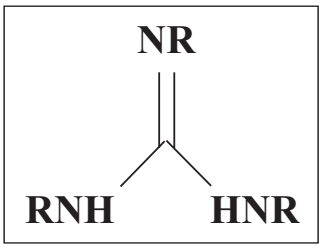

FIG 1 - General chemical structure of AuRIX®100 resin.

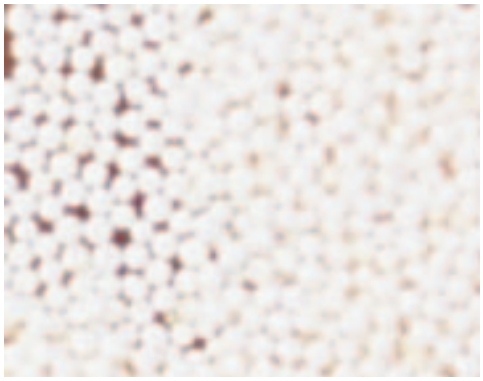

FIG 2 - AuRIX®100 resin beads.

Cognis Corporation has carried out extensive selectivity test work on the solvent extractant LIX®79, which uses the same guanidine functionality as used in AuRIX®100 resin, for the recovery of gold from clarified alkaline cyanide solutions (Virnig and Mackenzie, 1998). The relative selectivity of LIX®79 is shown in the pH isotherms given in Figure 3. The order of preference based on these pH isotherms would be Au>Hg>Zn>Ag~Ni>Cu. AuRIX®100 resin demonstrates some distinct differences in behaviour as compared to LIX®79 with the gold

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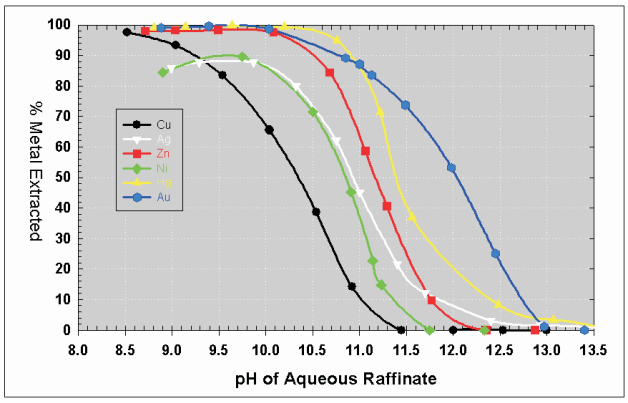

FIG 3 - LIX79 pH isotherm.

extraction isotherm shifted towards higher pH. Relative selectivity for metals with AuRIX®100 resin is also slightly different with an order of extraction: Au>Ag>Hg>Zn~Ni>Cu>Co>Fe. AuRIX®100 has also been shown to be more selective for gold over base metals than strong base resins by a factor of approximately four (Virnig and Mackenzie, 1998).

In general, copper absorption is lowest at high pH. At lower pH and cyanide levels the absorption of Cu is significant. The pH, as well as the NaCN concentration in solution can be adjusted to optimise gold absorption and minimise copper absorption. Stripping the resin with a strongly caustic solution will elute the absorbed elements.

As will be discussed later, based on the pH isotherms in Figure 3, it is possible to selectively recover gold and silver from copper, gold and silver solutions by manipulating the pregnant leach solution (PLS) pH to >12. It is also feasible to absorb copper, gold and silver at a low pH and then elute copper off the resin at pH >12 whilst leaving the gold and silver on the resin. The gold and silver would then be eluted at pH 14 as is standard practice for this resin.

The loading and elution chemistry of AuRIX®100 resin and the concomitant extraction and elution of anionic species has been described in a number of papers (Virnig, Mackenzie and Adamson, 1996; Virnig and Mackenzie, 1998; Kordosky *et al*, 1993) and is summarised in Figure 4.

The pH isotherms and elution equation in Figure 4 indicate the simplicity of the stripping process for AuRIX®100. 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 55 - 60°C to recover the absorbed elements off the resin. This makes the resulting stripping circuit very simple.

