J. S. Afr. Inst. Min. Metall., vol. 90, no. 12.
Dec. 1990. pp. 323-331.

Towards more effective simulation of CIP and CIL processes. 3. Validation and use of a new simulator

by W. STANGE*, L.C. WOOLLACOTT*, and R.P. KING*

SYNOPSIS

This paper presents data collected from full-scale plants in order to verify the predictions of a new simulator of CIP or CIL operations.

Good agreement was found between the experimental data and the simulator predictions. The simulator is able to predict the effects of many of the complex operating phenomena in CIP and CIL plants that previous simulation techniques could not describe. This is illustrated by predictions of how factors, such as the manner of carbon transfer, concurrent leaching, and gold loading on eluted carbon, can affect the performance of an adsorption plant.

SAMEVATTING

Hierdie referaat verstrek data wat by volskaalse aanlegte ingesamel is en die voorspellings van 'n nuwe simuleerder van KIP- of KIL-bewerkings te verifieer. Daar was 'n goeie ooreenkoms tussen die eksperimentele data en die simuleerdervoorspellings. Die simuleerder kan die uitwerking van baie van die komplekse bedryfsverskynsels in KIP- and KIL-aanlegte wat vorige simulasietegnieke nie kon beskryf nie, voorspel. Dit blyk uit voorspellings van baie faktore soos die wyse waarop die koolstof oorgedra word, gelyktydige loging, en die goudlading op die geëlueerde koolstof, die werkverrigting van 'n adsorpsieaanleg kan raak.

Introduction

The first paper in this series[1] dealt with the quantitative modelling of the gold adsorption rate onto activated carbon. Existing models for adsorption and leaching were evaluated.

The next paper[2] dealt with the detailed modelling of the CIP or CIL process configuration, i.e. the way in which carbon and slurry are contacted. Of primary importance is a detailed description of the carbon-transfer scheme. The flow of carbon co-current with pulp due to leakage through or past screens is also important. This complex movement of carbon within the adsorption section of a CIP or CIL plant leads to the development of complex distributions of the gold loaded onto carbon. A realistic model for the process cannot ignore these distributions. The development of a CIP or CIL simulator that accounts for these effects is described in the paper. In addition, methods for the determination of adsorption parameters for full-scale plants are discussed.

In the present paper, the predictions of the simulator are compared against data collected from full-scale plants. In view of the difficulties associated with the collection of such data from an operating plant, the agreement between the simulated predictions and the measured data is good.

In order to demonstrate the flexibility of the model developed, this paper also presents simulation results illustrating how various factors, which have not been examined in detail before, may influence the adsorption performance. The variables examined include

- the method of carbon transfer,
- concurrent leaching and carbon concentrations in each stage,
- the loading of gold onto regenerated carbon.

Simulator Validation Test 1

Estimation of Parameters

An extensive sampling campaign was carried out at Ergo's Daggafontein division, which is located on the Far East Rand and which treats material reclaimed from dumps. This is a modern plant and is relatively well instrumented. In general, the plant operation is trouble-free, resulting in good conditions for the collection of samples. The data were collected and processed in accordance with the sample scheme described in the second paper in this series[2]. Grab samples were collected from each contactor in the train, each contactor being sampled once a day for a number of days so that several data points per contactor could be obtained. The data consisted of assays for gold in solution and in the ore, gold loaded on the carbon, carbon concentration in the contactor, and estimates of the flowrate and relative density of the pulp for the relevant periods. No data were collected for carbon size distribution. The leaching effects could be quantified from assays performed on the samples of ore that were collected.

The equilibrium isotherms were determined under well-controlled laboratory conditions on carbon and feed solution from the plant. Fig. 1 gives a typical adsorption isotherm, showing the fit to the data obtained by use of the Langmuir equation.

Non-linear regression techniques were used to obtain numeric estimates of the kinetic and equilibrium para-

* Department of Metallurgy and Materials Engineering, University of the Witwatersrand, P.O. Wits, 2050 Transvaal.

 Paper received 19th Aug., 1989. Modified paper received 27th Aug., 1990. SA ISSN 0038-223X/3.00 + 0.00.

