

The recovery of gold from plant effluent by the use of activated carbon

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SYNOPSIS

The piloting and eventual large-scale operation of fixed-bed carbon columns for the recovery of gold from plant effluents is described.

A fixed-bed carbon pilot plant comprising three adsorption columns was used for the recovery of gold from clarified plant effluent at the Vaal Reefs Exploration and Mining Company (West Division). The effluent, which contained 0,1 to 0,5 g/t of gold and less than 10 g/t of free cyanide, was adjusted to pH 8 prior to use. Daily acid treatment of the carbon circuit with 3 per cent hydrochloric acid was shown to have a most significant effect on increasing the gold adsorption. The acid treatment involved a plant downtime of only 1 to 2 minutes per day. High loadings of gold (up to 30 kg/t) and copper (up to 75 kg/t) were obtained on the leading column, while the gold recoveries averaged 98 per cent over 17 weeks of continuous operation. The subsequent elution of loaded carbon in a pilot elution column indicated the use of abnormally high amounts of the pretreatment reagent (caustic soda and cyanide) used in gold elution. This was attributed to the high loading of copper on the carbon. However, the elution of both the gold and the copper at 110°C with demineralized water as the eluant was satisfactory.

In a similar large-scale operation, three fixed-bed carbon columns each containing 4,5 t of carbon were used to treat 80 to 120 t/h of plant effluent with a gold concentration of about 0,15 g/t. Gold loadings of 5 to 6 kg/t were obtained regularly, while the gold recovery averaged 97 per cent over a 12-month period. The capital cost of the plant was recovered in 2 to 3 months.

The evidence presented strongly suggests that copper plays a significant role in the adsorption and elution of gold under the prescribed conditions, and in the subsequent precipitation of gold following acidification of the eluates. The formation of a highly insoluble gold-copper complex produced under acid conditions appears to explain many of the observations made in the investigation.

SAMEVATTING

Die loods en uiteindelijke grootskaalse bedryf van vastebedding-koolstofkolomme wat vir die nawinning van goud uit aanleguitvloeiels gebruik word, word beskryf.

'n Vastebedding-koolstofloodsaanleg bestaande uit drie adsorpsiekolomme is vir die winning van goud uit verhelderde aanleguitvloeiels by Vaal Reefs Exploration and Mining Company (Wes-afdeling) gebruik. Die uitvloeiels wat 0,1 tot 0,5 g/t goud en minder as 10 g/t vrye sianied bevat, is vóór gebruik tot pH 8 aangepas. Daar is bewys dat die daaglikse suurbehandeling van die koolstofbaan met soutsuur van 3 persent 'n uiters belangrike uitwerking op die verhoging van goudadsorpsie het. Met die suurbehandeling was 'n staantyd van die aanleg van slegs 1 tot 2 minute per dag nodig. Hoë ladings goud (tot 30 kg/t) en koper (tot 75 kg/t) is op die leierkolom verkry, terwyl goudwinning oor 'n ononderbroke tydperk van 17 weke gemiddeld 98 persent was. Die latere uitwassing van gelaaiete koolstof in 'n loodsuitwassingskolom het die gebruik van buitengewoon hoë hoeveelhede van die byt-sianiedreagens, wat as voorbehandelingsmiddel by gouduitwassing gebruik word, getoon. Dit is toegeskryf aan die hoë lading van koper op die koolstof. Die uitwassing van goud sowel as koper by 110°C met die gebruik van gedemineraliseerde water as uitwasmiddel is egter bevredigend.

In 'n soorgelyke grootskaalse onderneming is drie vastebedding-koolstofkolomme wat elk 4,5 t koolstof bevat, gebruik om 80 tot 120 t/h aanleguitvloeiels te behandel wat ongeveer 0,15 g/t goud bevat. Goudafsettings van 5 tot 6 kg/t is gereeld verkry, terwyl goudwinning oor 'n tydperk van 12 maande gemiddeld 97 persent was. Die kapitaalkoste van die aanleg is binne 2 tot 3 maande verhaal.

Kragtens die bewys wat gelewer is, speel koper klaarblyklik 'n belangrike rol in die adsorpsie en uitwassing van goud onder die voorgeskrewe toestande asook met die latere presipitering van goud ná die aansuring van die uitwasmiddels. Die vorming van 'n hoogs onoplosbare goud-koperkompleks wat onder suurtoestaande gelewer word, is blykbaar 'n verklaring van baie van die waarnemings wat in die ondersoek gedoen is.

Introduction

Activated carbon is well known as a most efficient scavenger for gold from solutions containing less than 1 g/t of dissolved gold. In the South African gold-mining industry, there are a number of such process streams that lend themselves to the recovery of gold on activated carbon, yielding barren solutions with a gold content of less than 0,01 g/t. One such stream is the filtrate from the dewatering filters between gold and uranium plants. The filtrate from the West Uranium Plant, Vaal Reefs Exploration and Mining Co. Ltd, contains approximately

0,15 g/t of dissolved gold, and about 75 per cent of this solution reports to the slimes dams. No more than one-third of this liquor is returned to the plant.

This paper describes both the pilot operation and the first phase in the recovery of this dissolved gold from the dewatering filters that are at present in operation at the Vaal Reefs West Division.

