The development of a carbon-in-pulp in-column contactor for the recovery of gold from cyanided pulps

by A. Mehmet*

SYNOPSIS

The feasibility of employing a multi-stage column for the recovery of gold from cyanided pulps using extruded carbon was investigated on a pilot-plant scale. It was anticipated that the column contactor would have certain advantages over conventional carbon-in-pulp plants. The feed pulp was screened to remove particles larger than 200 μm and was diluted to a solids concentration of about 23 per cent. The column was operated continuously for 24 days at a pulp flowrate of about 60 l/min and a carbon flowrate of 44 litres per day. The average gold concentrations in the barren pulp 12 hours and 24 hours after the carbon transfer were 0,012 and 0,031 mg/l respectively. The average gold concentration in the solution phase in the feed was about 2,0 mg/l. The average gold loading on the carbon was 6290 g/t.

Calcium carbonate was removed from the loaded carbon by treatment with 0,5 bed-volumes of 2,8 per cent hydrochloric acid solution at ambient temperature. The calcium concentration was reduced from about 17 000 to about 500 g/t. The carbon was eluted by the Zadra procedure at atmospheric pressure. The results of the elution were highly satisfactory, the gold concentration being reduced from about 6000 to about 20 g/t in 48 hours. The eluted carbon was regenerated in a Rintoul kiln at about 700°C. The activity of the regenerated carbon was found to be at least as high as that of fresh carbon.

SAMEVATTING

Die uitvoerbaarheid van die gebruik van 'n meertrapkolom vir die herwinning van goud uit gesianidiseerde pulp met gebruik van uitgeperste koolstof is op 'n proefaanlegskaal ondersoek. Daar is verwag dat die kolomkontaktor sekere voordele bo die konvensionele koolstof-in-pulpaanleg (KIP) sou hê. Die toevoerpulp is vooraf gesif om partikels groter as 200 μm te verwyder en is daarna verdun tot 'n vaste stofkonsentrasie van omtrent 23 persent. Die kolom is 24 dae lank ononderbroke bedryf met 'n pulpvloeitempo van ongeveer 60 l/min en 'n koolstofvloeitempo van 44 liter per dag. Die gemiddelde goudkonsentrasie in die bar pulp was 12 en 24 uur na die koolstofoordrag onderskeidelik 0,012 en 0,031 mg/l, en die gemiddelde goudkonsentrasie in die toevoer was in die oplossingfase ongeveer 2,0 mg/l. Die gemiddelde goudlading op die koolstof was 6290 g/t.

Kalsiumkarbonaat is uit die gelaaide koolstof verwyder deur dit by omgewingstemperatuur met 0,5-laagvolumes van 2,8 persent-soutsuuroplossing te behandel. Die kalsium-konsentrasie is van ongeveer 17 000 tot ongeveer 500 g/t verlaag. Die koolstof is by atmosferiese druk volgens die Zadra-prosedure geëlueer. Die resultate van die eluering was uiters bevredigend en die goudkonsentrasie is in 48 uur van ongeveer 6000 tot ongeveer 20 g/t verlaag. Die geëlueerde koolstof is in 'n Rintoul-oond gereaktiveer by omtrent 700°C. Daar is gevind dat die aktiwiteit van die gereaktiveerde koolstof minstens so hoog soos dié van vars koolstof is.

INTRODUCTION

The successful application of carbon-in-pulp (CIP) technology to the recovery of gold from cyanided pulps is now recognized as the most significant development in the extractive metallurgy of gold since the Merrill–Crowe zinc-precipitation process. The lower capital cost of CIP plants, which was made possible by the elimination of the expensive filtration step, has shown the benefits of this route for the recovery of gold from high-grade ores and low-grade materials (e.g. tailings from previous operations).

The CIP process involves contacting of cyanided pulp with carbon, acid treatment, and elution of the loaded carbon and, finally, thermal regeneration of the carbon, which is then recycled to the adsorption circuit. Although CIP technology has reached a stage where all these operations are conducted with high efficiency, the major gold-producing countries are currently continuing with extensive research programmes to optimize this new process. It appears that the research efforts at present are aimed mainly at improving the efficiency of existing equipment (e.g. the development of more efficient interstage screens) without changing the basic design of

CIP plants. While these innovations are certainly necessary to make the CIP process more cost-effective, an alternative approach is the development of a CIP plant that is entirely different in concept from the conventional design. For instance, instead of improving the efficiency of interstage screening, the development of adsorption vessels without interstage screens could be considered.

The satisfactory performance of the NIMCIX contactor (a multi-stage fluidized-bed column) in the recovery of gold from various solutions using activated carbon suggested that a column contactor similar to the NIMCIX design could be employed for the adsorption duty in the CIP process. It was expected that a multi-stage fluidized-bed column would have the following benefits compared with the conventional CIP design:

- a significant reduction in the size of the adsorption stages because of a much higher concentration of carbon in the pulp;
- the elimination of mechanical agitators, interstage screens, and interstage carbon-transfer pumps, which would reduce the abrasion of carbon in the adsorption circuit;
- gentler agitation of the carbon, which would permit the use of softer and, possibly, more active carbon;
- a stable carbon inventory in each adsorption stage;
- more efficient contacting of pulp and carbon, owing to the minimization of back-mixing, bypassing, dead spaces, etc;

- the uniform transfer of carbon between adsorption stages in a much shorter time;
- the ability to handle wood chips and wood fibres;
- the ability to treat partially loaded carbon with acid solution in the column, avoiding the interstage mixing of carbon.

In view of these considerations, the suitability of a multi-stage fluidized-bed column for the recovery of gold from cyanided pulps using activated carbon was investigated on a pilot-plant scale. The major objectives of the pilot-plant campaign, which was carried out at Durban Roodepoort Deep Gold Mine, were as follows:
- to determine the metallurgical efficiency of the contactor for the recovery of gold;
- to establish the hydraulic behaviour of pulp and carbon in a multi-stage fluidized-bed column, i.e. to determine the flow patterns of pulp and carbon, the stability of operation, etc.; and
- to investigate the suitability of the acid-treatment, elution, and regeneration procedures for the extruded carbon that was used in this work.

This paper describes the pilot-plant work on the carbon-in-pulp in-column (CIPIC) contactor, and the results of the investigation.

