Comparison of resin-in-solution and carbon-in-solution for the recovery of gold from clarified solutions

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Synopsis

Testwork was done with two different adsorbents, Dowex-Minix gold-selective resin and activated carbon, to detemine their relative performances with regard to gold recovery from clarified low-grade solution employing a fixed-bed operation. The mill discharge from the milling-in-cyanide operation at a Witwatersrand gold mine was used as feed to the adsorption columns. A small amount of gold was leached during the milling process, so that this solution simulates, to a certain extent, a low-grade solution representative of a heap-leach operation.

A speciation of the feed solution was done to establish which metal complexes were present in the milling-in-cyanide solution. This information was necessary to interpret metal loadings on the resin, as base metal cyanide species and their respective charges have an effect on the final gold loading capacity of the resin.

Equilibrium isotherms were established for both adsorbents to estimate the rate of adsorbent flow anticipated for this specific feed solution. Breakthrough profiles were obtained at two different superficial linear velocities for each adsorbent. Mass transfer zone heights determined from the test work and the elution/regeneration time requirements were used to size a 150 m^3/h full-scale plant for both adsorbents. A countercurrent configuration of adsorption columns, using three columns, should be suitable to recover gold effectively and to produce an effluent with a gold concentration below 0.01 mg/l.

Based on the results obtained from the breakthrough tests, a preliminary techno-economic comparison was done between the resin-in-solution and carbon-in-solution options for the recovery of gold from low-grade solutions. This study indicated that the capital expenditure for a carbon-in-solution plant would be about 33 per cent higher than that of a resin-in-solution plant. The operating expenditure for a resin-in-solution plant is expected to be only 60 per cent of that for a carbon-in-solution plant.

Keywords: resin-in-solution, carbon-in-solution, heap leach.

Introduction

As a result of the depressed gold price, there is a worldwide trend towards low-cost heap-leaching operations. Heap leaching provides relatively low-grade, clear solutions from which the gold has to be recovered. In practice, carbon-in-solution (CIS) is generally used for the upgrading of the gold. With developments around gold-selective anion exchange resins over the past few years and the recent commercialization of a number of these resins, resin-in-solution (RIS) has become an alternative for the upgrading of gold from clarified solutions.

Mintek developed a gold-selective resin, Dowex-Minix, which is being manufactured and made commercially available by the Dow Chemical Company. Although Mintek has been promoting resin-in-pulp (RIP) over the past few years, very little attention has been given to the use of Dowex-Minix for the recovery of gold from clarified, pregnant leach liquors.

LTA Process Engineering approached Mintek to evaluate resin-in-solution (RIS) for the recovery of gold from a milling-in-cyanide operation at a Witwatersrand gold mine. A small amount of gold was leached during the milling process, so that this milling-in-cyanide solution simulated, to some extent, a low-grade solution typical of a heap-leach operation. This milling-in-cyanide solution was used to repulp some dump material before gold recovery via conventional processes, but it appeared that a degree of preg-robbing occurred during repulping and that some gold was lost. In order to prevent these gold losses, it was proposed that an adsorbent-in-solution process be employed to recover the gold from the milling-in-cyanide solution prior to using it for repulping.

This provided Mintek with the opportunity to do a direct techno-economic comparison between (RIS) and (CIS) for fixed-bed operations. Testwork was done on site at the mine using their milling-in-cyanide solution. This paper details the testwork done, the results obtained, and the outcome of a preliminary techno-economic comparison done by LTA Process Engineering.

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Background

Development of Dowex-Minix gold-selective resin

Earlier work showed that anion-exchange resins have some distinct advantages over activated carbon for the recovery of gold from cyanide leach liquors[1]. Resins have potentially higher loading capacities and loading rates, are less likely to be poisoned by organic matter such as lubricants and flotation reagents, and do not require thermal regeneration. Mintek has been involved in the development of macroporous gold-selective resins for a number of years, which culminated in the commercialization of the Dowex-Minix resin. This is a strong-base resin, manufactured by the Dow Chemical Company.