Pilot Plant

To provide information for the design and operation of the production plant, a pilot operation was launched as a joint venture between Vaal Reefs Exploration and Mining Company Limited (V.R.E.M.) and Anglo American Research Laboratories (A.A.R.L.). The pilot plant comprised three columns operating in a conventional merry-go-round sequence. Influent through the circuit travelled downwards in order to promote a high shear situation that would be beneficial to the recovery of gold

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from very dilute solutions. Also, the use of higher flow-rates of influent was made possible by the downwards flow provided that excessive pressure drops across the circuit were not incurred. Apart from high flowrates, this would depend largely on the clarity of the influent as well as on the careful selection of carbon particle size.

The pilot-plant unit was sited at the V.R.E.M. West Gold Plant, where the recovery of gold from plant effluent was being investigated. This investigation concerned the operation of this pilot plant over 17 weeks of continuous operation, together with the subsequent elution of loaded carbon from the pilot plant. The precipitation of gold from pregnant eluates using sulphuric acid was also briefly considered.

Adsorption of Gold

Clarified gold-plant effluent was pumped through three Perspex adsorption columns in series (each column being 50 mm in internal diameter and 4,0 m long). Fig. 1 illustrates the flowsheet of the circuit, showing that a merry-go-round type of operation was carried out. The influent was pumped at a constant flowrate by use of a diaphragm metering pump. Each column was packed with activated carbon to a bed depth of 3 m, and the sampling points were positioned at 1 m intervals down the length of each column. At the top and bottom of each column were 0,25 mm resin strainers to support and confine the carbon bed during normal and backwashing cycles respectively. The columns were designated A, B, and C. Carbon was transferred to the columns by means of a water-pressurized cone-shaped transfer vessel. Samples of solution corresponding to each metre of carbon through the circuit were taken on a daily basis, while a daily composite drip sample was taken from each column.

Backwashing of individual columns with regional water was carried out at intervals, as was acid washing of all three columns. Acid washing involved the pumping of 20 litres of 3 per cent (vol./vol.) hydrochloric acid into the circuit, and then allowing for a 30-minute soaking period before continuing normal operation. When daily acid washing was undertaken later, 3 to 5 litres of 3 per cent (vol./vol.) hydrochloric acid was pumped into the circuit and normal operation continued, i.e. no soaking period was allowed.

Use was made of 0,8 to 1,2 mm type G215 coconut-shell activated carbon (Le Carbone Pty Ltd). This relatively small particle size of granular carbon and its narrow range were selected¹ so that the kinetic adsorption of gold would be maximized while the pressure drop across the circuit during pumping at relatively high flowrates would be minimized. The bulk density of the wet-settled carbon was 0,42 g/cm³.

Clarified plant effluent was neutralized with sulphuric acid and stored in a 500 m³ storage tank. The column influent was pumped at a flowrate of 2,5 l/min, corresponding to a superficial flow velocity of 1,2 m/min and resulting in a pressure drop across the circuit of 267 to 310 kPa. For the initial 72 days of continuous operation (Phase I), the column influent adjusted to pH 7,4 contained the following: gold 0,15 g/t, silver 0,006 g/t, calcium 560 g/t, copper 8,3 g/t, nickel 5,9 g/t, iron 0,09

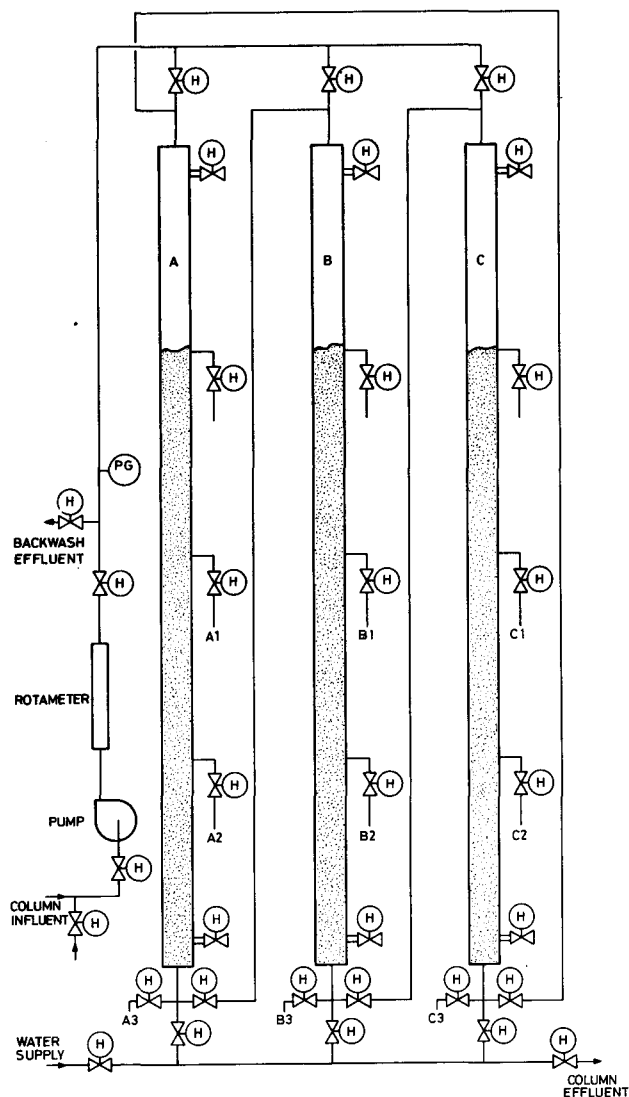


Fig. 1—The fixed-bed carbon pilot plant

g/t, cyanide ions less than 10 g/t, and suspended solids about 20 g/t.