Loading

$$RG_{(org)} + H_2O \rightleftharpoons RGH^{1+}OH^{1-}{}_{(org)}$$

$$RGH^{1+}OH^{1-}{}_{(org)} + Au(CN)_2{}^{1-} \rightleftharpoons RGH^{1+}Au(CN)_2{}^{1-}{}_{(org)} + OH^{1-}{}_{(aq)}$$

Elution

$$RGH^{1+}Au(CN)_2{}^{1-}{}_{(org)} + OH^{1-}{}_{(aq)} \rightleftharpoons RG_{(org)} + H_2O + Au(CN)_2{}^{1-}{}_{(aq)}$$

G = Guanidine, R = Resin, Alkyl

FIG 4 - Guanidine chemistry.

Advantages of using AuRIX®100 resin with the Gekko ILR

The combination of AuRIX®100 resin and the Gekko ILR offer unique synergies and advantages including:

- the ability to treat high copper/high silver concentrates and selectively recover the gold (and silver);
- the ability to produce a high concentration gold solution from a low- to medium-grade concentrate;
- simplicity; and
- modularisation of gold processing/stripping technologies.

Extensive test work programs have been conducted to investigate the selectivity of AuRIX®100 resin and in particular its ability to selectively absorb gold over copper, gold over silver and gold and silver over copper. The methodologies used and the results obtained are summarised in the following sections.

TESTWORK METHODOLOGY

Different test methods were examined. These are as follows:

- absorption kinetic tests in stirred beakers, and
- continuous resin in column tests in lab scale resin columns.

TEST RESULTS

Absorption from synthetic gold, copper and silver solution

At the request of a client wanting to examine the performance of AuRIX®100 in a heap leach application, a synthetic solution consisting of 2 ppm Au as $Au(CN)_2^-$, 300 ppm Ag as $Ag(CN)_2^-$ and 100 ppm Cu as $Cu(CN)_x^{-x-1}$ and one per cent NaCN was produced in the Gekko laboratory.

This solution was contacted with preconditioned AuRIX®100 in a magnetically stirred beaker at the following conditions:

- resin concentration of 62.5 and 125 mL resin/L of solution,
- pH from 9.6 to 12, and
- fresh and 'loaded' resin used.

Solution samples were taken every 15 minutes for two hours to determine absorption kinetics and extraction efficiencies.

Table 1 summarises the results of the absorption tests. Conclusions that have been drawn from these results are:

- absorption of gold by fresh resin was typically 100 per cent over the pH range tested;
- absorption of silver by fresh resin was consistently >90 per cent over the pH range tested;
- absorption of silver dropped as the silver loading on the resin increased whilst gold absorption remained high even at silver loadings of 8000 g/m^3 of resin (equivalent to 24 000 g Ag/t of resin); and
- copper absorption was 90 per cent with fresh resin at pH 11 (Tests 4 and 6) but there was no absorption at pH 12 and loaded resin was eluted (Tests 5 and 7).

The results of Tests 6 to 8 were particularly interesting. The absorption kinetic curves for these tests are given in Figures 5 to 7 respectively.

The kinetic curves show high and fast absorption of Ag, Cu and Au at pH 11 with fresh resin (Figure 5). The resin from Test 6 was then contacted with fresh solution at pH 12 in Test 7 (Figure 6). The absorption of gold remained high and fast, silver absorption slowed significantly and dropped to 60 per cent whilst the copper absorption was insignificant at the start with copper

TABLE 1

Ag, Au, Cu AuRIX®100 absorption test results.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8
Solution mls	200	200	200	200	200	200	200	200
Resin used	fresh	fresh	Test 2	fresh	Test 4	fresh	Test 6	Test 7
Resin mls	25	12.5	25	12.5	12.5	12.5	12.5	12.5
Resin conc mL/L	125	62.5	125	62.5	62.5	62.5	62.5	62.5
Solution %NaCN	1	1	1	1	1	1	1	1
pH initial	11	11	11	9.6	12	11.1	12	12
pH adjustment	-	-	-	-	11.68 - 12.00	11	12	12
Time (mins)	120	120	120	120	120	120	120	120
Initial Au (ppm)	1.87	1.74	1.73	2.1	1.85	1.95	1.95	2.13
Final Au (ppm)	0	0.03	0.11	0.25	0.21	0	0	0.34
Initial Ag (ppm)	278	311	285	322	312	338	319	324
Final Ag (ppm)	7	25	71	23	130	25	129	212
Initial Cu (ppm)	-	-	-	118	50	62	32	129
Final Cu (ppm)	-	-	-	12	105	6	50	115
Absorption Au (%)	100%	98%	94%	88%	89%	100%	100%	84%
Absorption Ag (%)	97%	92%	75%	93%	58%	93%	60%	35%
Absorption Cu (%)	0%	0%	0%	90%	-110%	90%	-56%	11%
Resin loading Au (g/m^3)	15	27	40	30	56	31	62	91
Resin loading Ag (g/m^3)	2168	4576	6288	4784	7696	5008	8048	9840
Resin loading Cu (g/m^3)	0	0	0	1696	816	896	608	832