The potential metallurgical performance of the Dowex-Minix resin in relation to that of some other adsorbents is illustrated in Table I[2]. Gold-selective anion-exchange resins are in general less selective for gold than carbon, but Dowex-Minix has the potential of significantly higher gold-loading capacities. It is also clear from these data that the Dowex-Minix resin has a much-improved selectivity for gold and higher gold-loading capacity than conventional water-treatment anion-exchange resins such as A161L.

Equilibrium isotherm

Adsorption of gold onto an adsorbent is a reversible reaction where an equilibrium exists between the concentration of gold in the solution and that on the adsorbent. During equilibrium tests, sufficient contact time must be allowed for equilibrium to be reached. This equilibrium is generally described by a Freundlich isotherm as follows:

$$Y = aX^b \qquad [1]$$

where Y = adsorbent loading at equilibrium
X = solution concentration at equilibrium
a,b = Freundlich constants.

An equilibrium isotherm is obtained by contacting the adsorbent and solution samples over a relatively long period of time to ensure that equilibrium is reached. Samples of the final solutions are analysed for the relevant metals. Metal loadings on the adsorbent are calculated and equilibrium profiles for the metals of interest are constructed.

Determination of mass transfer zone height

The design of fixed-bed ion-exchange equipment is based on the mass transfer zone (MTZ) in the bed at a specific superficial linear velocity. This zone is the section of the bed where the reaction between the adsorbent and solution occurs. At the top end of the MTZ, the adsorbent is fully loaded, while in the section below the MTZ, no adsorption has occurred as yet (Figure 1). Therefore, the height of the MTZ is the height of the section of the bed in which a loading gradient exists. This height depends on the rate of the overall reaction, which includes film diffusion, intraparticle diffusion and reaction rate. These are affected by a number of parameters, such as the linear velocity of solution through the bed, temperature and adsorbent bead size distribution.

The ion-exchange circuit is designed in such a way that maximum gold breakthrough through the lead (first) column is allowed, while maintaining the overall recovery and

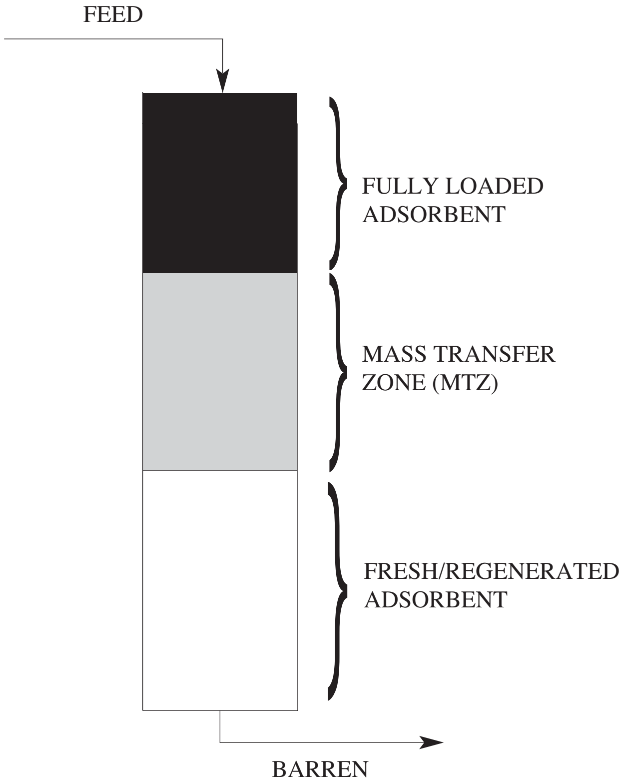

Figure 1— Schematic representation of mass transfer zone in a fixed bed ion-exchange column

Table I

Metallurgical performance of various adsorbents[a]