The column influent for the subsequent 58 days of continuous operation (Phase II) adjusted to pH 8,0 contained the following: gold 0,49 g/t, silver 0,007 g/t, sodium 3440 g/t, calcium 771 g/t, copper 0,8 g/t, nickel 4,7 g/t, zinc 0,3 g/t, cyanide ions less than 10 g/t, and suspended solids about 30 g/t. This solution was used as column influent for 66 days prior to the refilling of the bulk storage tank and adjustment of pH (Phase III).

Elution of Gold

Loaded carbon from the lead adsorption column was removed in 1 m sections for analytical purposes before the three samples were composited and the gold eluted. Loaded carbon was transferred to an oil-jacketed stainless-steel elution column (50 mm in internal diameter and 4,0 m long) as illustrated in Fig. 2. The transfer of carbon was again effected by means of a water-pressurized cone-shaped transfer vessel. Excess solution was allowed to drain from the column before the tempera-

ture of the oil bath was raised to 112°C. Unless otherwise specified, the carbon was then pretreated with 6 litres of a reagent containing 5 per cent sodium cyanide and 2 per cent sodium hydroxide, which was pumped into the column through a stainless-steel heat-exchange spiral, also maintained at 112°C. The pretreatment reagent was pumped at a flowrate of 6 l/h, corresponding to a superficial velocity of 0,05 m/min. Gold was then eluted at the same flowrate by the use of distilled water², and the column eluate was collected in 2-litre fractions prior to analysis.

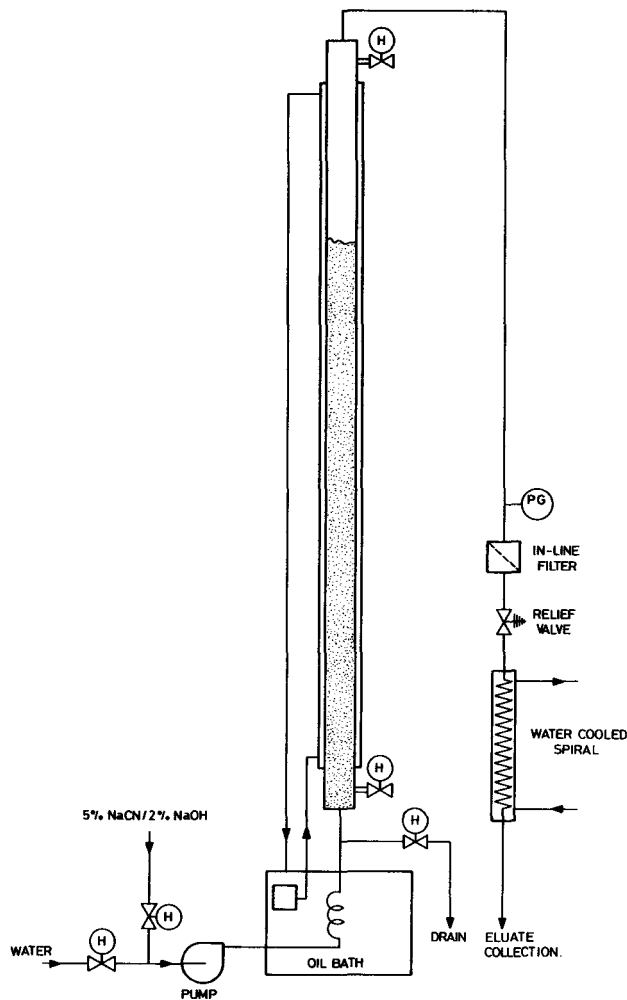


Fig. 2—The gold-elution pilot plant

The elution column together with the oil return-pipe line were well insulated with fibre glass, while pressure within the circuit was maintained at about 300 to 400 kPa by means of an adjustable relief valve. Under the above specified elution conditions, the temperature of the eluate from the top of the column was 109°C. Before being collected, the eluate was cooled by a water-cooled spiral.

Precipitation of Gold

Composite samples of eluate (1 litre each) from the elution column were acidified to a pH value of 1 by the use of sulphuric acid in a sealed 2-litre separating funnel agitated by a stirring mechanism. The resulting precipitate was allowed to settle before being collected for pressure filtration and analysis.

Pilot-plant Results

Adsorption of Gold, Phase I

Phase I entailed the treatment of a bulk solution with a gold content of 0,15 g/t. Table I gives a summary of the gold-adsorption results in the first five completed adsorption cycles during this period. The corresponding breakthrough curves for each metre of carbon through the circuit for the individual cycles are not presented.

TABLE I
OPERATION OF FIXED-BED CARBON PILOT PLANT

Adsorption cycle	Duration d	Average Au in daily effluent composites, g/t			Remarks
		1st column	2nd column	3rd column	
Phase I					
1A 1B 1C	15	0,054	0,011	0,003	
1B 1C 2A	11	0,098	0,050	0,005	
1C 2A 2B	7	0,125	0,063	0,003	
2A 2B 2C	10	0,116	0,038	0,002	
2B 2C 3A	29	0,094	0,040	0,004	20 litres of 3% HCl after 5, 10, 13, 23, and 39 days respectively
Phase II					
2C 3A 3B	0 to 33	0,184	0,055	0,002	20 litres of 3% HCl after 5, 15, 22, 28, and 33 days respectively
2C 3A 3B	34 to 45	0,073	0,020	0,004	3 litres of 3% HCl daily
2C 3A 3B	46 to 54	0,149	0,023	0,005	4 litres of 3% HCl daily
2C 3A 3B*	54 to 58	0,810	0,376	0,033	5 litres of 3% HCl daily
Phase III					
3A 3B 3C	12	0,541	0,137	0,009	4 litres of 3% HCl daily
3B 3C 4A	21	0,208	0,102	0,026	4 litres of 3% HCl daily