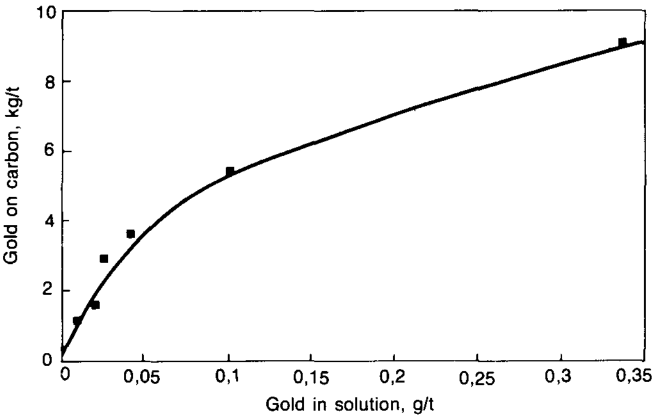


Fig. 1—Equilibrium data fitted to the Langmuir isotherm

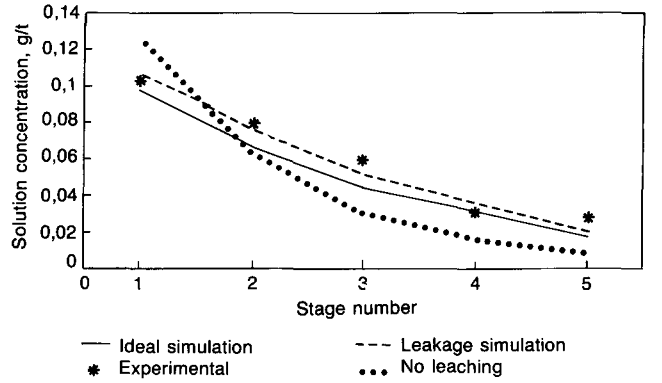


Fig. 2—Predicted and experimental solution profiles

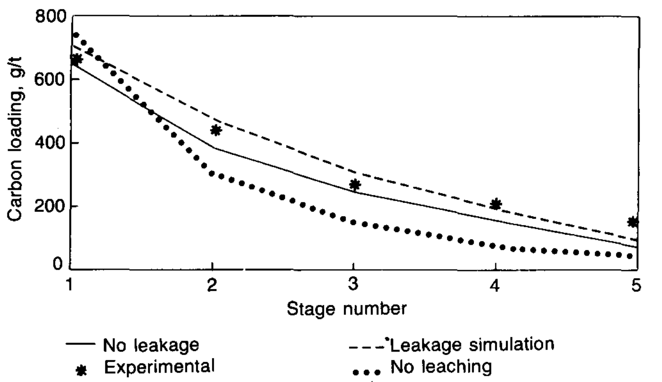


Fig. 3—Predicted and experimental carbon profiles

meters from these data. The values were estimated as follows.

Kinetic parameter:

$$\text{First-order rate constant, } k_2 = \frac{157 \text{ t of solution}}{\text{carbon, t/h}}$$

Equilibrium parameters:

The equilibrium data were fitted to the Langmuir model, which has the following form:

$$y_e = \frac{AC_e}{b + C_e}.$$

The values for the parameters were estimated as

A = 19 900 g/(t carbon)
b = 0,6 g/(t solution).

It should be noted that the simple first-order rate model $R = k_2 C$ was used in this case since no significant differences in fit between this simple expression and the more complex Dixon expression, $R = k_1 (C(y^+ - y) - k_L y)$, were found. This is due to the conditions of extremely low solution tenor and carbon loading on this plant.

Results

The adsorption constants measured for the plant (reported above) were used in the simulator with the appropriate (measured) operating parameters so that the plant behaviour and simulator predictions could be compared. The results of this exercise are presented in Figs. 2 and 3. It should be stressed that these graphs are predictions and not merely fits to experimental data. This is because the method of parameter estimation functions in a manner essentially independent of the way in which the plant operates. The graphs show the simulator predictions of average solution tenor and gold loading for 3 different situations. The data points plotted on the graphs are the average experimental values measured during the sampling campaign.

During the campaign, the plant was experiencing a relatively large co-current movement of carbon owing to the use of carbon that did not conform to the specifications. Estimates of the mass flowrate of carbon leaking through the interstage screens were obtained from samples of pulp that had passed through the interstage screens for each contactor. When the samples had been dried and screened at 850 μm, it was found that most of the material larger than 850 μm was carbon that had leaked through the screens. From the masses of this material and of the total sample, an estimate of the concentration of carbon leaking through the screens could be made.

The 'leakage' simulation in Figs. 2 and 3 shows the predictions for the measured plant conditions, including the effect of carbon leakage and leaching in the CIL tanks. The 'no leakage' simulation shows the simulator predictions for the case where leaching effects are accounted for but it is assumed that no carbon leakage takes place. It can be seen that the prediction with 'leakage' simulation is closer to the measured values than those for the 'no leakage' simulation. This confirms that the simulation model used in conjunction with the previously described methodology for parameter estimation can successfully predict the behaviour of full-scale plants. This particular example is an extreme case in which the effects of significant carbon leakage and leaching are present.

The 'no-leaching' simulation is a prediction of plant performance in which it was assumed that leaching is complete before the adsorption section, i.e. a conventional leach–CIP situation with little or no leaching in the adsorption section. The measured leakage flows of carbon are included in this simulation. The deleterious effect of concurrent leaching on the gold tenor in the effluent tailings is clearly indicated. The inefficiencies caused by 'squashing' the leach into the adsorption section have also been measured experimentally[3]. The interaction between leaching and adsorption will be examined in more detail later in the paper. The fact that the 'leaching simulation' is in considerable error with the experimentally measured data is further indicative that the simulation techniques presented in this series of papers can be used to accurately simulate full-scale CIP plants.

