

Small-scale pilot-plant tests on the resin-in-pulp extraction of gold from cyanide media

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SYNOPSIS

The results of small-scale resin-in-pulp pilot-plant investigations at Grootvlei Proprietary Mines Ltd, President Brand Gold Mining Co. Ltd, and Western Areas Gold Mine Co. Ltd are reported. At each mine, a pulp was fed simultaneously to a carbon-in-pulp plant, allowing a direct comparison of the metallurgical performance of the two processes.

With the Grootvlei pulp, gold was extracted more efficiently by resin than by carbon owing to the low concentration of competing base-metal cyanide complexes in solution. With the Western Areas pulp, the reverse was true because of the high concentrations of copper and nickel in solution. Finally, with the President Brand pulp, resin-in-pulp was significantly superior to carbon-in-pulp owing mainly to the inherently slow rate of gold extraction from calcine by activated carbon.

Results are presented that show the efficiency of the elution of gold and other elements with a variety of reagents from the loaded resins arising from these three campaigns. At Western Areas, a detailed investigation enabled a preliminary cost evaluation to be made of three techniques for the elution of strong-base resins.

SAMEVATTING

Daar word verslag gedoen oor die resultate van kleinskaalse hars-in-pulpproefaanlegondersoeke by die Grootvlei, President Brand- en Western Areas-goudmyn. Daar is by elke myn terselfdertyd pulp in die koolstof-in-pulpaanleg ingevoer sodat die metallurgiese werkverrigting van die twee prosesse regstreeks vergelyk kon word.

Met die Grootvlei-pulp is die goud meer doeltreffend met die hars as met die koolstof geëkstraheer, vanweë die lae konsentrasie van mededingende onedelmetaalsianiedkomplekse in die oplossing. Met die Western Areas-pulp was die teenoorgestelde weer waar, vanweë die hoë koper- en nikkelskoneentrasie in die oplossing. Ten slotte was die hars-in-pulp met die President Brand-pulp beduidend beter as die koolstof-in-pulp, hoofsaaklik as gevolg van die inherent stadige tempo van goudekstraksie uit kalsiene met geaktiveerde koolstof.

Daar word resultate aangegee wat die doeltreffendheid toon van die eluering van goud en ander elemente met 'n verskeidenheid reagense uit die gelaaide harse met hierdie drie kampanjes verkry. By Western Areas het 'n uitvoerige ondersoek dit moontlik gemaak om 'n voorlopige koste-evaluering te doen van drie tegnieke vir eluering uit sterkbasisharse.

Introduction

There have been rapid developments in recent years in the introduction of carbon-in-pulp (CIP) technology for the processing of gold-cyanide pulps. As a sequel to the successful development of this process, the Council for Mineral Technology (Mintek) embarked upon a research programme in which resin-in-pulp (RIP) was examined as a possible alternative to the CIP process. The chemistry involved in the absorption and elution of gold cyanide and other anions onto strong- and weak-base resins is given in two previous papers^{1,2}, and this paper reports the results of a number of small-scale RIP pilot-plant campaigns at South African gold mines. At each mine, the pilot plants were operated continuously for a sufficient period to allow the process to reach an approximately steady-state performance, and this performance was then compared with that of the CIP process under the same conditions and with the same feed material.

There are a number of chemical aspects in the absorption of gold cyanide onto anion-exchange resins and its elution that make the RIP process a potentially attractive alternative to CIP in certain applications. For example, in the CIP extraction of gold from pulp resulting from the cyanidation

of roasted pyrite concentrates, the rate of loading is severely retarded by the absorption of a 'skin' of fine particulate calcine on the carbon surface^{3,4}. In addition, the temperature of these pulps, which is generally some 10 to 20°C above ambient, has been shown to reduce the capacity of activated carbon for gold fairly significantly. Neither of these factors has a marked effect on the extraction of gold cyanide by ion-exchange resins, and results are presented here to demonstrate the superior performance that can be expected from RIP in this particular application. It is believed that highly oxidized materials, clays, and shales will behave similarly to calcine, and that RIP could perform more efficiently than CIP in the treatment of these materials.

Another application in which resins have been shown in small-scale tests to be more efficient than carbon³ is in the treatment of pulps containing entrained organic matter. One example is a solvent such as kerosene, which might be expected to contaminate the various aqueous streams on a South African gold-and-uranium mine. On these plants, uranium is always extracted by solvent extraction with a tertiary amine present in an inert diluent such as kerosene, and there is generally extensive recirculation of the mine waters between the gold and the uranium plants. Another example of contamination with organic matter in a pulp is the presence of flotation reagents. Much of the gold in South Africa is associated with pyritic material, and in many applications this material is treated to produce a flotation concentrate. In the event of such material

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SA ISSN 0038-223 X / \$3.00 + 0.00.

reporting to cyanidation and CIP without prior roasting, one would expect contamination of the carbon by flotation reagents. Results presented earlier³ show that, although such contamination has a serious effect on the capacity of carbon for gold, it has little effect on the capacity of ion-exchange resins for gold.

These examples all refer to specific applications in which the treatment of certain feed materials by CIP could be difficult owing to 'poisoning' of one sort or another. Of more general applicability are the chemical advantages of faster rates of reaction, higher loading capacities, and simpler, cheaper elution and regeneration techniques, in RIP than in CIP. These advantages would be of greatest benefit to small operators, who generally find it difficult to justify the expensive capital and operating costs involved in the regeneration of loaded carbon. The alternative, which is expensive and not always satisfactory, involves burning the carbon to recover the gold or selling the loaded carbon to a refinery. In both approaches, carbon represents an expensive consumable in the process. It is shown here that resin can be eluted, regenerated, and recycled at relatively low cost.

The advantages of resins over carbon are mainly chemical, while the disadvantages are mainly physical. The physical disadvantages relate mainly to the particle-size range of resins (minus 16 plus 20 mesh), which is smaller than that of carbon (minus 6 plus 16 mesh), and screens for separating resin from pulp have to be somewhat smaller than the screens that are being used currently in CIP. This may limit the size of an RIP plant. A largely unknown aspect of the RIP process is the loss of resin that is likely to be experienced owing both to physical attrition in the extraction stages and to osmotic cracking during elution and regeneration. Finally, resins, being less dense than activated carbon, tend to accumulate on the surface of the pulp unless properly mixed by, for example, a down-draft tube agitator. It has not been possible for these aspects to be studied in any detail because of the small scale of the pilot plants, but continuing research at Mintek will focus on these factors.