DESCRIPTION OF THE PILOT PLANT

The Adsorption Column

The column had an internal diameter of 25 cm and 13 stages, each with a height of 93 cm. The top stage had a freeboard of 107 cm to prevent the carry-over of carbon out of the column. The stages were separated by perforated plates. A schematic drawing of the column is shown in Figure 1.

The operation of the column entailed three phases, which can be summarized as follows.

Pulp Forward-flow Period. The pulp is introduced into the column through the apex of the conical bottom, and flows upwards, fluidizing the carbon in each stage. This is the period during which the carbon is loaded with gold. The barren pulp flows into an overflow launder and leaves the column via the barren-pulp outlet.

Carbon-settling Period. The pulp entering the column is taken out through an outlet situated on the side of the conical bottom (outlet M in Figure 1), thus interrupting the flow of pulp through the column. This allows the carbon to settle on the perforated plates in each stage, so that a stable transfer of carbon between the stages is achieved during the next phase. The settling period at the pilot plant was about a minute, and is not expected to be longer than that in a commercial operation.

Carbon-transfer Period. The carbon outlet valves situated immediately above the bottom plate (Figure 1) are opened, and the loaded carbon in the bottom stage is withdrawn from the column. The pilot-plant column had two outlets situated opposite each other. A column of much larger diameter would require more than two outlets to ensure a uniform transfer of carbon from the bottom stage, i.e. to prevent the withdrawal of partially loaded carbon from
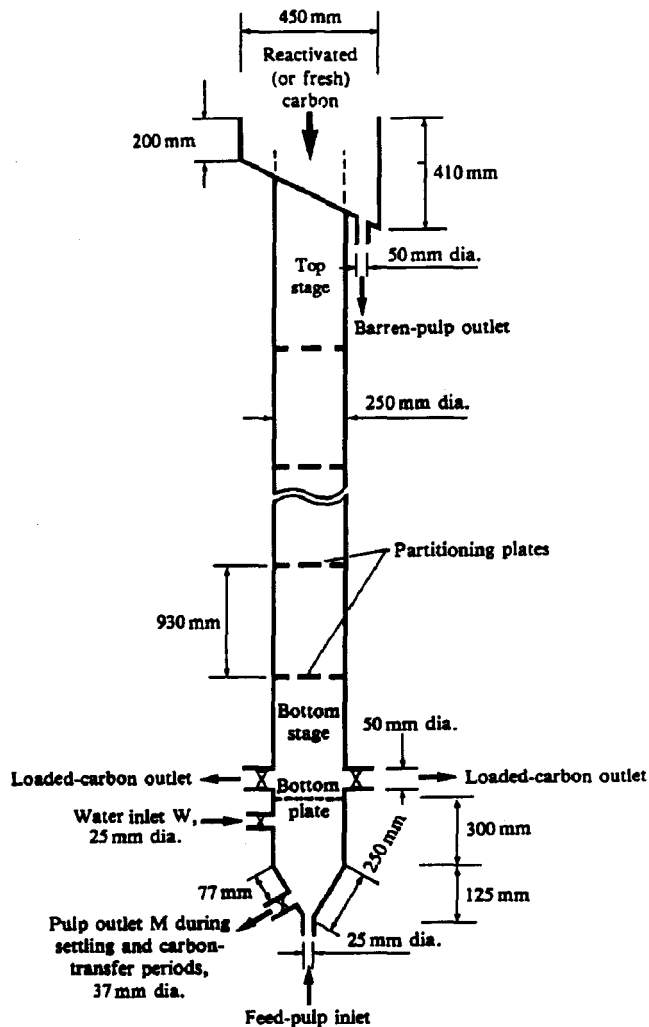

Figure 1—A schematic diagram of the adsorption column

the upper stages. The carbon and pulp flowing out of the column is directed onto a screen, which separates the loaded carbon from the pulp. The pulp is recycled to the pulp storage tank and the carbon is transported to the loaded-carbon storage tank. The withdrawal of loaded carbon from the column causes a downward flow of an almost identical amount of carbon through the stages so that, at the end of the carbon-transfer period, all the stages, with the exception of the top stage, contain nearly the same amount of carbon as before the transfer. After the withdrawal of the required volume of carbon, the carbon outlet valves are closed. An equivalent quantity of regenerated carbon is transported into the top stage, and the pulp forward-flow period is started by the closing of outlet M.

In order to withdraw the specified amount, the loaded carbon at the pilot plant was transferred with the carbon outlet valves only partially open. As a result, the carbon-transfer operation was completed in about 5 minutes.

During the carbon-settling period (i.e. when there is no flow of pulp through the column), there is a very slight downflow of carbon through the stages because of carbon particles falling through the perforations of the partitioning plates. In a situation when there is a deficiency of carbon in

the bottom stage (or in the lower stages) after the carbon transfer, the forward-flow period is delayed, and the column is 'kept' in the settling mode until a slight excess of carbon accumulates in the bottom stage. This can be observed through the sight glasses in each stage, or can be determined by the use of instruments that measure the carbon level. The forward-flow period is then started, and the carbon is fluidized in each stage. As a result of fluidization, any excess carbon in the bottom stage (or in the lower stages) is redistributed to the upper stages. This ensures a uniform carbon inventory in all the stages of the column.

The Partitioning Plates and the Bottom Plate

The column is partitioned by perforated plates to minimize the axial mixing of carbon through the column during the forward-flow, carbon-settling, and carbon-transfer periods. Extensive axial mixing results in carbon with a high gold loading being carried to the upper stages. This reduces the extraction efficiency in these stages, and results in a higher gold concentration in the barren pulp.

The plates partitioning the column were designed to meet the following primary objectives:

- the satisfactory fluidization of carbon in each stage,
- a uniform downflow of carbon through the stages (i.e. when the loaded carbon is withdrawn from the column), with minimum abrasion of the carbon, and
- a minimum downflow of carbon between the stages when there is no upflow of pulp through the column.

The requirements for the bottom plate are different, and necessitate a different design to meet the following objectives:

- the satisfactory fluidization of carbon in the bottom stage, and
- no downflow of carbon through the perforations during the carbon-settling and carbon-transfer periods.

In other words, the design of the bottom plate should ensure that the amount of carbon falling through this plate would be negligible in order to maintain a uniform carbon inventory in each stage of the column.