Adsorbent	Metal concentration (mg/kg) Au	Ag	Zn	Ni	Co	Cu	Fe	AU[c]/M
Metal in solution (mg/l)	5	0.5	2	5	1	10	10	
A161L[b]	13300	<250	9000	17800	4600	15800	21300	0.16
Activated carbon	25200	<200	<200	460	<200	<200	1500	0.93
Dowex-Minix	36300	300	10000	7300	<330	1200	<330	0.65

a – Metallurgical performance of adsorbents were determined with a column-loading test, which is one of the adsorbent-screening tests used at Mintek. This involves passage of a synthetic leach solution through an adsorbent bed at a relatively high flowrate for 72 hours. The high flowrate ensures contact of the adsorbent with constant concentrations of metals in solution
b – Conventional water treatment resin from Rohm and Haas
c – Ratio of gold concentration (mg/kg) to total metal concentration (mg/kg) on loaded resin, which is a measure of selectivity for gold

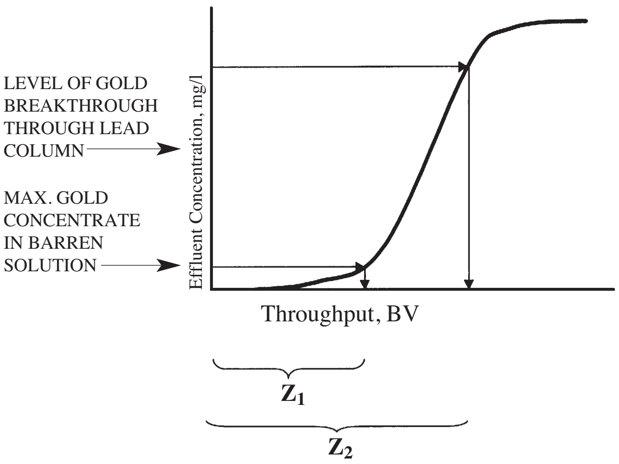

Figure 2—Calculation of height of mass transfer zone from breakthrough tests

without an excessive increase in the adsorbent inventory requirement.

Breakthrough tests on a specific feed solution are conducted at different superficial linear velocities to determine the effect of an increase in linear velocity on the height of the MTZ. Samples of the effluent from each bed are analysed for gold and a breakthrough curve is constructed for each linear velocity. The height of the mass transfer zone is determined from the breakthrough curve obtained during a column test, as illustrated in Equation [1] and Figure 2.

$$h = \left(\frac{z_2 - z_1}{z_2}\right) \bullet H \qquad [2]$$

where h = MTZ height
z_1 = run time at maximum tolerable gold concentration in barren solution
z_2 = run time at required (e.g. 80%) breakthrough
H = total height of adsorbent bed used for evaluation

Experimental

Adsorption tests were done with two adsorbents, Dowex-Minix gold-selective resin and CQ650 coconut-based activated carbon. Clarified solution from the milling-in-cyanide operation was used as pregnant liquor for these tests.

The Dowex-Minix resin was converted to the SO_4^{2-} form, prior to use. Resin volumes were measured as tapped volumes in the sulphate form. The average particle diameter (d_{50}) of the resin was about 800 μm, while that of the activated carbon (CQ650) was 1000 to 2000 μm.

Equilibrium tests

A seven-point equilibrium isotherm was established for each adsorbent by contacting samples of adsorbent with portions of feed solution in batch over a period of eight days. Metal loadings on the adsorbents were calculated from changes in the solution composition, i.e. differences between the feed and final solutions after equilibrium was reached.

Column breakthrough tests

Fixed-bed tests were conducted to establish breakthrough profiles for gold on both adsorbents. Clarified mill discharge solution was passed downwards through the columns. Flowrates and temperatures were monitored throughout the tests.

Samples of the effluent were analysed on-line for gold to construct breakthrough profiles for the two different adsorbents. Breakthrough profiles were established at two different superficial linear velocities for each adsorbent. Typical linear velocities for CIS operations treating heap leach liquors vary between 0.6 and 2 cm/s. The heights of the adsorbent beds tested were adjusted to accommodate anticipated differences in the mass transfer zone heights. Tests were done at ambient temperature. Detailed conditions for the testwork are listed in Table II.