Experimental

Three pilot plants were used in this investigation, ranging from a miniplant with 5-litre extraction stages to a pilot plant with 400-litre stages. In the treatment of cyanided pulp at Grootvlei, four mechanically agitated, baffled flat-bottomed tanks with a 28-mesh screen in the periphery of each vessel were employed as extraction stages. The capacity of each tank up to the screen overflow was 5 litres, and the screen overflow fed to the next stage by gravity. The pulp feed rate was controlled at 7 l/h by a Watson Marlow MHRE 100 peristaltic pump. Resin was transferred manually, in a direction countercurrent to the flow of pulp, by moving each stage up one position in the absorption train once every 48 hours; that is, the first stage was withdrawn from the absorption train and drained over a 35-mesh screen for the recovery of the loaded resin for elution, the second stage was moved into the position previously occupied by the first stage, and the third and fourth stages were moved accordingly, the original first

stage being recharged with fresh resin and moved into the position occupied previously by the fourth stage.

Before the start of the campaign at the Grootvlei miniplant, sufficient feed material for the entire experiment was collected and stored in a large air-agitated pachuca. This feed pulp was passed over a 35-mesh screen for the removal of woodchips and coarse material before being pumped into the first RIP absorption stage. The concentration of resin in each stage was 5 per cent by volume (250 ml per stage), and both strong- and weak-base resins were tested. The strong-base resin was IRA 400 made by Rohm & Haas, and the weak-base resin was A7 made by Duolite International. Both resins were screened to minus 16 plus 20 mesh.

During the RIP campaign at Grootvlei, Mintek operated a CIP pilot plant on a parallel stream of pulp. This plant consisted of five mechanically-agitated 400-litre absorption tanks through which pulp was pumped at a flowrate of 600 l/h. The carbon concentration was about 20 g/l (5 per cent by volume), and the residence time of the carbon in each stage was 48 hours. The activated carbon used in this campaign was METSORB 101 manufactured by Chemviron.

The pilot plant used in the treatment of cyanided calcine at President Brand consisted of five flat-bottomed mechanically-agitated tanks arranged in a cascade to permit pulp to flow by gravity from one tank to the next. The volume of each tank up to the 35-mesh peripheral screen was 50 litres, and mixing was achieved with 0,25 hp Lightning Aeromix mixers. The feed calcine was passed over a 48-mesh screen to a holding tank at the head of the absorption train, from which it was pumped at a flowrate of 100 l/h with a peristaltic pump to the first absorption tank. The resin concentration in each stage was varied between 5 and 8 per cent (2,5 to 4 litres per stage), and the resin flowrate was varied between 2 and 5 litres per day. The resin was transferred manually, as described above for the Grootvlei campaign. A strong-base resin, A101 DU (supplied by Duolite International), was used in the President Brand campaign. The resin was screened to the size range minus 16 plus 20 mesh. In the full-scale CIP operation at President Brand, from which operating data were drawn for comparative purposes, the activated carbon used was Le Carbone G210AS.

Finally, for the RIP campaign at Western Areas, the pilot plant consisted of three mechanically-agitated baffled pachucas, with 28-mesh peripheral screens. The volume of each stage was 400 litres, and the concentration of resin was 5 per cent by volume (20 litres per stage). The feed pulp for the RIP pilot plant was leached and stored in a 650 m³ Browns tank, from which it was pumped over a vibrating 28-mesh screen and into the first absorption tank at a flowrate of 800 l/h. The resin was transferred every 48 hours by draining each tank in turn over a 35-mesh screen; the pulp was pumped back into the tank from which it came, while the entire resin inventory was transferred to the next stage up the absorption train. The resin used in this campaign was the strong-base resin A101 DU (size minus 16 plus 20 mesh). On the completion of the RIP campaign, the pilot plant was operated for the same period and with the same