*Extremely hot weather on site with the effluent approaching 33 to 40°C

Apart from the duration of the individual cycles, only two operational changes were made. After the system was considered to be approaching equilibrium (illustrated by the considerable flattening of the breakthrough curves), the effects of backwashing and of acid treatment were investigated. In the first instance, during the cycle designated 2A 2B 2C, columns A and B were backwashed after 3 and 5 days respectively. The resulting effect on the gold adsorption was negligibly small, although a small decrease in pressure drop occurred across the circuit. In the second instance, acid washing of the columns during cycle 2B 2C 3A was carried out at

intervals of 5 to 8 days. The effect of the acid wash — 20 litres of 3 per cent (vol./vol.) hydrochloric acid — on the gold adsorption was seen to be most beneficial (see Phase II), with a consequent increase in the cycle time and gold loading. The average cycle time for the previous three cycles was about 9 days, whereas the cycle time for 2B 2C 3A was 29 days. Likewise, the average gold loading was about 1,6 kg/t, which subsequently increased to 3,0 kg/t (see below). The overall gold recovery during this period was more than 97 per cent, yielding effluent values with an average gold content of 0,004 g/t.

In the present investigation, use was made initially of the Bed Depth/Service Time (B.D.S.T.) model³⁻⁵ in an attempt to define the rate of advance of the adsorption reaction front. A plot of service time versus depth of carbon bed for adsorption indicated a linear relationship. For cycle 1A 1B 1C, where a solution front of 0,015 g/t of gold, corresponding to a gold recovery of 90 per cent, was used to define the reaction front, a critical bed depth of 0,70 m with the reaction front moving at 0,46 m per day was obtained.

The B.D.S.T. model thus appeared to have considerable promise in describing gold adsorption in a classical fixed-bed operation. However, with the advent of intermittent acid washing and its obviously beneficial effect on gold loadings and gold adsorption (cycle 2B 2C 3A), the system became too perturbed to be modelled in a simple fashion. Further attempts to model the gold adsorption were thus suspended.

Adsorption of Gold, Phase II

Phase II initially entailed the treatment of a bulk solution containing 0,49 g/t of gold and adjusted to pH 8,0. During the first cycle (2C 3A 3B), four operational changes were made. The first change involved the intermittent acid washing of the circuit with 20 litres of 3 per cent hydrochloric acid on a 5 to 10 day basis during the initial 33 days of the cycle. This acid-washing procedure was then changed to a daily operation entailing 3 litres of 3 per cent hydrochloric acid (34 to 45 days), which was then increased to 4 litres of 3 per cent hydrochloric acid (46 to 53 days), and finally to 5 litres of 3 per cent hydrochloric acid (54 to 58 days). The resulting breakthrough curves corresponding to each metre of carbon-bed depth during this cycle (2C 3A 3B) are presented in Figs. 3 and 4, while a summary of the operating data is given in Table I. The effect of these acid-washing procedures on the gold adsorption can be seen to be most significant. The gold recovery during the period 0 to 54 days exceeded 99 per cent, with gold effluent values averaging 0,003 g/t. The loaded carbon from this cycle had a gold concentration of 21 kg/t. The gold loading actually approached 30 kg/t on the lead column after 53 days but, owing to the extreme temperature conditions encountered on the site during the 54 to 58 day period (the hottest summer temperatures in 53 years, with the column influent approaching 40°C), considerable elution of gold from the lead column to the second column took place. This effect is well illustrated in Fig. 4.