Results and discussion

Feed solution

The composition of the feed solution is given in Table III. The gold concentration of the feed, for the duration of the testwork, varied between 0.59 and 0.75 mg/l. Calculations were based on the average value of 0.67 mg/l. For a milling-in-cyanide operation, the level of cyanide addition is generally relatively low, hence the low concentration of free cyanide in solution (a typical free cyanide concentration in a heap-leach operation should be around 100 mg/l). The pH of the feed solution was 7, which is extremely low and below the pH at which HCN forms. This might have contributed to the relatively low free cyanide level in the solution.

A speciation was done on the feed solution to determine the nature of the metal cyanide complexes present. Details of the speciation for the major metals present in the solution are given in Table IV.

The affinity of the resin for a certain metal depends on a number of factors, including the type of complex it forms with cyanide and the charge of the complex. Dowex-Minix

Table II

Conditions for column breakthrough testwork

Test number	Adsorbent volume (l)	Column diameter (cm)	Bed height (m)	Flowrate (ml/min)	Superficial linear velocity (cm/s)
Dowex-Minix:					
R-1	2.94	2.5	6	380	1.29
R-2	1.96	2.5	4	188	0.64
Carbon:					
C-1	27	5.4	12	1677	1.22
C-2	13.5	5.0	6	855	0.73

Table III

Composition of feed

Metal in feed (mg/l)								
Au	Ag	Co	Cu	Fe	Ni	Zn	SCN^-	CN^-
0.67[a]	<1.	7.14	9.54	<0.5	22.55	<1	183.5	12.3

a – average value over test period

Table IV

Details of speciation of feed solution

WAD[a] cyanide	**(mg/l)**	**12.3[b]**
Gold leachable cyanide[c]	**(mg/l)**	**0.1**
Total cyanide	**(mg/l)**	**35.3**
$[Au(CN)_2]^-$	(% of total metal)	100
$[Cu(CN)_2]^-$	(% of total metal)	99.8
$[Cu(CN)_3]^{2-}$	(% of total metal)	0.2
$[Co(CN)_6]^{3-}$	(% of total metal)	100
$[Ni(CN)]^+$	(% of total metal)	11.2
$[Ni(CN)_2]$	(% of total metal)	6.5
$[Ni(CN)_3]^-$	(% of total metal)	11.8
$[Ni(CN)_4]^{2-}$	(% of total metal)	5.9

[a] – Weak Acid Dissociable
[b] – Based on solution analysis
[c] – Consists of free CN, dissolved HCN and cyanide that is loosely bound to metals, i.e. CN associated with zinc and some of the CN associated with copper

was designed to be more selective for monovalent cyanide complexes, hence these complexes will compete strongly with gold for sites on the resin. This will lower the selectivity of the resin for gold over these metals, as well as its gold-loading capacity. Based on the speciation of the feed solution, the following complexes would have competed strongly with gold for sites on the resin: $[Cu(CN)_2]^-$ (~ 9.5 mg/l), $[Ni(CN)_3]^-$ (~ 2.7 mg/l), and $[SCN]^-$ (~184 mg/l).

The fact that $[Cu(CN)_2]^-$ is a linear molecule, similar to $[Au(CN)_2]^-$, would further enhance its competitiveness with gold. The relatively high concentration of thiocyanate (compared to the gold concentration), would also have played a significant role in depressing the gold-loading capacity of Dowex-Minix.

Adsorption

Equilibrium isotherms

Equilibrium isotherms were determined for Dowex-Minix and CQ650. Isotherms, including experimental data and a Freundlich fit, are shown in Figures 3 and 4. Loadings obtained over a period of 8 days should approximate loadings that can be anticipated during a fixed-bed adsorption operation.

The Freundlich constants for gold adsorption as determined from the equilibrium tests are listed in Table V.