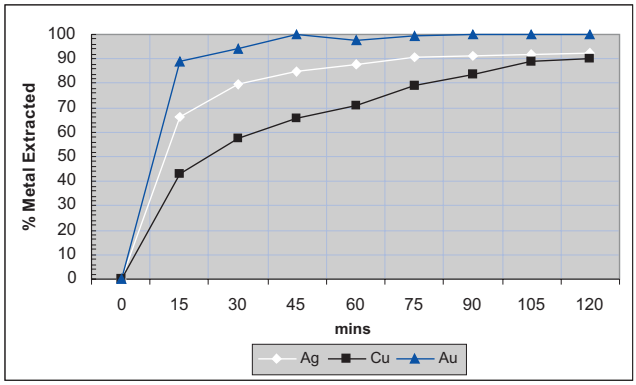

FIG 5 - Extraction curves for Test 6 at pH 11 using fresh resin.

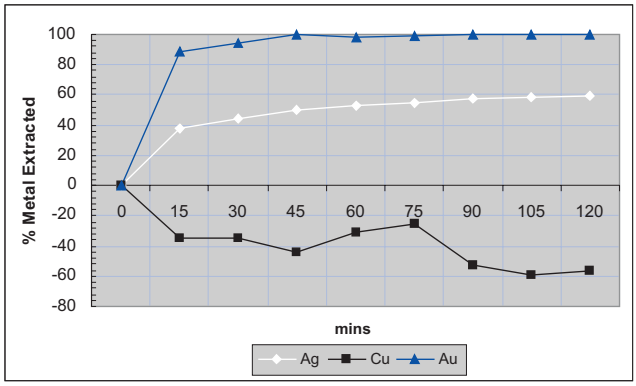

FIG 6 - Extraction curves for Test 7 at pH 12 using Test 6 loaded resin.

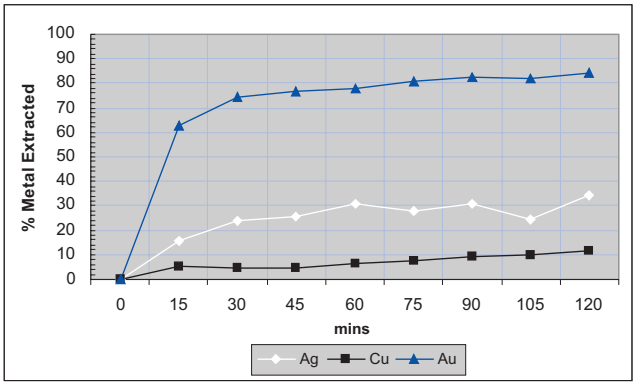

FIG 7 - Extraction curves for Test 8 at pH 12 using Test 7 loaded resin.

desorbed from the resin by the end of the test. These affects are explained by the silver in solution reaching equilibrium with the silver on the resin and the copper following the pH isotherms for the guanidine complex shown in Figure 3, which indicated little to no absorption at pH 12.

The final test in the series, Test 8, used the loaded resin from Test 7. Once again this resin was contacted with fresh solution at pH 12. Silver absorption dropped to 35 per cent indicating a pseudo equilibrium of 200 ppm silver in solution with 10 000 g/m^3 silver on resin loading. Gold absorption slowed and dropped to 84 per cent over the two-hour period as the gold cyanide complex competed with the high silver loading on the resin. Guanidine has a higher affinity for gold than silver and given time the gold will actually crowd off the silver.

Copper absorption was marginal at 11 per cent despite the high pH and could have been driven by the higher copper concentration in this test forming a new equilibrium with the resin.

The above analysis shows Ag and Au can be selectively absorbed from solution using AuRIX®100 resin at high pH and that copper absorbed can be eluted from the resin without affecting the Ag and Au concentration on the resin.