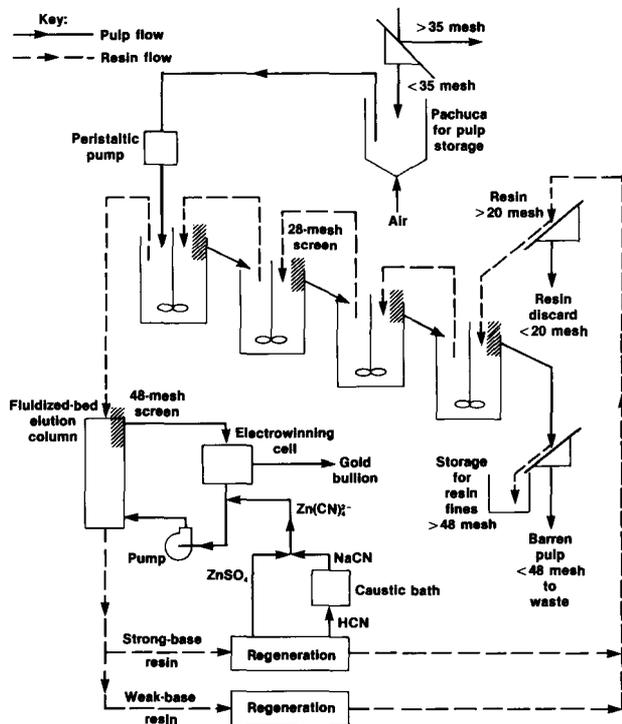


Fig. 1 — RIP miniplant used in the campaigns at Grootvlei and President Brand

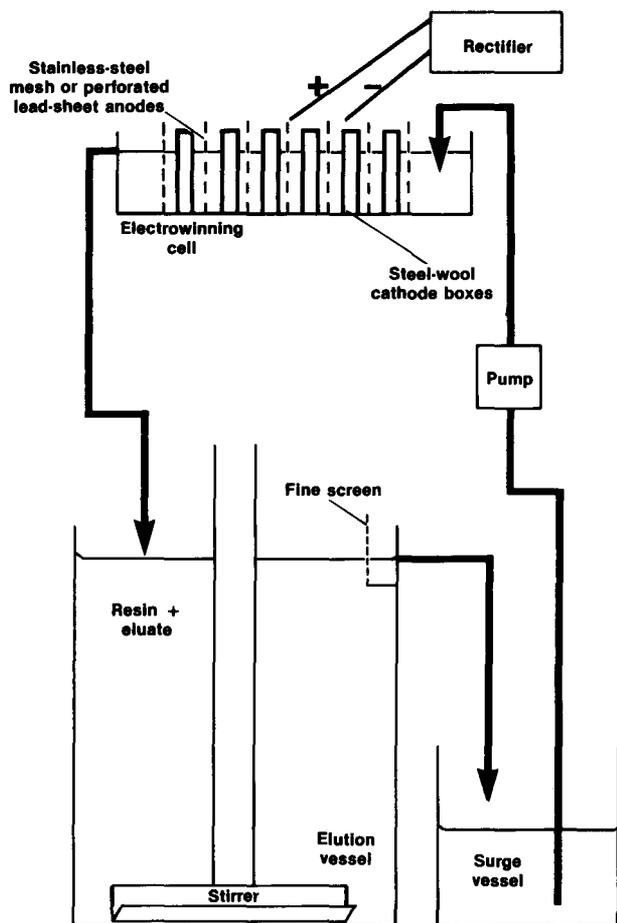


Fig. 2 — Apparatus for the electro-elution of gold cyanide from anion-exchange resins

feed material using the activated carbon Le Carbone G210AS. The flowrate of pulp, the carbon concentration, and the residence time of the carbon in each stage were the same as in the RIP run.

In each of the pilot-plant campaigns, the loaded resin was returned to Mintek for elution and regeneration. Much of the detailed chemistry involved in these two unit operations has already been reported², and the results given here are generally not the best obtainable since the optimum conditions had not been established at the time of the pilot-plant campaigns. The loaded strong-base resins from the Grootvlei and President Brand campaigns were eluted with a 0,5 M solution of zinc cyanide, $Zn(CN)_4^{2-}$. This species is loaded strongly onto anion-exchange resins, displacing the aurocyanide anion, $Au(CN)_2^-$, which, in the pilot-plant campaigns, was extracted continuously from the eluate by electrolysis. After being eluted, the resin is loaded with zinc cyanide and has to be regenerated before being recycled to absorption. This is achieved most conveniently by treatment of the resin with a dilute mineral acid, under which conditions the zinc cyanide complex decomposes. The weak-base resin from the Grootvlei campaign was eluted with 0,1 M sodium hydroxide and regenerated with dilute sulphuric acid. Elution and regeneration were carried out in an up-flow fluidized-bed column for the Grootvlei and President Brand campaigns. A schematic flowsheet of the overall RIP miniplant is shown in Fig. 1.

The following three eluants were evaluated and compared in the elution of the loaded strong-base resin from the Western Areas RIP campaign:

- (i) 1 M thiourea in 1 M sulphuric acid,
- (ii) 2 M ammonium thiocyanate, and
- (iii) 0,5 M zinc cyanide.

In the elution, 25 litres of resin was agitated mechanically in a cylindrical flat-bottomed tank with 160 litres of eluate. The eluate was pumped continuously through a fine screen (to prevent resin fines from entering the pump) into an electro-winning cell and back to the elution vessel at a flowrate of 200 l/h. The electro-winning cell consisted of seven anodes (dimensions 0,9 by 1,9 dm) with six cathodes (dimensions 0,9 by 1,9 by 0,4 dm) sandwiched between them. The cathode material was steel wool for all three eluants, and the anodes were made of perforated lead sheet for the thiourea and thiocyanate elutions, and of stainless-steel mesh for the zinc cyanide elution. The elution apparatus is shown in Fig. 2.

Results

Miniplant Campaign at Grootvlei

During the run with strong-base resin, the Mintek CIP pilot plant was operated on a parallel stream of feed material from the same storage vessel⁴. The results obtained in the two pilot plants are therefore directly comparable. (The campaign on weak-base resin was run several months later.) In the absence of kinetic effects (the mixing efficiency generally increases with decreasing size of contacting equipment), the main criteria in the comparison of data from the CIP and RIP plants are the concentrations of resin or carbon and the relative flowrates of pulp and of carbon or resin. In the Grootvlei pilot-plant investigation,

TABLE I
EXTRACTION RESULTS FROM THE RIP AND CIP PILOT PLANTS AT GROOTVLEI

Stage	Gold in solution, mg/l			Gold on resin, g/t			Extraction efficiency, %		
	SB RIP	WB RIP	CIP	SB RIP	WB RIP	CIP	SB RIP	WB RIP	CIP
Feed	2,63	2,06	2,81						
1	0,38	0,41	0,83	5 290	4 125	6 080	85	80	70
2	0,11	0,068	0,23	1 240	1 210	1 580	71	83	72
3	0,03	0,018	0,066	550	380	700	73	74	71
4	0,008	0,006	0,018	230	84	320	73	67	73
5			0,005			190			72

SB = Strong-base resin WB = Weak-base resin

TABLE II
ANALYSIS OF THE FEED SOLUTION AND LOADED RESIN OR CARBON FROM THE RIP AND CIP PILOT-PLANT CAMPAIGNS AT GROOTVLEI

Analysed	Metal concentration, g/t								
	Au	Ag	Cu	Ni	Ca	Fe	Si	Co	Zn
Feed solution	2,7	0,42	8,5	2,8	300	0,25	ND	0,32	1,7
SB resin	6 150	950	15 000	7 500	2 000	1 400	5 000	1 000	5 500
WB resin	4 753	215	14 600	10 940	1 700	1 665	2 415	1 270	3 100
Carbon	5 850	1 100	200	3 600	13 000	300	4 300	<100	<100

SB = Strong-base WB = Weak-base ND = Not determined

TABLE III
THE RECYCLING OF INSUFFICIENTLY ELUTED STRONG-BASE RESIN TO THE ABSORPTION PROCESS

	Gold concentration, g/t						Recycled resin
	Feed solution	Stage 1	Stage 2	Stage 3	Stage 4		
Solution	4,56	0,19	0,013	0,007	0,002		
Resin		7 310	488	70	22		0
Solution	2,30	0,31	0,038	0,022	0,019		
Resin		4 303	1 602	392	237		365
Solution	1,78	0,12	0,050	0,062	0,027		
Resin		5 794	1 400	840	870		960
Solution	2,40	0,27	0,054	0,033	0,089		
Resin		6 493	1 767	1 016	1 035		1 200