Results of preliminary testwork at Mintek in a transparent multi-stage column of 50 cm diameter were used in the design of the partitioning plates and the bottom plate. The main parameters that determine plate design are the diameter and the total area of holes (free area) in a plate. The holes in the partitioning plates were 15 mm in diameter, and those in the bottom plate were 7,5 mm in diameter. The free area on a partitioning plate was 9 per cent of the area of the plate, and that on the bottom plate was 7,6 per cent of the area of the plate. Further information on the design of the plates is available in a South African patent[1].

Carbon Suitable for Fluidized-bed Operation

A major requirement for the operation of fluidized-bed columns is a uniformly expanded bed with a high concentration of adsorbent at the desired flowrates of fluid passing through the column.

Preliminary testwork at Mintek using the 50 cm diameter transparent column showed that this requirement could not be met with coconut-shell carbon. At the desired flowrates of pulp through the column, the fluidization of the carbon bed was very irregular, some particles of carbon settling on the plates, and some being entrained in the pulp and flowing out of the column. It is believed that this behaviour is the result of the irregular shape and size of the carbon particles. However, it was expected that extruded carbon, which has completely regular shaped particles and a small size range, could be used in this application. Subsequent tests with Norit RO 3515, which had carbon particles with an average diameter of 1,4 mm and an average length of 3,5 mm, indicated that a uniformly fluidized bed with a high concentration of carbon particles (e.g. 200 g of carbon per litre) could be obtained at the desired flowrates of pulp through the column. Owing to its high activity for the adsorption of gold from cyanided pulps, Norit RO 3515 was chosen for the pilot-plant campaign. It is recommended that the suitability of extruded carbon having larger particles should be investigated since this could allow the use of higher flowrates of pulp through the fluidized carbon bed.

Operating Conditions

The Adsorption Circuit

In fluidized-bed columns, the density of the fluidizing medium should be somewhat lower than the density of the fluidized solids to prevent the transport of particles out of the column. Preliminary testwork in the 50 cm diameter transparent column showed that pulps with a density of 1,20 g/cm³ (i.e. 26,5 per cent solids) could readily pass through the fluidized bed at the desired flowrates without the carry-over of carbon particles out of the column. It was also observed that the fluidization of the carbon bed at various flowrates of pulp was remarkably uniform, with the fluidized-bed having a high concentration of carbon particles (e.g. 150 to 200 g of carbon per litre).

It was decided to operate the pilot-plant column at a pulp density slightly lower than 1,20 g/cm³, and a value of about 1,17 g/cm³ was used. This corresponded to a solids concentration of about 23 per cent in the pulp.

In order to ensure stable operation of the column, any accumulation of solids from the feed pulp in the column should be prevented. The settling of solids would depend mainly on the particle size and the superficial velocity of pulp through the column. It is obvious that a sufficiently high flowrate of pulp through the column would prevent the settling of coarse solids. This, however, may not always be feasible since the velocity of the pulp through the column should be low enough to prevent the transport of carbon particles out of the column. Even when the carbon particles are not carried out, a high pulp velocity results in a lower concentration of carbon in the fluidized bed (because of higher bed expansion), which would then require more adsorption stages to achieve the specified gold recovery. This may not be desirable if the increase in the capital cost of the column becomes significant. It was thought that a practical alternative would be offered by the screening of the coarse solids from the pulp so that the column could be operated at a reasonable pulp flowrate. A maximum particle size of 200 μm was specified for the solids in the feed pulp to the column.

The pre-treatment of cyanided pulp would therefore consist of screening at 200 μm and dilution. The pulp could be diluted before, during, or after screening, as shown in Figure 2, depending on which method would be most suitable. The barren pulp from the column would be treated (e.g. in a thickener) to recover the solution, which would then be used for the dilution of incoming cyanided pulp. The barren pulp, having the same density as the cyanided pulp before dilution, would be pumped to the slimes dam (Figure 2).

The cyanided pulp at the Durban Roodepoort Deep Gold Mine had a gold concentration of about 2,2 mg/l, which would be reduced to about 0,7 mg/l after dilution. As this would be too low to be representative of most commercial operations, the cyanided pulp was diluted with pregnant solution from the filter plant. The arrangement used at the pilot plant is shown in Figure 3. The cyanided pulp from the pachucas was screened on a KHD Humbold–Wedag microscreen[2], which is a polyurethane screen mounted on a vibrating frame and inclined at an angle of 42 degrees. The upper half of the screen had slots measuring 12,5 mm by 300 μm, and the lower half had slots of 12,5 mm by 160 μm. Although it was specified that screening would be carried out at 200 μm, a slot size of 12,5 by 300 μm was used in the upper deck so that a higher screening capacity could be achieved.

The screen underflow, which had a solids concentration of about 53 per cent, was pumped into a 350 m³ storage tank, in which it was diluted to about 23 per cent solids

with pregnant gold solution. The dilute pulp in the storage tank was agitated by air. The pH value of the diluted pulp ranged between 10,1 and 11,3.

The adsorption column was operated continuously for 24 days at a pulp flowrate of about 60 l/min, which produced a bed expansion of about 150 per cent. The carbon concentration in the pulp at this bed expansion was about 150 g/l.

The superficial velocity of the pulp through the column was about 2,0 cm/s. Based on this velocity, the residence time of the pulp in the column was calculated as about 9,6 minutes. Since the residence time of the pulp in a conventional CIP plant is about 360 minutes, the advantage of the column contactor over much smaller equipment becomes obvious. Although, because of the dilution of the feed pulp, a column contactor has to handle 2,7 times more pulp (on a volume basis) than a conventional CIP plant, the reduction in equipment size is still impressive. On the assumption that the column will need 17 stages (each 1 m high) to achieve the required gold extraction (which will be discussed later), the volume of the contactor will be reduced approximately 9,4 times.