Selective absorption of gold from gold/silver solutions

As previously reported (Virnig *et al* 2004), pregnant leach solution from intensive leaching test work at Gekko's laboratory was found to have significant levels of heavy metals, cyanide and kerosene, which affects the performance of carbon, conventional resins, zinc precipitation and direct electro-winning.

The evaluation of AuRIX®100 for this application was undertaken and included a pilot trial of a conventional resin in solution (RIS) system similar to the RIS systems previously piloted for heap leach operations.

The pilot plant consisted of four columns in a carousel arrangement. The pregnant solution was passed through the four columns in series for 16 hours to load the resin. After 16 hours pregnant solution flow was stopped, the first column removed and stripped, then replaced at the end of the series of columns, becoming the final column in the sequence. Pregnant solution flow then recommenced and continued for a further 16 hours. A total of five loading and four stripping cycles was performed.

The aim of the trial was to confirm design parameters for gold absorption and check for any reduction in resin performance due to a build-up of silver, which was at high levels in the solution, or other elements.

The solution used was derived from a bulk leach of the concentrate to be treated. The resin used was preloaded to gold levels predicted from earlier test work. This was to accelerate the approach of the system to steady state and therefore minimise the number of cycles required.

Electro-winning was not practical at the scale of the test so a fresh strip solution was used throughout.

The column geometry was designed to emulate the expected full-scale resin hydraulics. Therefore the height of the column was as per full scale design and the column area was proportional to the solution flow to give the same superficial flow velocity and bed expansion.

The major test parameters and results are summarised in Table 2. Loading recoveries are the average over the last three absorption cycles. Stripping recoveries are for all four strips and are related back to the first four loading cycles.

TABLE 2

Summary of pilot test design and results.

Column design		**Result summary**	
Loading		**Loading**	
Design gold recovery	97.5%	**Final gold recovery**	**98.3%**
Aurix per stage	92.5 mL	Gold initial grade	13.4 ppm
Stage diameter	15 mm	Final silver recovery	31%
Aurix rest height	523 mm	Silver initial grade	64.3 ppm
Cylinder height	1047 mm		
Solution flow rate	28 mL/min	**Stripping**	
Residence time per stage	2.6 min	**Total gold recovery**	**97%**
Total residence time	10.6 min	Average gold grade	88 ppm
Load cycle time	16 hours	Total silver recovery	18%
Total test loading time	73 hours	Average silver grade	77 ppm
Solution pH	11.5		
Stripping		Gold recovered to bar	13.2 ppm
Strip flow rate	4.5 mL/min	Silver recovered to bar	19.9 ppm
Strip duration	15 hours		

Gold recovery was high at over 98 per cent and agreed well between the loading and stripping performance indicating the steady state was reasonably close to the initial conditions chosen. Silver recovery was lower, as had been expected, and more silver was loaded than stripped indicating the steady state loading of silver on the columns increased through the tests. This was to be expected since no preloading with silver was performed. Assuming the loaded silver will be stripped in future cycles, the gold content of the final bars has increased from a ratio of 64:13 or 5:1 silver to gold in the PLS to 20:13 or 3:2 silver to gold in the 'eluate', which is a large increase in the purity of the expected gold bars from this plant.

The loading performance of the four-column system over time is shown in Figure 8. It is seen that the recoveries of gold are high throughout the test and are gradually improving, indicating the steady state performance was slightly better than predicted in the design calculations.