TABLE IV
THE RATES OF ELUTION OF LOADED STRONG-BASE RESIN WITH 0,5 M $Zn(CN)_4^{2-}$ AND OF WEAK-BASE RESIN WITH 0,1 M NaOH AT 20 °C

Time h	Strong-base resin		Weak-base resin	
	Gold in solution mg/l	Gold on the resin g/t	Gold in solution mg/l	Gold on the resin g/t
0	50	6 000	—	8 753
1	17	4 900	60	3 536
2	13	3 300	—	—
3	9	2 300	42	2 661
4	6	1 550	—	—
6	4	950	14	1 134
8	2,5	600	—	—
24	1,1	85	0,2	187

the concentrations of resin and carbon were both about 20 g/l, while the ratio of flowrates (on a mass basis) was about 2000 in each case. Table I shows the concentration of gold in solution, and on the resin or carbon. These results represent the average steady-state performance over a period of at least three weeks, in which solution profiles were measured three times a day and carbon or resin profiles once a day. The results indicate that the performance of the RIP and CIP plants was similar, with stage efficiencies of between 70 and 80 per cent, under the chosen operating conditions.

An average analysis of the loaded carbon or resin from stage 1 of the pilot plants is given in Table II. These results highlight the non-selectivity of anion-exchange resins, with the concentrations of copper, nickel, iron, cobalt, and zinc on the loaded resins significantly higher than on the loaded carbon. The fact that the gold-extraction efficiency was similar in the three pilot-plant campaigns can therefore be attributed to the higher loading capacity of resins than of carbon.

For a period during the run with strong-base resin, resin that had not been properly eluted was recycled to the

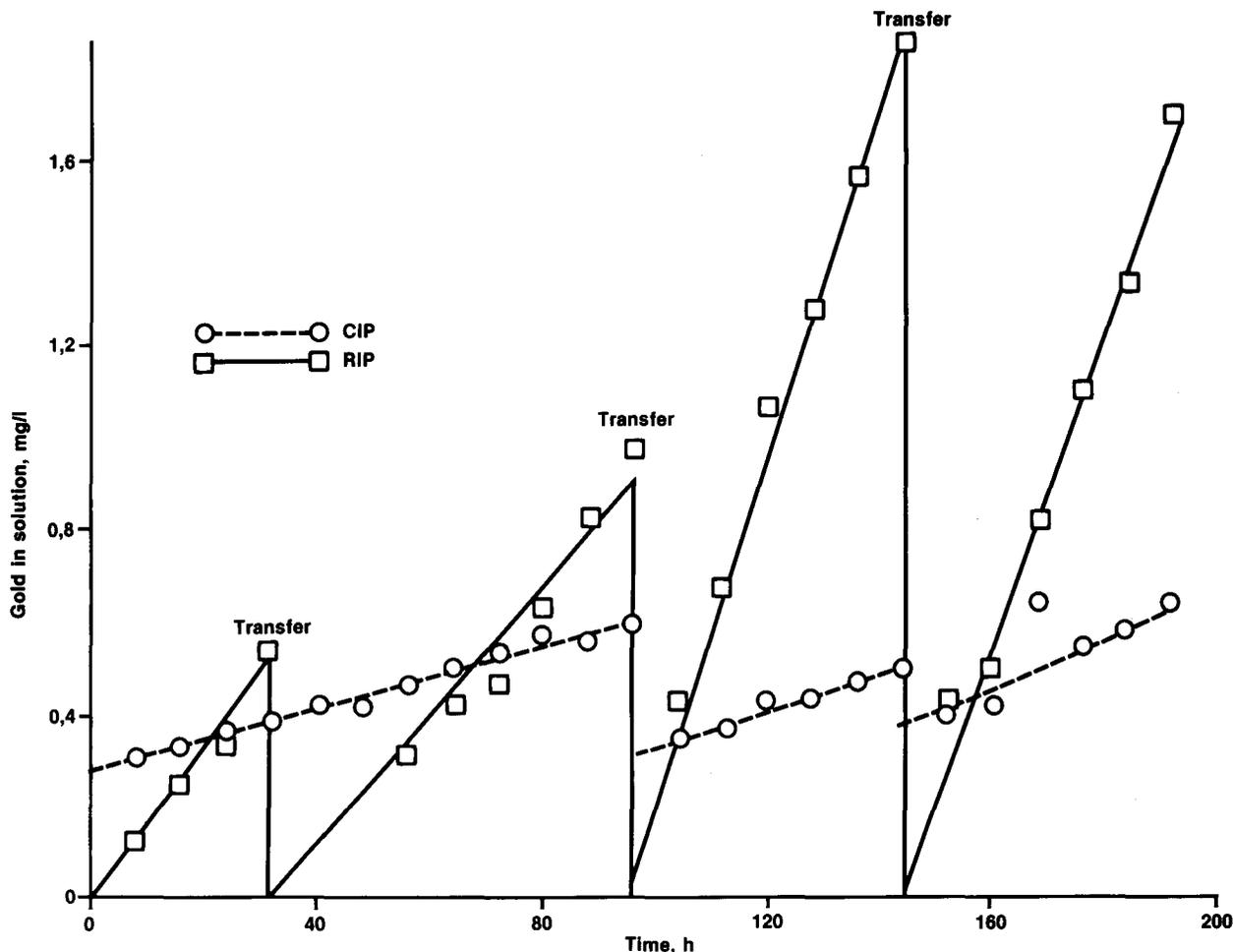


Fig. 3 — Concentration of gold in solution in the first extraction stage of the pilot plant at Western Areas

TABLE V
THE ELUTION EFFICIENCY OF VARIOUS ELEMENTS FROM LOADED STRONG-BASE RESIN WITH $Zn(CN)_4^{2-}$ (0,5 M) AND LOADED WEAK-BASE RESIN WITH SODIUM HYDROXIDE (0,1 M)

Metal ion	Concentration of metals, g/t			
	Loaded strong-base resin	Eluted strong-base resin	Loaded weak-base resin	Eluted weak-base resin
Gold	6 000	50	8 753	187
Silver	594	30	215	<20
Copper	14 400	360	14 600	3 250
Nickel	6 336	1 150	10 940	4 080
Calcium	1 870	900	1 700	600
Iron	1 530	440	1 665	1 780
Silica	4 360	850	2 415	70 000*
Cobalt	810	320	1 270	570
Zinc	6 370	110 000	3 100	3 100

* Probably contaminated

miniplant to show the effect of this on the solution profile and the losses of soluble gold from the plant. The results, which are presented in Table III, highlight the importance of good elution. For barren solutions containing less than 0,01 mg of gold per litre, the residual gold on the eluted resin should probably be less than 100 g/t.