The flowrate of carbon was 44 litres per day. The stage inventory was about 18,5 litres, and hence more than two stage inventories were transferred per adsorption cycle. This may not be the best procedure, and a better alternative would be the transfer of a stage inventory of carbon (at an increased frequency of carbon transfer) so that any axial mixing of carbon in the column can be minimized.
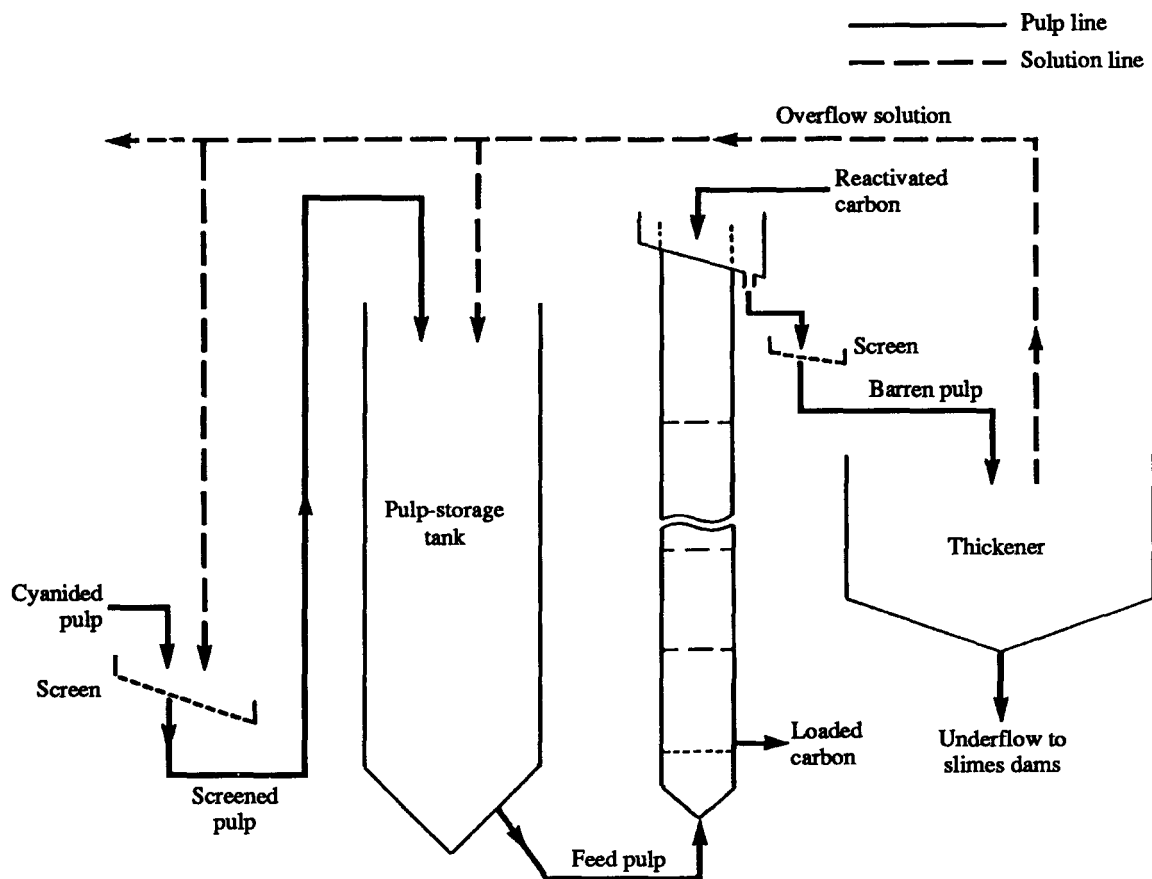

Figure 2—Conceptual flow chart of the adsorption section of the CIPIC plant
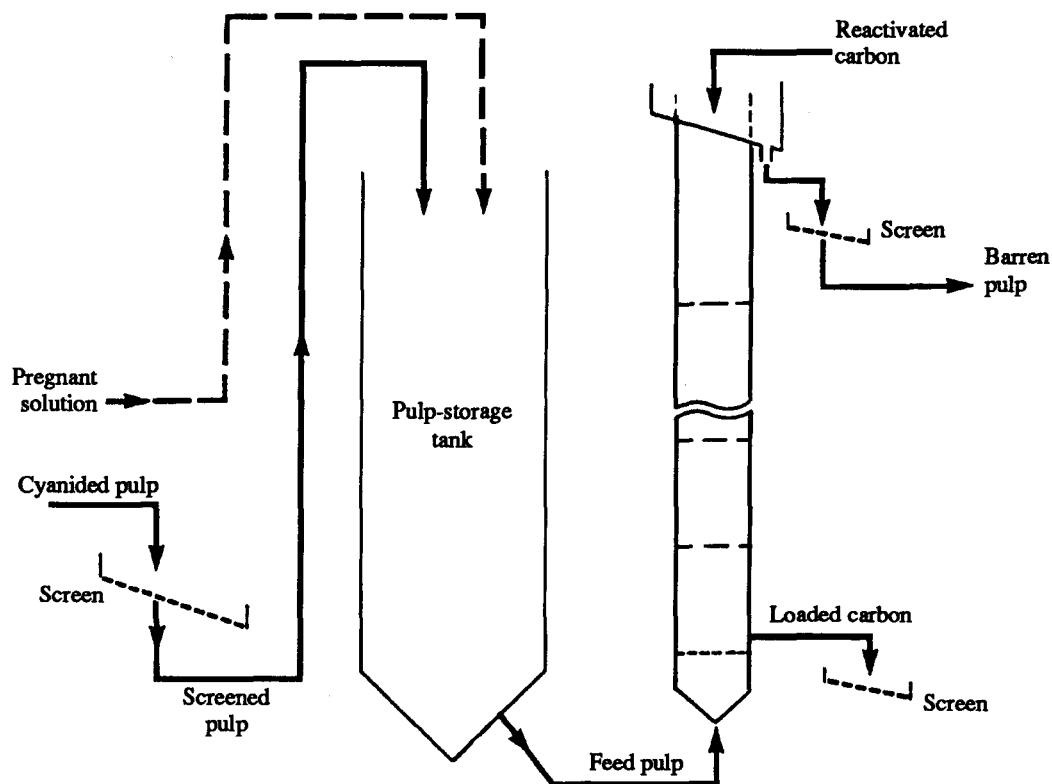
Figure 3—The adsorption section at the pilot plant

The availability of the column for the adsorption duty, i.e. the pulp forward-flow period, was approximately 99,3 per cent of the cycle time.

Acid Treatment, Elution, and Regeneration

The carbon was contacted with 0,5 bed-volumes of 2,8 per cent (28 g/l) hydrochloric acid solution in the elution column for 24 hours at ambient temperature (about 20°C). Each batch of carbon comprised about 180 litres. Following the acid treatment, the carbon was washed with sodium hydroxide solution (4,5 g/l) to neutralize the acid remaining in the pores of the carbon.