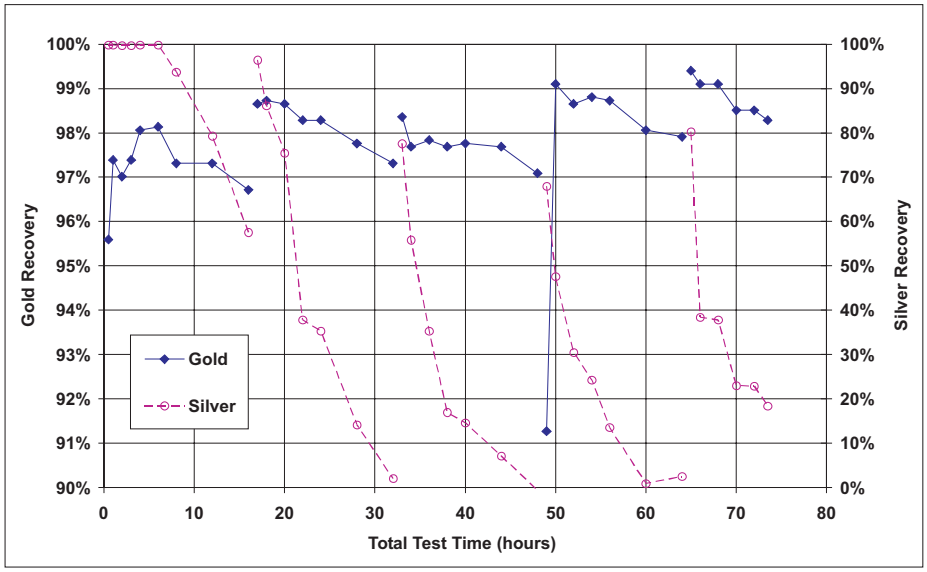

FIG 8 - Gold and silver recovery in AuRIX®100 RIS pilot test.

The silver recoveries can be seen to drop over the duration of the test as the silver loading on the columns built up. The silver recoveries also drop sharply over each loading cycle showing the columns are fully loaded with silver.

Analysis of the final loaded resin showed no significant build-up of minor elements and no signs of poisoning were observed during the test. There was no indication of silver levels interfering with gold absorption.

The results demonstrated AuRIX®100 could be used to recover gold from a complex solution at design performance and could increase the gold purity of the final gold bars.

Absorption of gold from copper/gold solutions

Gray and Katsikaros (1999) reported the absorption of gold by 200 g/L AuRIX®100 resin from a 4000 ppm gold, 11 000 ppm copper solution at pH13.1 followed the absorption curve given in Figure 9. Ninety-five per cent 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®100 for gold over copper at high pH.

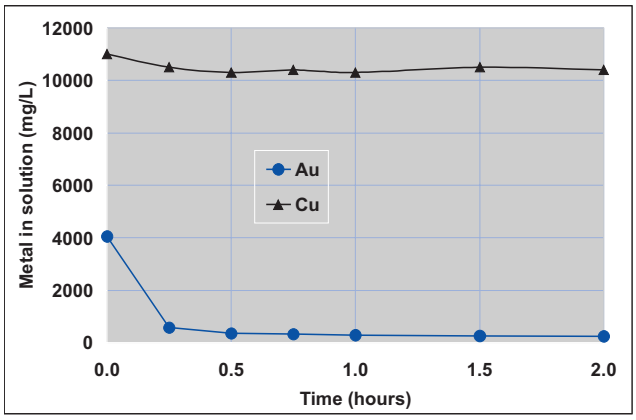

FIG 9 - Copper/gold absorption curves for Brown's Creek gold/copper solution.

Effects of other elements

During a number of the tests performed at the Gekko Laboratory, an ICP analysis of the feed and tail solutions from AuRIX®100 resin test work was undertaken to determine if there was significant absorption of elements other than those displayed in the pH isotherms in Figure 3. The results of these analyses are given in Table 3.

The ICP analyses show very little absorption of deleterious elements such as Fe and As from the solutions tested. There is evidence of thiocyanate (CNS) absorption, which if allowed to build up in leach solutions will affect absorption kinetics. Further work is underway at Gekko's laboratory to determine the affect of varying concentrations of the other elements likely to be found in leach solutions.

APPLICATIONS

AuRIX®100 resin can be used in a variety of applications to absorb gold from leach solutions and slurries, including resin in solution, resin in leach and resin in pulp. Gekko Systems has developed a novel way of using AuRIX®100 resin in combination with its continuous InLine Leach Reactor – the Gekko Resin Column.

TABLE 3

ICP results for AuRIX®100 absorption from leach solutions.

Element		Test 1		Test 2	
		Feed	Tail	Feed	Tail
Au	mg/L	5.45	1.37	150	3.15
Ag	mg/L	0.66	0.52	54.6	26.6
Hg	mg/L	0.016	0.008		
CNS	mg/L	140	130	1126	1069
Al	mg/L	2.2	1.8		
As	mg/L	120	110	2.4	2.42
Ca	mg/L	34	32		
Cd	mg/L	0.3	0.28		
Co	mg/L	0.4	0.4		
Cr	mg/L	0.2	0.2		
Cu	mg/L	9.2	8.8	246	492
Fe	mg/L	130	130	110	160
K	mg/L	28	28		
Na	mg/L	2900	2900		
Ni	mg/L	<0.6	<0.6	7.52	6.9
Pb	mg/L			0.18	0.20
Zn	mg/L	68	61	24.2	32.5