Table IV shows the rate of elution of strong-base resins with zinc cyanide and of weak-base resins with sodium hydroxide. The concentration of gold in solution was reduced by the incorporation of an electrowinning cell in

the elution cycle. In the optimization of elution reported in an earlier paper², it was shown that elution rates considerably faster than those given in Table IV can be achieved by an increase in temperature, electrowinning efficiency, or concentration of eluant. The concentration of sodium hydroxide used in these experiments was, for example, too low and is the reason for the high value of gold on the weak-base resin after 24 hours of elution.

The elution of other metals from strong- and weak-base resins is shown in Table V. The elution efficiency of some of

TABLE VI
SOLUTION, RESIN, AND CARBON PROFILES IN THE RIP PILOT PLANT AND IN THE FULL-SCALE CIP PLANT TREATING CYANIDED CALCINE AT PRESIDENT BRAND GOLD MINE

Stage	Concentration of gold, g/t							
	First RIP run		Second RIP run		Third RIP run		CIP plant	
	Solution	Resin	Solution	Resin	Solution	Resin	Solution	Resin
Feed	6,10		5,35		5,59		5,30	
1	4,64	5 631	4,40	6 803	3,26	6 030	3,40	6 008
2	3,25	4 996	2,70	5 447	1,12	3 515	1,87	4 216
3	1,37	2 862	1,33	2 991	0,31	1 628	0,93	2 484
4	0,34	1 559	0,34	1 465	0,056	755	0,48	1 343
5	0,13	407	0,063	357	0,019	495	0,18	742
6							0,068	417
7							0,027	261

TABLE VII
ELUTION AND REGENERATION OF LOADED STRONG-BASE RESIN (A101 DU) FROM THE RIP PILOT PLANT AT PRESIDENT BRAND GOLD MINE
Conditions: $Zn(CN)_4^{2-} \approx 0,5M$, temperature 55°C, period of elution 24h

Metal ion	Concentration of metal, g/t		
	Loaded resin	Eluted resin	Regenerated resin
Gold	8 170	30	30
Silver	392	<20	<20
Copper	16 400	851	240
Nickel	5 390	998	400
Calcium	1 600	1 700	300
Iron	7 050	804	650
Silica	253	44	75
Cobalt	3 760	400	420
Zinc	11 400	106 000	3 200

the elements was poor (notably nickel and iron from the strong-base resin, and copper, nickel, iron, cobalt, and zinc from the weak-base resin), but there was no evidence of these elements building up on the resin in cyclic operation and no evidence of any adverse effect on the gold-extraction efficiency when the resin was recycled to the absorption process.

As shown in an earlier paper², all the base-metal cyanide complexes can be stripped from strong- or weak-base resins under optimum elution and regeneration conditions. During the miniplant campaign, the zinc cyanide and sodium hydroxide eluates were re-used for about ten batches of loaded resin. The concentration of the various base-metal cyanides in the eluate increased to between 2 and 15 g/l with no noticeable deleterious effects on either the elution or the electrowinning of gold, although this

could explain in part the poor elution efficiency of some of the base metals. RIP therefore offers the possibility that base metals can be recovered for their own commercial value, which, in the case of cobalt for example, could be significant.

During the Grootvlei campaign, eluted strong-base resin was regenerated with either sulphuric acid or hydrochloric acid in a batch reaction. The resin was stirred gently in a reaction vessel with about 1 bed volume of acid solution, which was maintained at a constant pH value by periodic additions of concentrated acid solution. At pH values of 2 or less, the zinc on the resin was generally reduced from about 100 000 g/t to less than 100 g/t in a period of 4 to 8 hours.

Pilot-plant Campaign at President Brand

The RIP pilot-plant results from the campaign at President Brand are compared in Table VI with the results from the full-scale CIP plant treating calcine at President Brand. The flowrate of calcine through the CIP plant was about 1200 t per day, while the flowrate of a parallel stream through the RIP pilot plant was 2,4 m³ per day. The pilot plant was run under several sets of operating conditions before optimum extraction efficiency was achieved. In the initial stages, the conditions established in the Grootvlei campaign were tested, but were found to be inadequate owing to the far higher concentration of base-metal cyanide complexes in the feed material at President Brand. (This is a feature that is common to calcines.) In the first run, the resin concentration was 4 litres per stage, the resin flowrate was 2 litres per day, and the average concentration of gold in the barren solution was 0,13 mg/l. In the second run, the resin flowrate was increased to 4 litres per day and the

TABLE VIII
AVERAGE CONCENTRATIONS OF GOLD IN SOLUTION AND ON RESIN OR CARBON DURING THE PILOT-PLANT CAMPAIGNS AT WESTERN AREAS

Stage	RIP Gold concentration in solution and on resin			CIP Gold concentration in solution and on carbon		
	Solution, mg/l	Resin, g/t	SE, %	Solution, mg/l	Carbon, g/t	SE, %
Feed	2,11			2,25		
1	1,12	4 780	47	0,52	3 905	77
2	0,29	2 590	74	0,073	805	86
3	0,039	490	87	0,024	130	67

SE = Stage extraction efficiency

concentration of gold in the barren solution dropped to 0,06 mg/l. Finally, in the third run, when the resin concentration was decreased to 2,5 litres per stage and the resin flowrate was increased to 5 litres per day, satisfactory performance was achieved in the pilot plant. The flowrate of pulp was 100 l/h throughout.

The pilot plant ran continuously for a period of a week under each set of conditions to allow the plant to come to an approximate steady state. The results under steady-state conditions are shown in Table VI, where they are compared with results from the full-scale CIP plant. The operating conditions during the third RIP run were very similar to the conditions on the CIP plant, i.e. the relative flowrates on a mass basis, of solution on the one hand and carbon or resin on the other hand, were about 1000, while the concentrations of resin (15 g/l) and of carbon (20 g/l) were also similar. The results in Table VI therefore indicate that a far better performance can be expected from RIP than from CIP in the treatment of calcines, gold values in the barren solution being lower after 5 stages of RIP than after 7 stages of CIP. Moreover, the superior performance of the resins was achieved despite the presence of high concentrations of the cyanide complexes of copper, nickel, and zinc. The superior performance of resin is due to the adverse effects in the CIP process of temperature (the temperature of the feed pulp was 40 °C) and the adsorption of calcine onto the surface of the activated-carbon granules^{5,6}. Neither of these parameters has a significant effect in the RIP process¹.