The carbon was eluted by the atmospheric Zadra process[3], i.e. using a solution of sodium hydroxide and sodium cyanide at a temperature of about 92 to 95°C.

Each batch of carbon (about 180 litres) was eluted for two days. During the elution, the concentration of cyanide ions in the eluant was maintained between about 80 and 1100 mg/l. The pH value of the eluant was maintained at or above 13 (to avoid the corrosion of the Type 316 stainless-steel anodes in the Mintek electrowinning cell[4]) by the periodic addition of sodium hydroxide to the eluant. The spent eluant was re-used in successive elutions to reduce the consumption of reagents. The amount of sodium cyanide added per elution was about 2000 g, and the amount of sodium hydroxide varied between 2500 and 5500 g.

The carbon was regenerated in a Rintoul kiln[5] at about 700°C with superheated steam passing through the carbon bed for 20 minutes at a flowrate of about 15 kg/h. A detailed description of the elution–electrowinning circuit and the regeneration kiln has been given elsewhere[6].

RESULTS AND DISCUSSION

Adsorption of Gold and Other Species

In cyclic countercurrent operations, i.e. with a continuous flow of pulp and a periodic flow of carbon, the concentration of gold in the barren pulp is lowest immediately after the carbon transfer, and increases until the next carbon transfer, as illustrated in Figure 4. Hence, the average concentration of gold in the barren pulp can be determined from a composite sample consisting of a combination of spot samples that are taken at equal intervals during the adsorption cycle. As this procedure required additional manpower, it could not be carried out at the pilot plant, where the cycle time was 24 hours. Instead, two spot samples were obtained from the barren pulp during each cycle, 12 hours and 24 hours after the carbon transfer. The 24-hour sample would show the highest gold concentration in the barren pulp during each adsorption cycle.

Typical recoveries of gold from the feed pulp are presented in Table I. The average gold concentration in the barren pulp at the 12th hour was 0,012 mg/l. This is very close to the target value of 0,01 mg/l or less. The average gold concentration in the barren pulp at the 24th hour (i.e. at the end of the cycle) was significantly higher, at 0,031 mg/l. This indicates that the operating conditions should be altered so that the gold concentration in the barren pulp remains at or below the target level during the entire adsorption period. The average gold concentration on the loaded carbon was 6290 g/t.

The concentration profile of gold in the pulp and on the carbon along the column just before carbon transfer is shown in Table II. The results show a high gold loading on
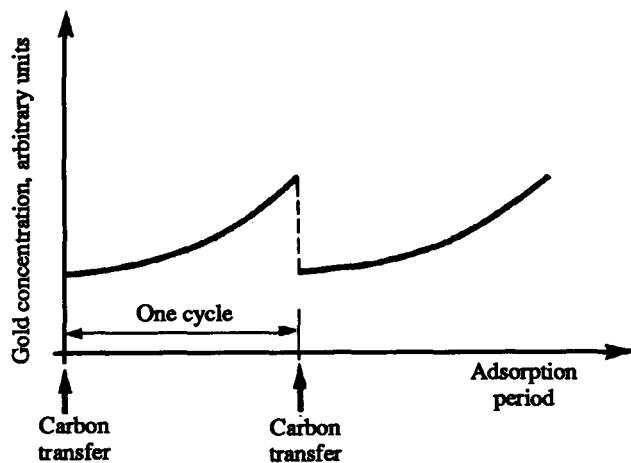
Figure 4—Variation of the gold concentration in the barren pulp during a cyclic countercurrent operation

increase in the cost of acid treatment, elution, and regeneration in terms of the gold recovered.

At present, it is estimated that a column with 17 stages will produce barren pulps with a gold concentration of less than 0,01 mg/l during the entire adsorption cycle.

The concentrations of all the metals of interest (including gold) in the feed and barren pulp, the adsorption of these species at the 24th hour, and the loading of these metals onto the carbon are shown in Table III. The adsorption of silver (68,8 per cent) is significantly lower than that of gold (98,4 per cent), while the adsorption of base metals is extremely low. These results show that silver and base metals cannot be recovered simultaneously with gold (for their economic value or for pollution control) by carbon under the conditions employed at the pilot plant.

The high loading of calcium indicates that the carbon should be treated with hydrochloric acid solution before it is recycled to the adsorption column. The concentration of calcium on the carbon along the column just before the carbon transfer is shown in Table IV. It can be seen that almost all the calcium is loaded in the top stage.

the carbon in the upper stages, especially in the top stage of the column. This high gold loading decreases, or probably stops, the adsorption of gold from the pulp in the top stage, causing the high gold concentration in the barren pulp towards the end of the cycle. These results suggest that the gold concentration in the barren pulp can be lowered by an increase in the number of adsorption stages and/or the use of a higher flowrate of carbon. The first alternative will increase the capital cost of the plant (this cost increase will not, however, be significant), while the second alternative will result in a lower gold loading on the carbon and an

Maximum Loading of Gold onto Norit RO 3515 Carbon

A significant parameter in the design of CIP plants to minimize capital and operating costs is the optimum gold loading on the carbon. It was thought that data on the maximum loading of gold from cyanided pulps onto extruded carbon would be useful in showing the potential suitability of this type of carbon for the CIPIC technology.