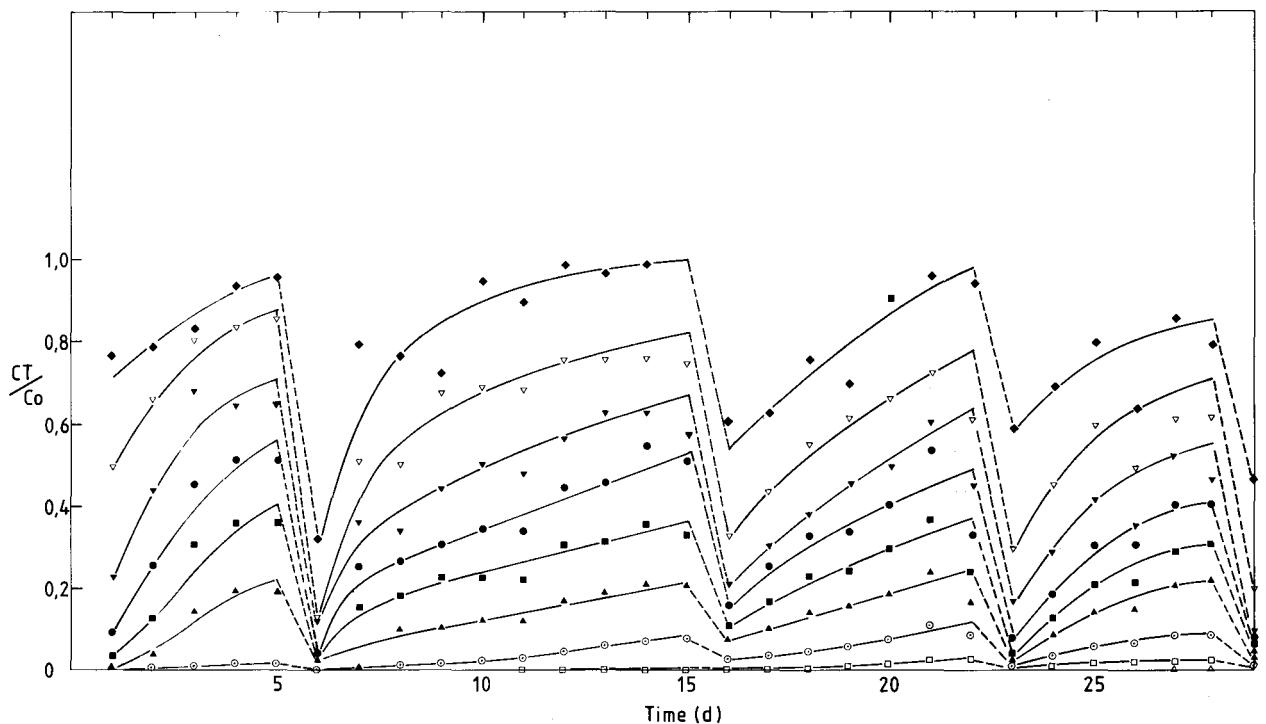


Fig. 3—The effect of periodic acid washing on the gold adsorption in a fixed-bed pilot plant
 CT = gold concentration in effluent at specified depth of carbon bed; Co = gold concentration in column influent; break-through curves correspond to each metre of bed depth of carbon in the circuit as follows:

- ◆ = 1 m
- ▽ = 2 m
- ▼ = 3 m
- = 4 m
- = 5 m
- ▲ = 6 m
- = 7 m
- = 8 m
- △ = 9 m

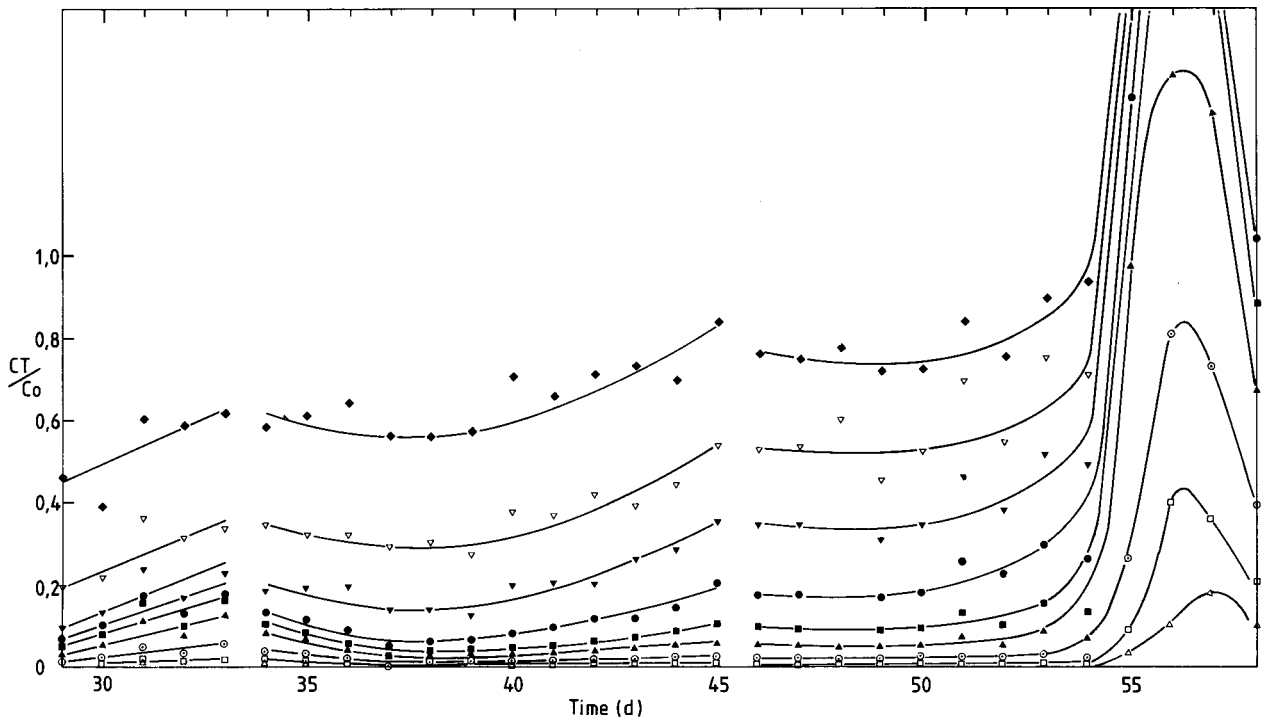


Fig. 4—The effect of daily acid washing on the gold adsorption in a fixed-bed pilot plant
Designations to the individual breakthrough curves are similar to those in Fig. 3; breaks in the curves coincide with the refilling of the bulk storage tank

Adsorption of Gold, Phase III

The next adsorption cycle (3A 3B 3C of Phase III) was carried out at pH 8.5, using a daily acid wash of 4 litres of 3 per cent hydrochloric acid as described above. The resulting breakthrough curves indicated that the refilling of the bulk storage tank after 9 days of operation had a very serious adverse effect on the gold adsorption. This effect was almost certainly due to an increase in the pH value of the influent. The gold in the column effluent during this period averaged 0.009 g/t, corresponding to a gold recovery of 98 per cent, while the leading column (3A) averaged 16 kg/t of gold and 44 kg/t of copper (Table II).