Gekko Resin Column

The Gekko Resin Column is a multi-stage, counter-current, pulsed reactor developed specifically for the absorption of gold from low-density slurries (<10 per cent solids). The reactor consists of a series of four compartments loaded with AuRIX®100 resin (test work has shown that four stages is optimal for gold absorption). The column stages are separated by 400 µm screens which hold the resin in place. Slurry flows down the column and resin is educted up in stages every six to 12 hours. Loaded resin is educted from the top of the column to a resin strip column. It is then stripped in a simple process using a 40 g/L caustic, 200 ppm NaCN solution heated to 55 - 60°C. The gold loaded strip solution is pumped through an electro-winning cell for gold (and silver) recovery and the return solution recycled back to the strip column. The barren slurry from the bottom of the resin column is pumped to a security screen before the thickener. Barren resin is introduced to the bottom of the column to ensure that all gold in the slurry is scavenged and a low tails grade is achieved. The column is pulsed using a diaphragm to ensure that there is no blinding in the screens, there is intimate contact between the slurry and the resin and that the solids are kept fluidised so that they aren't held-up within the column. A schematic and picture of the Gekko Resin flow sheet are shown in Figures 10 and 11 respectively.

CONCLUSION

Test work carried out using AuRIX®100 resin has demonstrated the selectivity of this resin for gold and silver from a gold/silver/copper solution, gold from a gold/silver solution and gold from a gold/copper solution by the simple modification of the solution pH. Some work has been performed to determine other compounds that may be absorbed but to date no major issues have been observed. The recently developed Gekko Resin Column is an enabling technology which allows 'dirty' solutions (approximately ten per cent solids) to be treated using AuRIX®100 and is ideally suited to the solutions typically produced by an Intensive Leach Reactor.

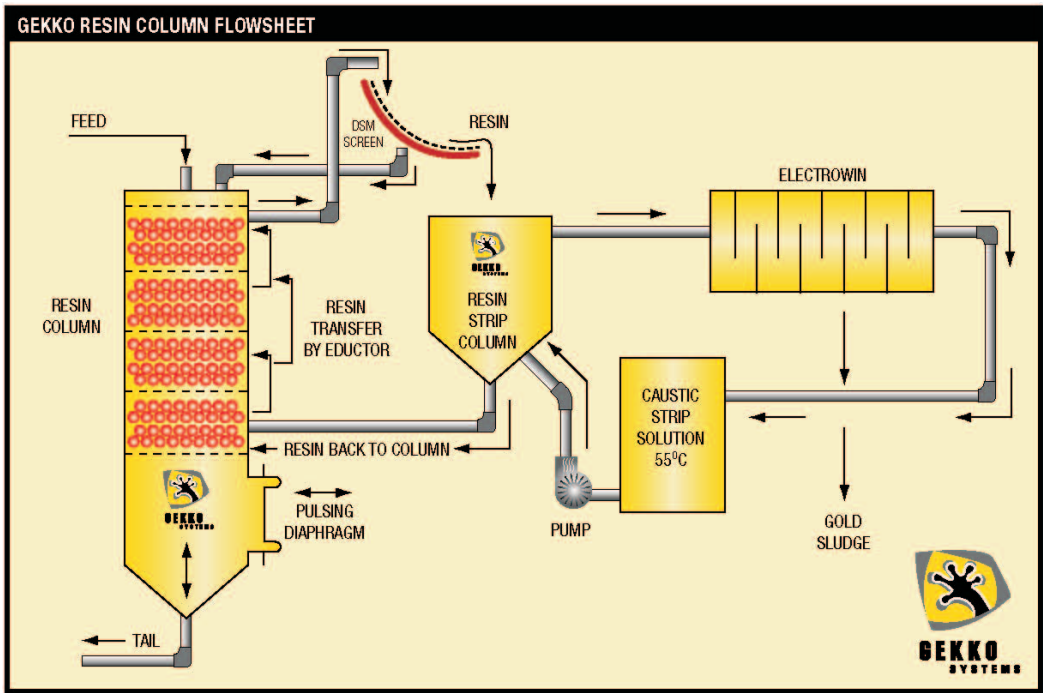

FIG 10 - Schematic of Gekko resin column flow sheet.

FIG 11 - Picture of the Gekko resin column modular plant, capable of recovering 50 000 oz gold/annum.

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