Table I

Typical results for gold extraction from the feed pulp

Day	Au in feed pulp mg/l	Au in barren pulp mg/l		Extraction %		Au on loaded carbon g/t	Au on carbon added to the column g/t	pH of feed pulp
		After 12 h	After 24 h	After 12 h	After 24 h			
14	2,03	0,009	0,030	99,56	98,52	6920	<10	10,98
15	2,10	0,016	0,028	99,24	98,67	5925	10	11,09
17	2,10	0,009	0,019	99,57	99,10	5100	<10	10,31
20	1,79	0,015	0,060	99,16	96,65	6200	<10	11,34
22	1,91	0,016	0,050	99,16	97,38	6150	<10	11,30
24	2,20	0,005	0,011	99,77	99,50	6725	15	10,99

Table II

Concentration profiles for gold along the column

Gold in pulp, mg/l

Feed	Stage 13 (bottom)	Stage 12	Stage 11	Stage 10	Stage 9	Stage 8	Stage 7	Stage 6	Stage 5	Stage 4	Stage 3	Stage 2	Stage 1
2,7	2,4	1,9	1,0	0,71	0,47	0,42	0,33	0,19	0,07	0,10	0,037	n.d.	0,043

Gold on carbon, g/t

Loaded carbon	Stage 13 (bottom)	Stage 12	Stage 11	Stage 10	Stage 9	Stage 8	Stage 7	Stage 6	Stage 5	Stage 4	Stage 3	Stage 2	Stage 1
8 240	7 910	8 490	8 580	7 570	6 930	4 950	3 060	2 530	2 200	2 010	1 760	1 330	1 520

Note: The gold concentration on the carbon added to the column was <10 g/t
    n.d. Not determined

The maximum loading of gold from Durban Deep pulp was determined by continuously contacting carbon with fresh pulp in a mechanically stirred vessel for 31 days. The results (Table V) indicate that gold loadings of up to 28 400 g/t can be achieved at a pH value between 9,0 and 9,9.

Removal of 'Coarse' Solids from the Feed Pulp

Typical particle-size analyses of the solids in the overflow and underflow from the microscreen are shown in Table VI. The mass fraction of solids larger than 212 µm in the underflow was less than 1 per cent, which was considered satisfactory for the purpose of this investigation.

The particle-size analyses (Table VI) show that the feed pulp contained particles exceeding 212 µm, and even 300 µm. It was assumed that the coarse particles that may have accumulated in the bottom part of the column below the bottom plate would be carried out by the pulp flowing out through outlet M (Figure 1) during the carbon-settling and carbon-transfer periods. This assumption was tested by the particle-size analysis of solids in the pulp leaving through outlet M. The results (Table VI) indicate that there was some accumulation of coarse solids, and these solids were carried out during the carbon-settling and carbon-transfer periods. If required, the accumulating solids could be removed more frequently by operation of the column at the settling-period mode for a while, followed by the resumption of the forward-flow period. If necessary, water can be injected into the column through inlet W, which is located just below the bottom plate (Figure 1), to remove the accumulating solids more efficiently. (This procedure was not required during the pilot-plant campaign.)

Another possible place in which coarse solids could accumulate is in the bottom stage, i.e. above the bottom plate. However, any serious accumulation in this part is prevented, since these solids will flow out of the column with loaded carbon during the carbon-transfer period. If necessary, the frequency of carbon transfer can be increased (by reduction of the amount of loaded carbon withdrawn in every cycle) to prevent any serious accumulation of coarse solids in the bottom stage. The stable operation of the pilot-plant column during the 24-day campaign indicates that satisfactory removal of the accumulating solids was achieved during the carbon-settling and carbon-transfer periods, which occurred once in 24 hours.

Treatment of Carbon with Hydrochloric Acid

The results of acid treatment (Table VII) indicate a satisfactory removal of calcium and carbonate ions from the loaded carbon. The results also show a significant removal of zinc, nickel, and iron.

Elution of Gold and Other Metals

The concentration of gold on the eluted carbon must be low enough to provide a satisfactory driving force for the adsorption of gold in the top stage of the adsorption column. Typical results (Table VIII) indicate an excellent elution of gold, the gold concentration being reduced from approximately 6400 g/t to about 14 g/t in 2 days. These results clearly indicate the technical feasibility of the Zadra procedure for the elution of extruded carbon.

Results showing the elution of all metals and other species are given in Table IX, which shows that the elution of silver is low. The elution of copper and nickel is high, while iron is not eluted. It is interesting to observe that the Au $(CN)_2^-$ complex, which is most efficiently adsorbed from the pulp (Table III), has the highest elution efficiency.

Table III

Adsorption of gold and other species

Parameter	Au	Ag	Cu	Zn	Ni	Pb	Fe	Co	Ca	Si
Metal in feed, mg/l	2,7	0,32	7,3	7,0	2,2	0,7	1,5	0,56	742	12
Metal in barren pulp, mg/l	0,043	0,10	6,9	6,3	1,9	0,8	1,0	0,56	732	11
Adsorption, %	98,4	68,8	5,5	10,0	13,6	–	33,3	0	1,3	8,3
Loading on carbon, g/t	8 240	450	630	460	3 320	<50	1 400	<50	16 400	6 040

Table IV

Concentration profile for calcium on carbon along the column, expressed in g/t

Loaded carbon	Stage 13 (bottom)	Stage 12	Stage 11	Stage 10	Stage 9	Stage 8	Stage 7	Stage 6	Stage 5	Stage 4	Stage 3	Stage 2	Stage 1
16 400	15 300	15 900	17 200	16 800	17 200	16 300	15 300	15 500	15 700	15 000	16 100	14 450	16 400

Note: The concentration of calcium on the carbon added to the column was approximately 5000 g/t

Table V

Loading of gold from cyanided pulp onto Norit RO 3515 carbon

Parameter	Loading period, days												
	0	1	2	4	7	9	11	14	17	21	24	28	31
Au on carbon, g/t	<1	10 100	14 900	26 200	28 400	24 500	21 600	20 300	20 600	18 400	20 600	22 900	25 100
Au in barren pulp, mg/l	–	1,8	2,2	2,5	2,8	2,5	2,5	,2,3	2,1	2,0	2,3	2,3	2,2
pH value of pulp	–	9,98	9,08	9,15	n.d	8,97	9,61	8,97	9,50	9,47	9,65	9,09	9,21

n.d. Not determined

+600 μm	+425 μm	+300 μm	+212 μm	+150 μm	+106 μm	−106 μm
Solids from the screen overflow, %						
0,07	0,3	1,8	16,6	33,4	24,0	24,1
Solids from the screen underflow, %						
–	–	0,05	0,5	3,1	18,9	77,5
Solids in the feed pulp to the column, %						
–	–	0,09	1,0	5,8	18,0	76,2
Solids in the barren pulp from the column, %						
–	–	–	1,0	6,3	16,3	77,0
Solids in the pulp from the bottom of the column, %						
0,9	0,1	1,3	3,3	10,0	23,7	60,4

Another interesting aspect is the significant increase in the concentration of carbonate ions on the eluted carbon. This phenomenon was also observed during the recovery of gold from a return-dam solution using coconut-shell carbon[6].