In a comparison of the results from the three RIP runs, it is interesting to note that the concentration of gold on the loaded resin was fairly constant at about 6000 p.p.m., despite an increase in the resin flowrate from 2 to 5 litres per day. This indicates that 6000 p.p.m. is the maximum loading that can be achieved for the President Brand calcine, and that, in the first two runs at least, true steady-state had not been reached.

Loaded strong-base resin from the pilot plant was returned to Mintek periodically for elution and regeneration. Zinc cyanide was used as the eluant throughout, and the concentration was maintained at about 0,5 M by the addition to the eluate of requisite amounts of zinc sulphate

and sodium cyanide 2 hours after the start of each batch elution. It was found that very good elution efficiencies could be achieved in 24 hours at a temperature of 55 °C.

The eluted resin was regenerated by a gentle agitation of the resin for 4 hours in a cylindrical flat-bottomed vessel with about 1 bed volume of sulphuric acid solution, which was maintained at a pH value between 1 and 2. Typical results for the elution and regeneration of loaded resin are shown in Table VII. Those batches of resin in which the concentration of gold on the resin after elution and regeneration was less than 50 p.p.m. were recycled to the last absorption stage of the pilot plant at President Brand Gold Mine.

Pilot-plant Campaign at Western Areas

The RIP run at Western Areas was carried out in the Mintek CIP pilot plant, which has been described in detail elsewhere⁴. One of the Browns tanks at Western Areas was isolated for this exercise, and a batch of 650 m³ of pulp was leached with cyanide. Pulp was drawn from this storage vessel at the rate of 800 l/h and pumped through three stages of extraction. The pilot plant was operated for 360 hours with resin and then for the same period with activated carbon. The concentrations of resin and carbon were the same (20 litres per stage, i.e. about 20 g/l), as were the relative flowrates of pulp and resin or carbon (about 3000 on a mass basis). The results obtained from the two pilot plants are therefore directly comparable. The average steady-state results for the three extraction stages are shown in Table VIII, from which it can be seen that CIP performed more efficiently than RIP in this application.

The lower extraction efficiency of RIP is due to the presence of relatively high concentrations of base-metal cyanide complexes in the Western Areas pulp. These species were loaded to high concentrations on the resin but were hardly loaded at all on the carbon (Table IX), and this results in poorer extraction of gold and silver in RIP than in CIP.

The results in Table VIII reflect the average solution, resin, or carbon concentration over the entire period of steady-state operation of the two pilot-plant campaigns. The results presented in Figs. 3 and 4, on the other hand, reflect the transient behaviour in the period between resin or carbon transfers, during which sampling and analysis were carried out every 8 hours.

The concentration of gold in solution in the first extraction stage is shown in Fig. 3, from which it can be seen that the variation in concentration was far greater in RIP than in CIP. In RIP the extraction efficiency in the first stage decreased from almost 100 per cent immediately after resin transfer to less than 20 per cent just before the next transfer; in CIP the variation between carbon transfers was from 86 to only 73 per cent. The very high efficiency just after resin transfer in RIP can be attributed to the inherently faster rate of extraction by resins, while the low efficiency just before resin transfer can be attributed to competition from another anionic species.

The transient behaviour in the resin and carbon phases is shown in Fig. 4. As might be expected for equivalent flowrates of resin and carbon at a constant flowrate of pulp, the

TABLE IX
CONCENTRATION OF VARIOUS ELEMENTS IN SOLUTION AND ON LOADED RESIN OR CARBON DURING THE PILOT-PLANT CAMPAIGNS AT WESTERN AREAS

Metal ion	Metal in solution, mg/l			Metal on resin or carbon, g/t	
	Feed	Residue RIP	Residue CIP	Loaded resin	Loaded carbon
Gold	2,20	0,04	0,02	5 660	5 530
Silver	0,48	0,12	0,01	700	810
Copper	9,55	<0,3	9,60	28 630	190
Nickel	8,32	<0,3	6,20	24 600	5 340
Calcium	ND	ND	ND	1 400	6 900
Iron	1,85	<0,3	1,80	5 910	360
Silica	ND	ND	ND	4 700	3 140
Cobalt	2,10	<0,3	2,20	5 920	<20
Zinc	1,45	<0,3	1,42	4 700	<200