The next cycle (3B 3C 4A) was carried out at pH 7.0 using a daily acid wash of 4 litres of 3 per cent hydrochloric acid as described above. The daily sampling of effluent from each metre depth of carbon bed was discontinued at this stage of the investigation. Compared with the earlier adsorption results, the gold recoveries were not good during this cycle — the gold in the column effluent averaged 0.026 g/t, corresponding to a gold recovery of only 91 per cent (Table I). Loaded carbon from column 3B averaged 18 kg/t of gold and 58 kg/t of copper. The excessive loading of copper at this lower influent pH may well be the cause of the poor adsorption response observed. (Although copper has been shown to irreversibly 'fix' gold under the prescribed acid-washing conditions, an excessive loading of copper may well physically passivate the carbon.)

Composition of Loaded Carbon

Table II lists the composition of the loaded carbon

taken from the circuit during Phases I to III. The high loadings of copper (up to 53 kg/t), zinc (up to 21 kg/t), and nickel (up to 16 kg/t) are immediately evident under normal operation (i.e. no acid washing) and can be compared with the loadings achieved using a daily acid wash, when high loadings of gold (up to 22 kg/t) and copper (28 to 58 kg/t) and low loadings of nickel, zinc, and calcium are evident. There was no progressive build-up of either silica or calcium, while the loading of iron and cobalt was negligible.

Elution of Gold

Owing to the high loadings of base metals, copper in particular (Table II), the elution of the loaded carbon initially presented some problems. The excessive consumption of reagent, yielding low eluate pH levels (pH 8 to 9), resulted in the precipitation of calcium silicate in the eluate pipe lines while also adversely affecting the gold elution. The eventual use of larger volumes of the pretreatment reagent (5 per cent sodium cyanide and 2 per cent sodium hydroxide) was found to overcome these problems. Table III gives further elution results from this aspect of the investigation, while Fig. 5 illustrates the elution of gold and copper from the loaded carbon of 2C (adsorption cycle 2C 3A 3B).

Precipitation of Gold

The acidification of column eluates (see above) to pH 1 by the use of either hydrochloric acid or sulphuric acid resulted in the precipitation of more than 99 per cent of the contained gold from solution⁶. The resulting precipitate was a mixed gold-copper cyanide compound.

Adsorption Isotherms

As a result of the findings obtained from the fixed-bed miniplant, a series of equilibrium adsorption experiments was performed in borate buffer⁷ at pH 7 with copper-loaded carbon in both the absence and presence of cyanide. The copper was initially loaded on the carbon as a cyanide complex.

In the absence of cyanide, the adsorbed copper had little influence on the gold adsorption. Linear isotherms were obtained following a $\log_x\text{-}\log$ plot, compared with the slightly curved isotherms for borate buffer. There was

little difference between carbon loaded with 13 kg of copper and that loaded with 32 kg of copper per ton of carbon.

In the presence of 200 mg/l of sodium cyanide, the gold loading was considerably lower for the copper-loaded carbon. The k -values were 30,5 and 27,5 kg of gold per ton of carbon for the carbon loaded with 13 and 32 kg of copper per ton of carbon respectively, compared with a k -value of 40 kg/t for the virgin carbon. The k -value is defined as the gold loading in equilibrium with 1 g/t of gold in solution.

TABLE II

THE COMPOSITION OF LOADED CARBON FROM THE FIXED-BED CARBON PILOT PLANT

Loaded carbon from lead column	Constituent, kg/t						
	Au	Ag	Cu	Ni	Zn	Ca	SiO ₂
1A1	1,86	0,02	32,2	11,4	—	7,0	1,61
1A2	1,92	0,03	32,6	14,0	17,0	7,5	1,16
1A3	1,48	0,03	31,6	15,3	—	7,8	1,09
1B1	1,60	0,02	51,0	13,9	—	7,2	—
1B2	1,46	0,03	50,3	14,6	—	7,6	—
1B3	1,36	0,02	47,9	16,2	—	7,6	—
1C1	1,69	0,03	53,4	14,9	20,5	7,3	1,45
1C2	1,56	0,03	48,3	13,6	18,6	7,9	1,22
1C3	1,45	0,03	42,9	12,7	16,6	7,3	1,22
2A1	1,68	0,04	74,6	16,3	0,77	0,20	1,23
2B1	3,41	0,04	55,7	22,2	0,23	0,21	1,31
2B2	2,80	0,04	52,3	17,0	0,17	0,33	1,40
2B3	2,66	0,04	48,3	17,1	0,17	0,47	0,58
2C1	20,10	0,16	28,3	0,82	0,02	0,58	1,25
2C2	21,70	0,18	35,0	1,03	0,03	0,27	0,58
2C3	20,59	0,02	37,6	0,10	0,01	0,32	0,68
3A1	15,19	0,17	45,3	7,44	1,15	5,62	1,55
3A2	16,30	0,19	43,4	6,28	0,88	4,17	1,22
3A3	16,11	0,23	43,4	5,47	0,66	3,45	1,10
3B (Composite)	17,59	0,33	57,8	2,28	0,21	0,56	0,91