Regeneration of Eluted Carbon

The efficiency of regeneration was evaluated by a comparison of the activities of eluted and regenerated carbons with that of fresh carbon as determined by the Mintek activity test. This test involves the contacting of 1 g of carbon with 400 ml of synthetic gold solution. The relative activity of the carbon is determined as follows:

$$\text{Activity (\%)} = \frac{\text{Gold adsorbed in 60 minutes by used carbon}}{\text{Gold adsorbed in 60 minutes by fresh carbon}} \times 100.$$

Typical results (Table X) show that the regenerated carbon had a higher activity than that of fresh carbon, which indicates a highly satisfactory regeneration. It also shows that the eluted carbon has a relatively high activity, suggesting that regeneration of carbon after every cycle may not be necessary.

CONCLUSIONS

The pilot-plant campaign demonstrated the feasibility of a multi-stage fluidized-bed column for the recovery of gold from cyanided pulps using extruded carbon. While the gold

Table VIII
Elution of gold from carbon by the Zadra procedure

Elution period, days	Gold on carbon, g/t
0	6 400
1	434
2	14

concentration in the barren pulp was somewhat higher than the target value, the results suggest that the specified gold recovery can be achieved provided that the column has a sufficient number of stages. In view of the high gold recoveries that were achieved in the 13-stage column, it is probable that not more than 20 stages would be required in a commercial column to achieve a gold concentration of less than 0,01 mg/l in the barren pulp during an entire adsorption cycle.

The high activity (at least as good as that of fresh carbon) of the regenerated carbon indicates clearly that the conditions employed for the acid treatment, elution, and regeneration are adequate, and that they permit the repeated utilization of extruded carbon (Norit RO 3515) on a cyclic basis.

It is expected that the CIPIC contactor will have advantages over conventional CIP design in certain operations (e.g. where a high flowrate of carbon is required) and in the treatment of fine pulps that may result from fine milling, sand–slime separation, backfill operations (i.e. cyclone overflow), underground operations (e.g. underground sludge), etc.

A further potential application is the recovery of dissolved gold from the cyclone overflow in plants using the milling-in-cyanide process. In this process, the cyclone overflow from the milling circuit (which contains a suitable concentration of solids as feed pulp) can be treated in the adsorption column. The barren pulp from the column is treated for the recovery of the solution that contains the free cyanide.

The solution is recycled to the mill, and the thickened pulp is treated for the recovery of the remaining gold by further leaching and use of either the CIP or the Merrill–Crowe zinc-precipitation process. The recovery of dissolved gold from the cyclone overflow will lower the gold value of the solution passing into the thickener of the milling circuit, and reduce the load on the downstream gold-recovery plant.

It is believed that the pilot-plant campaign has provided sufficient information to establish interest in the CIPIC contactor as an alternative to conventional CIP design for various applications in the gold-mining industry.

Table VII
Typical results of the acid treatment of loaded carbon

Condition of carbon	Ca	CO_3^{2-}	SO_4^{2-}	Au	Ag	Cu	Zn	Ni	Fe	Si
Before acid wash, g/t	15 700	14 500	4 000	5 960	548	735	388	4 510	1 170	3 390
After acid wash, g/t	447	2 000	3 000	6 150	383	663	87	2 530	290	3 460
Removal, %	97	86	25	–	30	10	78	44	44	–

Table IX

Elution of all species from carbon

Parameter	Au	Ag	Cu	Zn	Ni	Fe	Ca	Si	CO_3^{2-}	SO_4^{2-}
Concentration on acid-treated carbon, g/t	6 400	440	752	87	2 475	381	500	3 820	<5 000	3 000
Concentration on eluted carbon, g/t	14	274	67	51	298	568	3 490	2 340	11 000	<3 000
Elution, %	99,8	38	91	41	88	–	–	39	–	–

Table X

The activities of fresh, eluted, and regenerated carbons

Carbon	Gold in solution, mg/l		Relative activity, %
	t = 0 min	t = 60 min	
Fresh	20	5,5	100
Eluted	20	6,5	93
Regenerated	20	3,9	110

ACKNOWLEDGEMENTS

REFERENCES

1. MEHMET, A. Recovery of gold by a carbon-in-pulp process. *S. Afr. Pat.* Appl. 88-6268.
2. KHD (Southern Africa) (Pty) Ltd. Humboldt Wedag Division.
3. ZADRA, J.B., ENGEL, A.L., and HEINEN, H.J. Process for recovering gold and silver from activated carbon by leaching and electrolysis. Washington, U.S. Bureau of Mines, *Report of Investigations* 4843. 1952.
4. PAUL, R.L., FILMER, A.O., and NICOL, M.J. The recovery of gold from concentrated aurocyanide solutions. *Hydrometallurgy: Research, development and plant practice.* Osseo-Assare, K., and Miller, J.D. (eds.) Warrendale, The Metallurgical Society of AIME, 1982. pp. 689-704.
5. COLE, P.M., VON BROEMBSEN, D.S., and LAXEN, P.A. A novel process for the regeneration of carbon. *GOLD 100.* Fivaz, C.E. and King, R.P. (eds.). Johannesburg, South African Institute of Mining and Metallurgy, 1986. vol. 2. pp. 133-155.
6. MEHMET, A., and TE RIELE, W.A.M. Recovery of gold from return-dam solutions by activated carbon in a multistage column. *Miner. Metall. Process.*, Aug. 1989. pp. 105-112.

Technology Transfer Awards*

Seven Mintek researchers in its Measurement and Control Division have received Mintek's coveted Technology Transfer Awards for their successful implementation of multivariable control in run-of-mine (ROM) milling circuits. These awards are made from time to time to staff who have contributed significantly to developments that lead to measurable, bottom-line benefits for clients.

Dr Dave Hulbert received a gold medal (his second), and Ian Craig and Gunter Metzner were awarded silver medals, while certificates were presented to Brian Fitzgerald, Barto Groeneveld, Tiberius Viljoen, and St. John Hunt for their efforts.

Automatic process-control techniques are essential for the optimization of modern, complex metallurgical processes, and Mintek's Measurement and Control Division develops techniques that provide an understanding of the dynamic nature of these processes so that appropriate control strategies can be selected and applied to ensure that key variables are kept at their optimum values.