ND = Not determined

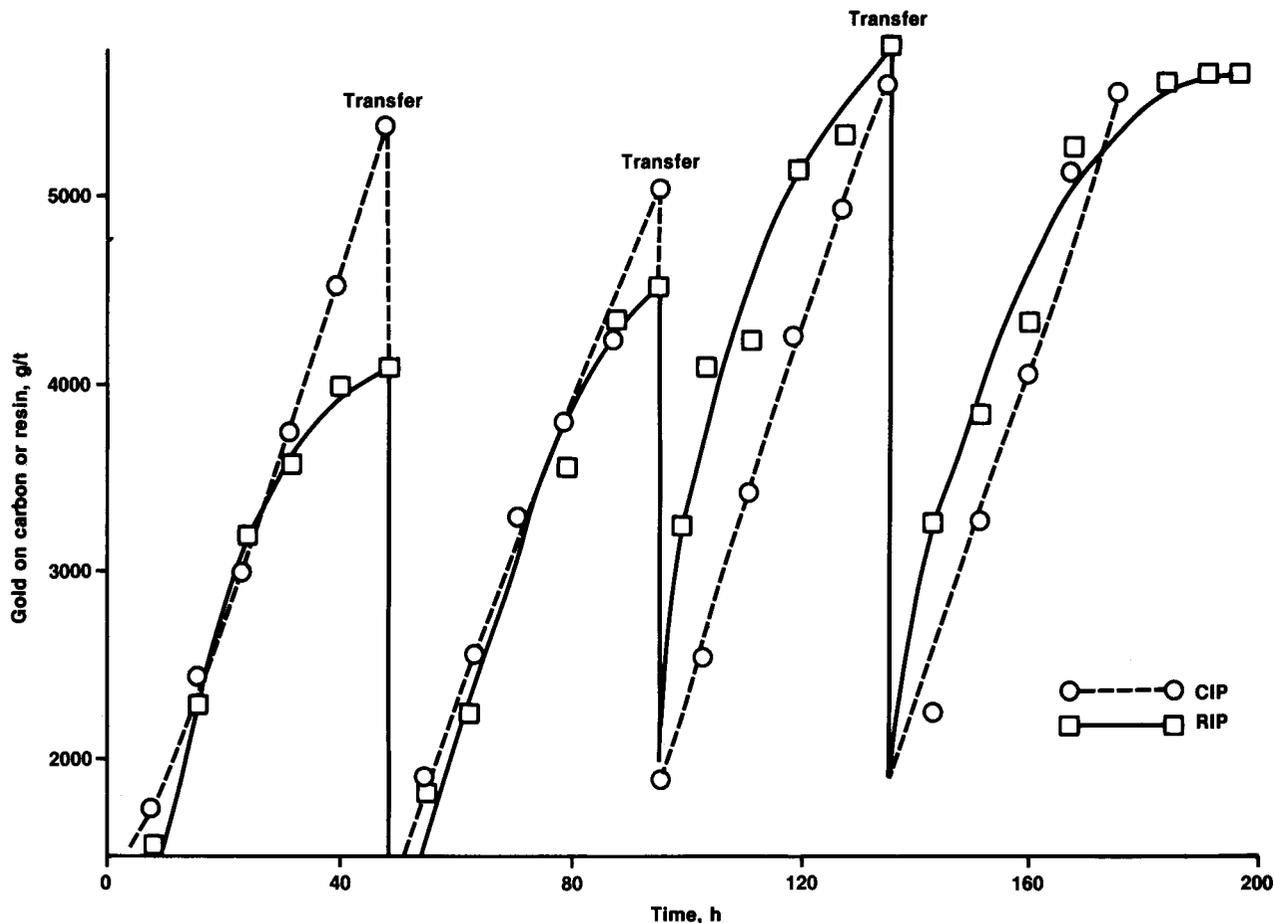


Fig. 4 — Concentration of gold on carbon or on resin in the first stage of the pilot plant at Western Areas

patterns are similar except that the carbon loading increases approximately linearly with time between transfers, whereas the resin-loading increase is non-linear, the initial rate being faster than in CIP and the final rate considerably slower.

The loaded resin from the RIP pilot-plant campaign was used in a comparison and evaluation of three eluants for strong-base resins. Apart from the efficiency of gold elution from the resin, other factors that were considered were the efficiency of elution of other elements, the efficiency and cost of electrowinning, and the consumption of chemicals in elution and regeneration.

The rates of elution are compared in Fig. 5, from which it can be seen that thiocyanate is the most efficient, followed by thiourea and zinc cyanide. In each case there was an initial rapid decrease in the concentration of the eluant, either because of decomposition (in the case of thiourea) or because of absorption on the anion-exchange resin (in the case of thiocyanate and zinc cyanide). So that the concentration of the eluant would remain as close as possible to the initial value, reagent was added to the eluant 6 hours after the start of each elution, and then periodically as required. The amount of reagent added during elution was used in an economic evaluation of the three techniques.

The rates of gold recovery by electrolysis (Table X) indicate that electrowinning efficiency is best in the zinc cyanide solution, followed by thiocyanate and thiourea.

The concentration of gold in solution is a reflection of the rate of elution, and the results in Table X mirror those in Fig. 5.

Another most important aspect of elution is the behaviour of metal complexes other than gold cyanide, and the results in Table XI show the concentrations of various elements on the resin both before and after elution with the three eluants. With zinc cyanide and thiocyanate, all the elements were reduced to acceptably low levels either during elution or during elution and regeneration. However, with thiourea the elution characteristics of copper, nickel, iron, cobalt, and zinc were all poor. In the case of cobalt, and to a lesser extent iron, this could cause severe operating problems since these species build up as 'poisons' to high levels on the resin, significantly reducing its ion-exchange capacity.

The operating costs of the three processes in terms of their consumption of reagents and electricity during both elution and regeneration were compared. The zinc cyanide process, at a cost of 5 cents per gram of gold recovered, was the cheapest, followed by the ammonium thiocyanate process (34 cents per gram of gold) and the thiourea process (37 cents per gram of gold). The high cost of the thiocyanate process is mainly due to the fact that no credit was given for the recycling of thiocyanate after the regeneration of the eluted resin. Work currently in progress indicates that this is technically feasible and could substantially