Note: The loading of Fe and Co in column 1C averaged 60 and 80 g/t respectively

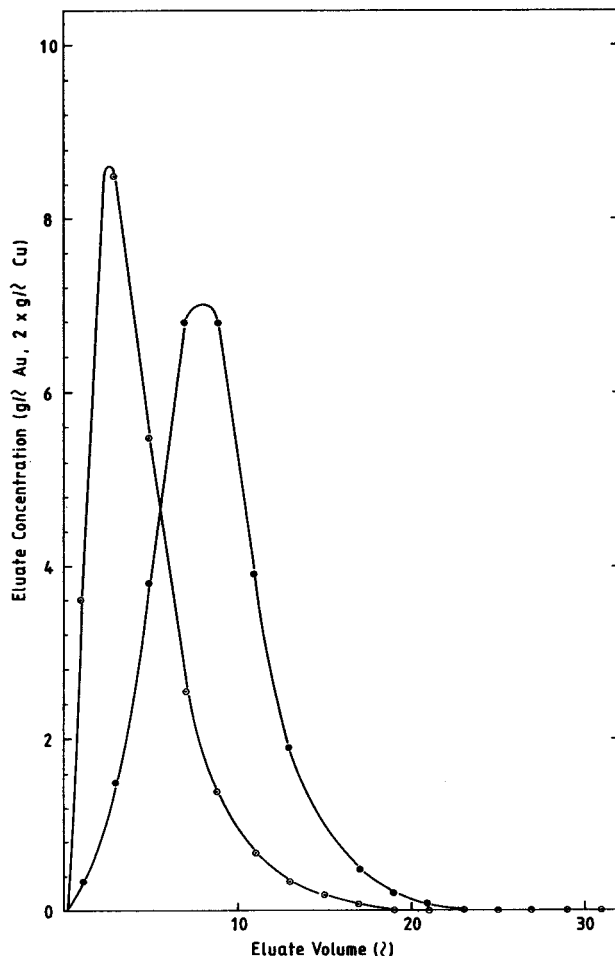


Fig. 5—The elution of gold (shaded) and copper (unshaded) in the elution pilot plant

TABLE III

THE COMPOSITION OF ELUTED CARBON FROM THE FIXED-BED CARBON PILOT PLANT

Eluted carbon from lead column	Pretreatment reagent		Constituent, g/t						
	Quantity, litre	Composition	Au	Ag	Cu	Ni	Zn	Ca	SiO ₂
1A	5	5% NaCN-0,5% NaOH	9	1	7	13	626	4350	714
1B	5	5% NaCN-0,5% NaOH	10	1	75	20	49	4170	978
1C	5	5% NaCN-1,0% NaOH	58	5	1055	23	102	4540	1130
2A	6	5% NaCN-2,0% NaOH	116	22	4010	92	89	416	579
2B	6	5% NaCN-2,0% NaOH	300	51	3610	1168	73	354	540
2C	8	5% NaCN-2,0% NaOH	36	37	73	13	16	332	678
3A	8	5% NaCN-2,0% NaOH	127	29	48	—	—	—	—
3B	8	5% NaCN-2,0% NaOH	283	—	50	20	40	2400	1280

Optimum results were obtained with copper-loaded carbon (13 kg of copper per ton of carbon) after acid washing (3 per cent hydrochloric acid) and in the absence of cyanide. After acid washing, the k -value was 70 kg compared with 42,5 kg for the virgin carbon. When the carbon was loaded with 13 kg of copper plus 21 kg of gold per ton of carbon and subsequently acid-washed and re-equilibrated with gold solution, a k -value of 80 kg of gold per ton of carbon was obtained. (In the presence of 200 mg/l of sodium cyanide, the k -values were 28,5 and 31 kg under the same conditions as above, compared with 40 kg for the virgin carbon.)

In many respects, the above results confirm earlier findings⁸ on the use of copper sulphate to chemically regenerate used carbon. The formation of a highly insoluble gold-copper cyanide compound following such treatment (see earlier) could explain the irreversible character of the mechanism, together with the abnormally high gold loadings achieved — concentration factors of 3000 to 5000 are often obtained in a conventional carbon-in-pulp operation, which can be compared with the concentration factor of about 60 000 obtained in the present work.

Full-scale Plant

Following the successful pilot-plant testwork, it was decided that a carbon-column plant should be built to treat approximately half the plant effluent from the West Uranium Plant, i.e. 120 kt of solution per month. On site at the plant were 24 obsolete columns that had originally been used in the ion-exchange plant for uranium extraction. Three of these columns were moved over to the gold plant, lined with rubber, and fitted with stainless-steel screens, top and bottom. The column dimensions were 3,70 m long by 2,14 m in diameter. After the screen installation, each column was filled with 4,5 t of G210 carbon (Le Carbone (Pty) Ltd) with a particle size of 0,6 to 1,7 mm. The bulk density of this carbon was 0,55 g/cm³.

Filtrate from the uranium plant was clarified in gold-plant leaf clarifiers and then pumped to 500 m³ holding tanks, where the pH value was adjusted to 7,5 as in the pilot-plant operation. These tanks were open to the sunlight, which would assist in destroying the cyanide. The pilot-plant testwork had shown that this was the optimum pH value for gold loadings, possibly because it reduced the cyanide content of the feed and increased the loading of copper. Several problems were experienced on the initial water commissioning owing to buckling of the screens and subsequent bypassing of carbon. Thus, the carbon had to be removed and more substantial screen supports installed with associated rubber sealing. After one week of water commissioning, gold-bearing filtrate was introduced to the columns in March 1982. Composite samples were taken daily from each column so that an accurate picture could be obtained of the gold loadings across the system.

Results for the first hundred days of operation are presented in Table IV. As can be seen, the progressive gold adsorption decreased steadily in the lead column (A) over the 100 days, but the barren solution from column C rose to 0,021 g/t of gold with an average plant-

feed value of 0,145 g/t. A decision was made to keep the same operating sequence until a definite gold 'break-through' occurred in the lead column (A). This actually happened after 112 days of operation, when the samples of feed and barren solution for column A contained 0,094 and 0,208 g/t respectively. Whether this was due to self-elution was not known.