A gold loading of approximately 2.8 g/l was obtained on the CQ 650 carbon granules in a solution containing 0.488 mg/l gold. A lower loading of approximately 1.5 g/l was obtained on the resin from a solution containing 0.44 mg/l gold. This relatively low loading on the resin can probably be attributed to competition by other metals with gold for sites on the resin, whereas carbon adsorbs mainly gold and to a lesser extent silver, which was absent from the feed solution.

Column breakthrough tests

Resin

Breakthrough profiles, at a linear velocity of 1.22 cm/s, as established from sample points at heights of 2, 4 and 6 m from the top of the column, are shown in Figure 5.

Typically, a fixed-bed ion-exchange circuit for the recovery of gold should be designed to deliver an effluent containing less than 0.01 mg/l gold. However, the inaccuracy of the on-line results made it not feasible to design for such a low effluent. Hence, the mass transfer zone height was based on the breakthrough of 0.1 mg/l (in the effluent) to 0.54 mg/l (80 per cent of the average feed concentration for the duration of the testwork) gold. A summary of the results for Dowex-Minix resin is shown in Table VI.

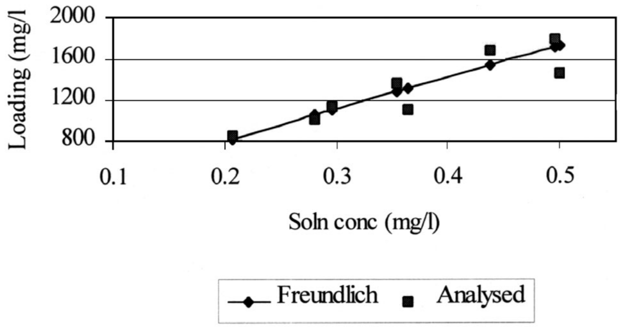

Figure 3—Equilibrium data for Dowex-Minix resin

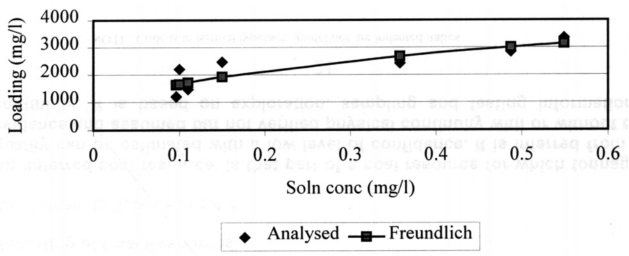

Figure 4—Equilibrium data for CQ650 carbon

Table V

Summary of Freundlich constants for adsorption of gold on CQ650 carbon and Dowex-Minix resin

Adsorbent	Freundlich a	Freundlich b
Dowex–Minix	3 100	0.86
CQ650	3 900	0.38

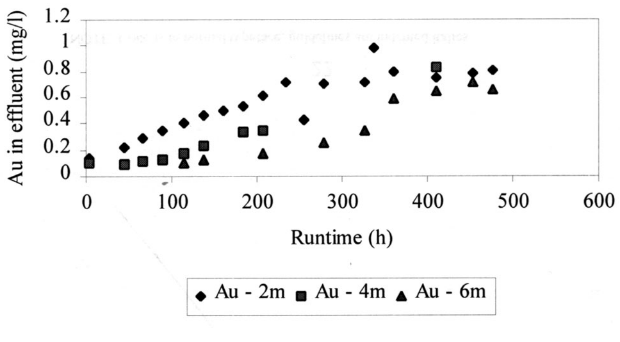

Figure 5—Breakthrough profiles for gold on Dowex-Minix resin at linear velocity of 1.22 cm/s and different column heights

Table VI

Summary of results for Dowex-Minix

Test Linear velocity (cm/s)	R1 1.22	R2 0.61
Gold loading (g/l)[a]	1.4	1.7
Copper loading (g/l)[a]	7	9
Nickel loading (g/l)[a]	3	3.5
Selectivity (Au/Cu)[a]	2.9	2.7
Selectivity (Au/Ni)[a]	21	17
Mass transfer zone height (m)	4.1	2.3
Required solution residence time (min)	5.6	6.3

a – based on resin analysis at 100% breakthrough of Au in solution

Gold loadings obtained for Dowex-Minix during the column tests varied between 1.4 g/l for test R1 and 1.7 g/l for test R2 (allowing 100% breakthrough through the first 2 meters of each column). This ties in well with the loadings obtained during the equilibrium test, which was 1.5 g/l (calculated). The Freundlich constants, as determined in Table V, could therefore be used to predict changes in the resin loading with fluctuations in the feed gold concentration between the limits evaluated during this study.