For several years, the Division has been involved in the development of a unique system for the control of product size in milling and classification circuits, which has resulted in increased capacity, decreased power consumption, and a superior product.

Because the profitable recovery of most minerals depends directly on milling, which is an energy-intensive procedure, milling and classification circuits contribute a large proportion of the capital and operating costs of mineral-recovery plants, and the quality of the product has a critical bearing on the influence of downstream processes such as flotation and leaching.

Multivariable control was implemented in the ROM milling circuit at Vaal Reefs Gold Mine in June 1986. In order to extend the limits of operation and to obtain better control over some of the parameters, hardware and software were developed to maximize the throughput at a specific grind. The range of product-size control was extended by the incorporation of a unique instrument that measures the angle of the discharge spray from hydrocyclone underflow. At the end of 1990, the project was completed, and since then the automated optimizing MVC controller has been in continuous use. An evaluation showed that the incorporation of the optimizer resulted in an 11,4 per cent increase in throughput, with a lower power consumption and a better grind.

MVC was implemented at Deelkraal in 1988, and testwork was started at Cooke. At present, one mill at Cooke is being controlled by the MVC strategy developed by the Mintek team, and long-term tests are being conducted in a comparison of the milling circuit's performance with one that has not yet benefited from the modern control strategy.

Mintek has now implemented the optimizing multivariable strategy into a user-friendly software package and an MVC controller. This first commercial unit will be implemented at Vaal Reefs during 1992, and two ROM mills will be tightly controlled using this equipment. Extensive interest has been shown in this development, and plans have been formulated to implement at least another three installations in the coming year.

Students' presentations

Such was the interest in the recent students' evening at the Chamber of Mines, hosted by the Johannesburg Branch of the Institute, that it was 'standing room only' for latecomers.

This was the third annual presentation of papers by student members, and the researched material, as well as its presentation, was of a very high standard.

The major mining houses support these functions in rotation, and Genmin was this year's sponsor.

Mr George Lee, Chairman of the Johannesburg Branch, said that the Institute placed great stock on its student members, and added that it was important for them to realize that the knowledge gleaned during their years of study had relevance in the world outside the university or technikon.

Among the subjects presented were: 'Neural network in cyclone control', by Sanje Bhoowanpursadh of the Metallurgical Department of the University of the Witwatersrand; 'Hoist chamber excavation at Wildebeestfontein South Mine', by Frikkie Holl of Technikon Witwatersrand, Mining Department; 'Environmental impact of shallow defunct coal mines', by Dave Athey of the University of the Witwatersrand, Mining Department, and 'The determination of a viable process route for the treatment

Mr George Lee addresses guests at the students' evening, sponsored by Genmin, at the Chamber of Mines in Johannesburg

of gold concentrates from run-of-mine mills', by Chris Koch of Technikon Witwatersrand, Metallurgical Department.

At the conclusion of their presentations, the student speakers were presented with book awards on behalf of the Institute.

Carbon measuring unit*

An innovative metallurgical instrument that is used for continuous on-line measurements of carbon concentrations in carbon-in-pulp (CIP) adsorption tanks in the gold-mining industry has been launched by the Electronics Division of Debex (Pty) Ltd. Branded the Debex C^2 Meter†, the carbon-concentration meter makes it possible for the first time to achieve precise on-line measurement of carbon concentrations during the gold-recovery process, resulting in significant improvements and cost savings in gold-recovery plants.

The instrument was developed by the Mintek research organization after five years of in-depth research and development. Debex, as a leading manufacturer of process-control instrumentation in mining applications, was selected to manufacture and market the equipment.

Using ultrasonics to measure pulp and carbon mixtures, the dip-in instrument is a major improvement on the method currently used on mines, in which several 1-litre grab samples are taken three or four times a day for

analysis in a laboratory, which is a cumbersome and time-consuming method.

The new unit provides continuous, reliable measurements of carbon concentrations with an accuracy guaranteed to within 2,5 g/l over the operating range. The meter features user-friendly operating procedures, and has an output signal for direct communication with process instrumentation in the control room. The probe is robust in construction, and extensive field testing has shown it can withstand prolonged exposure to harsh operational environments.

Debex Electronics Manager, John Williams, says that, prior to the development of this equipment, the accurate measurement of carbon-concentration levels in CIP operations was a major problem in that the necessary measurement technology simply did not exist. 'Now for the first time, this measuring device allows the plant metallurgist to monitor the CIP process using off-the-shelf instrumentation. This enables gold plants to operate at higher efficiency levels and more cost effectively.'

Debex is currently developing a C^2 unit that will be capable of simultaneously monitoring multiple probes.

Rope anchors doing great job at Brandspruit Colliery*

Brandspruit Colliery, one of Sasol Coal's three underground mines at Secunda, has adapted a roof-anchoring technique that is used in gold mines for application in collieries.

Brandspruit has been using the adapted rope-anchor system successfully for the past two years, and one of its sister collieries at Secunda, Bossjesspruit, recently began using the system to good effect.

The system has been found to be the only effective method of securing the roof in parts of the mine where the coal seam and shale is devolatiled by dolorite dykes and sills. Besides proving highly effective where other methods have failed, the rope-anchor system is also the least expensive.

Underground Manager, John Collins, said two other systems—one using roof trusses, the other with steel arches

---

* Issued by The Richmond Public Relations Group, P.O. Box 212, Melville, 2109 Transvaal.

—had been tried and abandoned before the rope-anchor system was brought into operation.

About 1000 metres of development in Brandspruit has been done by the rope-anchoring method, all the support being as stable as when it was put in.

Over 1400 anchors have been installed at Brandspruit to date. 'Development costs with this method, at around R2500 per metre labour included, are half of what the development cost with steel arches', said Mr Collins.

Unlike the much shorter conventional roof-bolt, the 10-metre long steel rope can be used to secure thick coal seams and laminated shale layers. The rope is initially held in the hole with a resin capsule, and the rope is pre-stressed at a pressure of up to 15 tons before cement is pumped into the hole to secure it. In some areas, W-straps are bolted against the roof for additional support. In addition, rope anchors are used in conjunction with wire mesh to prevent crumbling of the side walls.

SAIMM BRANCH DIARY

Further information is available from:

The Secretaries, SAIMM, P.O. Box 61127, Marshalltown, 2107. Telephone (011) 834-1273/7, Telex 4-86431, Fax (011) 838-5923