TABLE IV
OPERATION OF THE FULL-SCALE PLANT

Run- ning time d	Progressive gold adsorption %	Gold loading, kg/t		
		Column A	Column B	Column C
1	99,23	0,1015	0,0023	—
10	98,79	0,8712	0,0207	0,0040
20	98,40	1,3609	0,1241	0,0263
30	98,50	2,0981	0,3736	0,0560
40	98,32	2,7781	0,6266	0,1391
50	97,38	3,3677	0,9258	0,2628
60	95,82	3,8477	1,3046	0,4257
70	95,60	4,4556	1,5450	0,6238
80	95,24	4,9174	1,8530	0,8833
90	93,95	5,0532	2,0210	1,1760
100	93,26	5,1571	2,2025	1,3039

The plant was closed down and backwashed with regional water, and the loaded carbon was pumped out of the lead column. After the column had been recharged with fresh carbon, the plant was restarted in the merry-go-round sequence. Since then, this self-elution or breakthrough phenomenon has occurred at regular intervals of 100 to 120 days, after which the loaded carbon in the lead column has been recharged. The recovery of gold from the plant effluent has, however, averaged 97 per cent over a 12-month period.

Loaded carbon from the columns was withdrawn, dried, and thoroughly mixed. The samples were analysed at V.R.E.M., A.A.R.L., and the Rand Refinery laboratories, and it is gratifying to note that the three gold loadings recorded were always within very close agreement. For example, the first batch of carbon analysed by the three laboratories gave gold loadings of 5,0 kg/t, 5,1 kg/t, and 5,1 kg/t. Up to now, three batches of carbon have been incinerated at the Rand Refinery, giving a total mass of gold recovered of 72 kg, i.e. approximately 24 kg of gold per loaded column. As the total capital cost of the plant including the first 17 t of carbon was R210 000, it can be seen that the first batch of loaded carbon paid for the plant. The operating costs were extremely low excluding the carbon costs.

At present, a second series of three columns is being erected and modified alongside the first full-scale plant, to treat all the effluent from the West Uranium Plant. One of the disappointing features of the full-scale operation was its inability to treat 120 kt of effluent per month, which corresponds to a feed rate of 166 t/h. The plant was able to run at only 120 t/h, which slowly decreased to 80 t/h. As a matter of routine, the columns were treated daily with 0,2 bed volume of 3 per cent (vol./vol.) hydrochloric acid, which resulted in a pressure drop across the circuit and thus maintained acceptable feed rates. When the feed rate was increased to more than 120 t/h, the stainless-steel support screens flexed, with a resultant

loss of carbon to the spillage area. The columns were not backwashed at regular intervals because of the absence of suitable screens positioned at the top of each column. Such backwashing would have improved the plant capacity. Thus, for the six-column plant, the screens will be six radial spirally wound distribution candles at the top and bottom of each column. These will not be able to flex, and it is hoped that they will promote higher throughputs and gold loadings because of better feed distribution. The six-column plant was scheduled for commissioning in April 1983.

As far as future work is concerned, an exercise is being carried out in conjunction with V.R.E.M. East Division. That division is planning to commission a similar plant in 1983, and a critical survey is being conducted of the economics of an elution-regeneration system for the loaded carbon from both divisions. No decision had been made at the time of writing.

Discussion

Vaal Reefs West Gold Plant, like many other South African plants, utilizes rotary-drum filters to dewater the leached slime prior to gold precipitation. This process obviously depends very much upon vacuum efficiency, filter-cloth and wash efficiency, etc. Thus, a finite amount of gold always leaves the plant as effluent gold and reports to the slimes dams. With the introduction of the carbon columns as a 'scavenger' circuit, this gold loss has been reduced substantially. The cost of the gold recovery, excluding carbon, is very low.

An added advantage is that the barren solution from the columns is extremely clear, and is bled straight into water tanks as a replacement for river water. Not only does this contribute directly to a saving of river water, but it also results in a cost saving seeing that river water is currently charged at about 4 cents per cubic metre. If the full-scale plant generates approximately 200 kt of solution per month, this represents a saving of R8000 per month to the company.

The evidence presented in this study indicates the very significant role played by copper in gold adsorption, elution, and precipitation. The formation of a highly insoluble copper-gold complex in all three processes is strongly suggested. When the evidence is related to the gold-adsorption mechanism proposed by McDougall *et al.*⁹, it strongly supports the concept that the specific character of gold adsorption is related to the solubility of the adsorbed species.

When this mechanism is related to established obser-

vations, it becomes evident how decreases in temperature, cyanide concentration, and pH all tend to decrease the solubility of the adsorbed species. The subsequent acid-washing of the loaded carbon and the resultant formation of a highly insoluble gold-copper complex (see gold precipitation) would thus effectively regenerate the carbon and so promote further gold adsorption. Of course, such a mechanism would proceed only at low concentrations of cyanide and/or at low pH values owing to the solubility of the complex in alkaline cyanide solutions⁶. Such a mechanism can be expected to become very sensitive to changes in temperature, cyanide concentration, and pH at high gold loadings, which would explain the self-elution of gold that was observed in both the pilot-plant and the full-scale operations. It can thus be seen that the formation of this insoluble gold-copper complex appears to play a most significant role — not only in the adsorption of gold, where significant effects have been demonstrated — but in the elution of gold and its subsequent precipitation after acidification of the eluate. A simple reversal of the chemistry involved in each instance would explain many of the observations made in the present investigation.

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