Dowex-Minix is generally quite selective for gold over copper and nickel. However, in this specific milling-in-cyanide solution, where the free cyanide concentration and pH value were extremely low, the primary copper cyanide species present was $[Cu(CN)2]^{-}$. The copper concentration was also more than an order of magnitude higher than that of gold. These conditions caused the resin to be less selective for gold over copper, with a selectivity coefficient for gold over copper of around 3, compared to an average value of 60 found during previous studies[2]. The selectivity coefficient for gold over nickel was around 20.

The mass transfer zone heights determined at superficial linear velocities of 0.61 and 1.22 cm/s were 2.3 and 4.1 m respectively. This translated to a superficial solution residence time requirement of approximately 6 minutes to reduce the solution concentration from 0.54 to 0.1 mg/l.

Carbon

Breakthrough profiles, at a linear velocity of 1.14 cm/s, as established from sample points at heights of 2, 4 and 6 m from the top of the column, are shown in Figure 6.

Determination of the mass transfer zone height was based on a breakthrough of 80% of the feed concentration (about 0.54 mg/l) and 0.1 mg/l gold in the effluent. A summary of the results is shown in Table VII.

Gold loadings obtained for CQ650 during the breakthrough tests were 3.35 g/l (C1) and 2.5 g/l (C2) respectively, (allowing 100% breakthrough through the first 2 m of each column). The loading obtained during the equilibrium test on carbon was 3.0 g/l (for a contact period of eight days). The Freundlich constants determined from the equilibrium tests on carbon (Table V) could therefore be used to predict changes in the carbon loading with fluctuations in feed concentration within the concentrations limits evaluated during this study.

The mass transfer zone heights determined at superficial linear velocities of 1.14 and 0.73 cm/s were 3 and 2 m respectively. This translated to a superficial solution residence time requirement of approximately 4.5 minutes to reduce the solution concentration from 0.54 to 0.1 mg/l.

Design and proposed operating strategy

A fixed-bed adsorption circuit (similar for carbon and Dowex-Minix) employing three columns operated as a lead-lag-lag configuration is proposed for the adsorption of gold from low-grade solutions. The bed height was based on allowing a minimum of 8 minutes solution residence time to decrease the gold concentration from 1.5 mg/l (typical feed concentration after heap-leach operation) to 0.01 mg/l. However, this solution residence time will have to be verified during a pilot plant campaign.

Solid particles in the feed to a fixed bed adsorption column could cause major problems with pressure drop across the bed. Therefore it is crucial to ensure proper filtration and clarification of the feed solution before feeding it to the adsorption plant.

In order to minimize resin handling and associated resin losses, it is proposed that elution be done in the same column in which adsorption takes place. For the Dowex-Minix resin a two-step elution is done. Base metals are removed during an acid wash step, followed by gold elution at 60°C, using an eluant containing thiourea (1M) and sulphuric acid (0.5M). The same elution plant design as for the MINRIP process[3] is used. Hence, the adsorption columns will have to be rubber-lined mild steel, or fibre glass columns. Resin losses are estimated to be about 5 per cent per year (based on information from water purification plants).