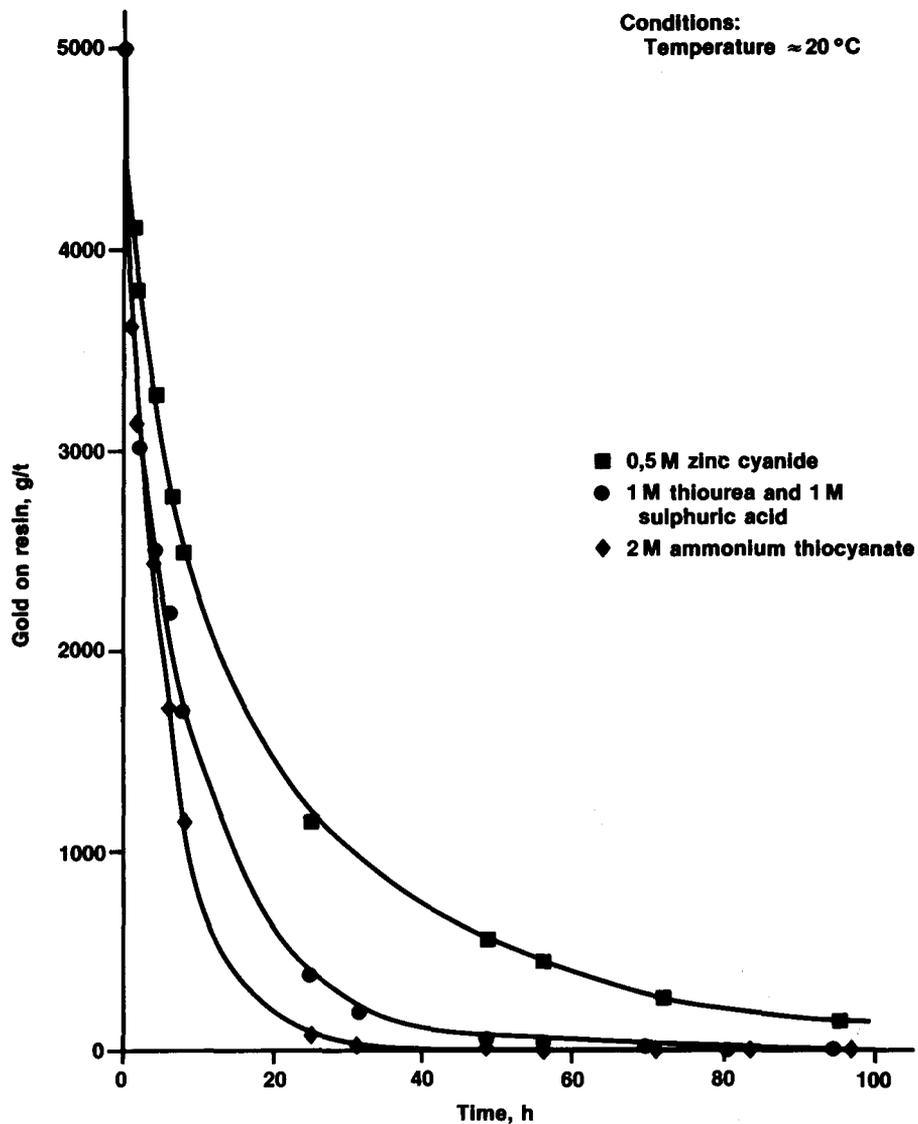


Fig. 5 — Rate of elution of gold from a strong-base resin with various eluants

TABLE X

RATES OF GOLD RECOVERY BY ELECTROLYSIS

Conditions: Cell current 22 A, cell voltage 2,8 V (NH_4SCN), 2,1 V (acid thiourea), 2,4 V ($\text{Zn}(\text{CN})_4^{2-}$), temperature $\approx 20^\circ\text{C}$

Time h	2 M NH_4SCN			1 M $\text{CS}(\text{NH}_2)_2 + 1 \text{ M H}_2\text{SO}_4$			0,5 M $\text{Zn}(\text{CN})_4^{2-}$		
	(Au) _{in}	(Au) _{out}	E, %	(Au) _{in}	(Au) _{out}	E, %	(Au) _{in}	(Au) _{out}	E, %
1	54	30	44	35	19	46	9,9	1,2	88
2	52	25	52	42	26	38	9,3	1,2	87
4	41	8,8	79	43	26	40	7,9	1,1	86
6	31	4,1	87	38	19	50	6,9	0,7	90
8	21	5,1	76	38	23	39	5,6	<0,5	>90
24	1,2	0,3	75	5,2	2,5	53	1,6	<0,5	
48	0,1	0,05	50	1,4	1,1	21	0,5	<0,5	
72	<0,05	<0,05		1,0	0,7	30	<0,5	<0,5	

(Au)_{in} and (Au)_{out} are concentrations of gold (milligrams per litre) in the solution entering and leaving the electrowinning cell, and E is the single-pass extraction efficiency in the cell given by $((\text{Au})_{\text{in}} - (\text{Au})_{\text{out}}) / (\text{Au})_{\text{in}}$

TABLE XI
CONCENTRATION OF VARIOUS METALS ON THE RESIN BEFORE AND AFTER ELUTION OF THE STRONG-BASE RESIN FROM THE WESTERN AREAS PILOT-PLANT CAMPAIGN

Metal ion	Loaded resin, g/t	Eluted resin, g/t		
		NH ₄ SCN	CS(NH ₂) ₂ /H ₂ SO ₄	Zn(CN) ₄ ²⁻
Gold	5 660	2	8	140
Silver	700	<50	<50	<50
Copper	28 630	<50	5 900	240
Nickel	24 600	1 600	8 700	3 000
Calcium	1 400	400	600	900
Iron	5 910	934	5 800	1 020
Silica	4 700	933	719	1 390
Cobalt	5 920	606	3 800	1 080
Zinc	4 700	2 500	3 400	105 000*

* Zinc concentration is reduced to 1000 g/t by acid regeneration

reduce the costs of this process. The high cost of the thiourea method is due to the rapid decomposition of this reagent in acid solution. While the absolute cost is undoubtedly subject to market conditions, the relative costs given here are probably a fairly accurate indication of the three processes. In this comparison, no attempt was made to quantify the costs of resin losses due to 'poisoning' or physical degradation of the resin beads. These losses would be highest in the acid-thiourea process.

Conclusions

Strong- and weak-base resins extract gold cyanide efficiently from pulps under the same operating conditions as those generally adopted in CIP processing. In situations where the concentration of competing anionic complexes in solution is low, resins are more efficient than activated carbon; where the concentration of competing anions is high, the reverse is generally true.

In the treatment of calcines, the gold-extraction efficiency of resins is significantly better than that of activated carbon. This is largely attributable to the fact that calcine is physically adsorbed on the surface of activated carbon (but not resins) and inhibits the mass transfer of gold cyanide to the carbon particles.

The concentration of gold on the resin should be reduced to less than 100 g/t during elution if the losses of soluble gold are to be less than 0,01 mg/l when the eluted resin is recycled to the absorption stages. This object can be achieved in a 24-hour elution cycle by the use of 0,5 M zinc cyanide solution for strong-base resins or 0,5 M sodium hydroxide solution for weak-base resins.

In an evaluation of three elution techniques for strong-base resins, the zinc cyanide method appears to be substantially cheaper than either the thiourea or the thiocyanate method. The rate of elution and the overall elution efficiency with thiocyanate are excellent and, if an efficient

method could be found for the recycling of the thiocyanate from the eluted resin, this method could compete with the zinc cyanide method. The thiourea method does not compare favourably with the other two methods for two reasons: firstly, the cost of the reagent is prohibitive owing to the decomposition of thiourea in acid solution and, secondly, the elution efficiency of base metals such as cobalt, iron, zinc, copper, and nickel is very poor.

Acknowledgements

This paper is published by permission of the Council for Mineral Technology (Mintek) and the management at Grootvlei, President Brand, and Western Areas. Dr M.J. Nicol's technical inspiration and enthusiasm for the RIP process are gratefully acknowledged.

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