After adsorption, carbon has to be transferred to a separate elution column, which can tolerate the carbon elution conditions of 120°C and approximately 3 bar

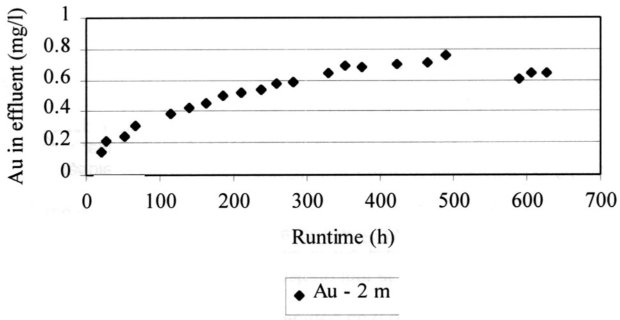

Figure 6—Breakthrough profiles for gold on CQ650 at linear velocity of 1.14 cm/s

Table VII

Summary of results for CQ650

Test Linear velocity (cm/s)	C1 1.14	C2 0.73
Gold loading (g/l)[a]	3.35	2.5
MTZ height (m)	3	2
Required solution residence time (min)	4.4	4.6

a – based on carbon analysis at 100% breakthrough of gold through carbon column pressure. The relatively low cost of replacing carbon renders it impractical to build all the adsorption columns to comply with elution column specifications.

A summary of the sizing for the adsorption circuit of both Dowex-Minix and carbon is shown in Table VIII. For this it was assumed that the gold loading of Dowex-Minix and activated carbon would be similar for heap leach liquors where the copper cyanide species should be divalent, and thiocyanate concentrations will be limited.

The operating strategy, including transfer time, has to be optimized during a pilot plant campaign.

Costing

Based on the sizing of a fixed-bed adsorption plant as estimated from the breakthrough profiles, LTA Process Engineering completed a preliminary comparative costing for RIS and CIS plants. Costs associated with pumping of solution were excluded, as it will be the same for both options.

The sizes of the two plants were the same, following the gold upgrading and solution residence time requirements that were determined during the test programme. A summary of the capital and operating expenditure associated with each plant is shown in Tables IX and X. CAPEX estimates for the RIS and CIS plants were based on a feed throughput of 150 m^3/h containing 1.5 g/l Au. Labour and water requirements were assumed to be the same for both options. Maintenance on the plant was assumed at 5% of CAPEX per annum.

The capital expenditure associated with a CIS plant amounted to R7.2 million. The cost for a RIS plant was R4.8 million, which is a 33 per cent saving compared to the CIS plant. The adsorption section of a RIS plant is more expensive than that of the CAPEX of the CIS plant due to the cost of the resin. The CAPEX associated with the desorption or elution section of the plant is more expensive for a CIS plant, due to the expensive regeneration kiln needed to reactivate the carbon and a pressure vessel for the elution column. On a RIS plant no regeneration of the resin is required.

Based on the preliminary techno-economic evaluation, the operating expenditure for the RIS plant should be only 60% of that of a CIS plant for treating a solution containing 1.5 g/l gold.

Table VIII

Sizing of the adsorption section of in-solution plant for the recovery of gold from low-grade solutions

Process:	Feed: flowrate	(m^3/h)	150
	Feed: linear velocity	(cm/s)	1.2
	Feed: gold concentration	(mg/l)	1.5
	Adsorbent: gold loading	(mg/l)	3500
	Operating temperature	(°C)	ambient
	Resin elution time	(h)	8
	Carbon elution and regeneration time	(h)	24
Equipment:	Configuration		lead-lag-lag
	Number of columns		3
	Column: diameter	(m)	2.1
	Column: height	(m)	4
	Adsorbent: bed height	(m)	3.1
	Adsorbent: volume	(m^3/column)	11

Conclusions

Test results showed that gold could be successfully recovered from low-grade solutions using Dowex-Minix resin or CQ 650 activated carbon. Gold loadings obtained for Dowex-Minix during the column breakthrough tests varied between 1.4 and 1.7 g/l. This was determined from resin analyses where the resin was in equilibrium with the feed concentration of gold (100 per cent breakthrough was allowed through the top of the column). Loadings were confirmed by the equilibrium isotherms.

Dowex-Minix is generally very selective for gold over copper and nickel. However, in this specific milling-in-cyanide solution the free cyanide concentration and the pH value were extremely low so that the primary copper cyanide species present was $[Cu(CN)_2]^-$. The copper concentration was also more than an order of magnitude higher than that of gold. These conditions caused the resin to be less selective for gold over copper, with the selectivity coefficient for gold over copper around 3, compared to an average value of 60 obtained in previous laboratory testwork. The thiocyanate concentration in the feed was also relatively high, which would have depressed gold loading significantly. Gold

Table IX

Summary of CAPEX estimates for RIS and CIS plants

		RIS	CIS
TOTAL CAPEX:	(R)	4 830 000	7 260 000
Adsorption	(R)	2 280 000	1 200 000
Desorption	(R)	1 170 000	2310 000
Regeneration	(R)	0	2 370 000
Electrowinning and smelting	(R)	1 380 000	1 380 000

Table X

Summary of OPEX estimates for RIS and CIS plants

	Consumption	Unit cost R/kg	RIS R/month	CIS R/month
TOTAL	**(R/month)**		**65 165**	**107 208**
	(R/t solution)		**0.6**	**0.99**
Resin[a]	(5% per annum)	101.5	3 806	
Thiourea[b]	(70 kg/t resin)	10.38	10 463	
H_sSO_4[b]	(500 kg/t resin)	0.94	5 768	
NaOH[c]	(55 kg/t resin)	3.5	2 772	
Carbon	(0.02 g/t ore treated)	8.8		8 712
NaOH	(0.06 g/t ore treated)	3.5		6 510
NaCN	(0.06 g/t ore treated)	7		21 000
HCl	(0.07 g/t ore treated)	0.95		3 278
Water	(10 000 kg/month)	0.35	3 500	3 500
Diesel[d]	(0.1 g/t ore treated)	1.18	0	5 806
Labour			20 000	20 000
Maintenance	(5% of CAPEX)		5700	10 063
Power	(243 /t ore treated)	0.1275	11 154	28 340

a - based on information from water purification plants
b - consumptions based on confidential data, Mintek
c - adsorbs any HCN produced and form NaCN
d – diesel requested as heating medium by client for this specific plant

loadings that can be obtained with typical heap leach solutions are anticipated to be much higher than the 1.5 g/l obtained during this testwork.

Loadings obtained for CQ650 carbon during the column breakthrough tests were 3.35 and 2.5 g/l at linear velocities of 1.14 and 0.73 cm/s respectively. Breakthrough of 100% was allowed through the top section of the column. Gold loadings obtained during equilibrium tests on carbon was around 3.0 g/l.

Due to inaccuracies in analyses of the solution samples at low concentrations, the mass transfer zone height was determined for a gold effluent concentration of 0.1 mg/l and 80% breakthrough (0.54 mg l). Mass transfer zone heights obtained during this study translated to solution residence time requirements of approximately 6 minutes for Dowex-Minix and 5 minutes for carbon. These residence times will have to be confirmed during pilot plant trials with a solution representing heap leach liquors more closely.

Typical heap leach solutions contain approximately 1.5 mg/l gold. A lead-lag-lag configuration of adsorption columns, using 3 columns, should be suitable to recover the gold effectively and produce an effluent of 0.01 mg/l. For a feed throughput of 150 m^3/h, the column dimensions for both adsorbent plants would be as follows:

Diameter = 2.1 m

Height = 4 m

Adsorbent bed height per column = 3.1 m

The total adsorbent inventory requirement would be 33 m^3.

A preliminary techno-economic evaluation was done by LTA Process Engineering to compare CIS and RIS for the recovery of gold from low-grade solutions. The CAPEX estimate for a CIS plant amounted to R7.2 million, while that for a RIS plant was R4.8 million. This indicates a 33% CAPEX saving for a RIS plant when compared to a CIS plant. The operating expenditure for the RIS plant is expected to be 60% of that of a CIS plant at 60c/t solution treated as opposed to R1.03/t for a CIS plant.

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- Auditing of projects and operating mines
- Vetting of codes of practices

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