Simulator Validation Test 2

The second validation exercise used data from the Grootvlei CIP circuit. Again, no data for the carbon size distribution were collected. The plant was sampled over two separate periods a year apart, between which the circuit configuration was changed. Model parameters were estimated from the circuit when six contactors were being used, and were then used to predict the plant performance one year later, when only five contactors were being used. The results are shown in Figs. 4 and 5. The data points plotted in these graphs are average values measured during the sampling campaigns, in which up to seventeen samples per tank were collected.

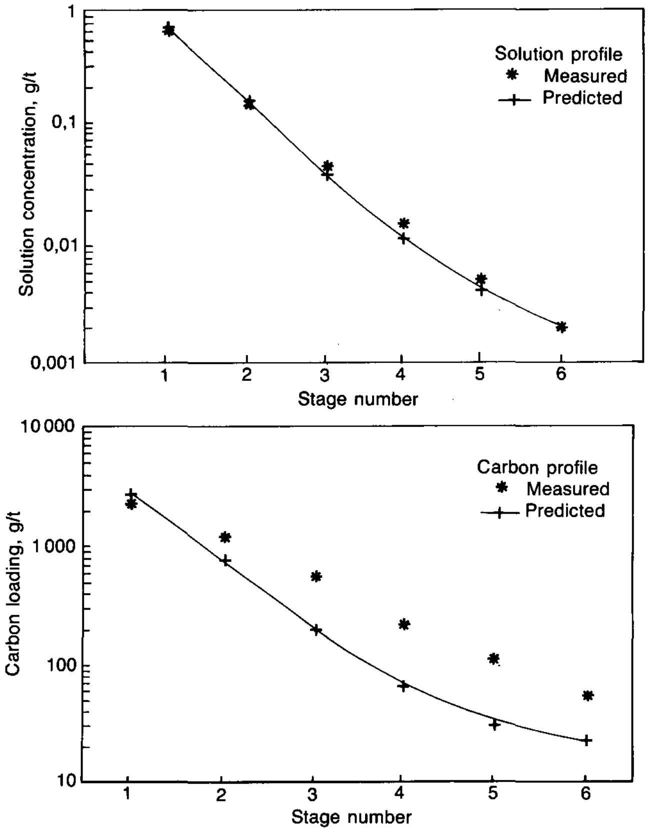


Fig. 4—Initial exercise (6-stage circuit) in validation test 2

The data for the six-stage plant were obtained over a period of about a month using the spot-sampling method described earlier and in the previous paper. Before the sampling campaign, it had been established that very little leaching took place in the adsorption section. No estimation of carbon leakage through the screens was made. The slurry flowrates used for the parameter estimations were shift averages and not instantaneous readings. The carbon-transfer scheme was not consistent over the sampling period. As a consequence, the simulations were performed using a simplified 'average' transfer scheme that was modified until the predicted pseudo-steady-state carbon concentrations in each stage were the same as the average over the sampling period. It can be seen that the

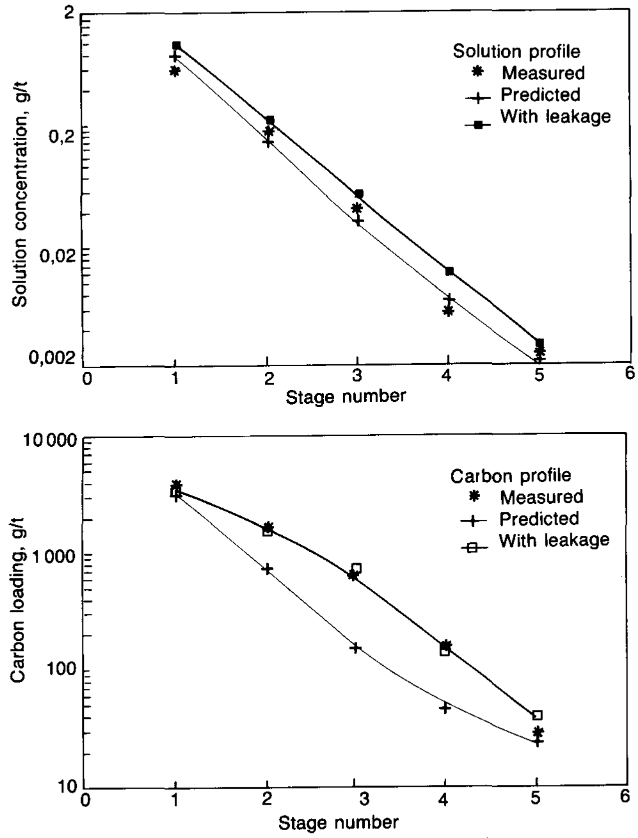


Fig. 5—Predictions for 5-stage circuit in validation test 2

predicted solution profile is in excellent agreement with the observed profile. The prediction of the carbon profile was not as good, although the logarithmic scale accentuates the differences at low loadings. However, the prediction of the loaded-carbon value was correct.

The parameters estimated for the Dixon rate expression were as follows:

$$k_1 = 0{,}022$$
$$k_L = 0{,}032$$
$$y^+ = 4830\,\text{g/t}.$$

With the same simulation approach, the performance of the five-stage configuration was predicted one year later. The result, shown in Fig. 5, is a true independent prediction of the performance of the circuit. Again, the prediction of the solution profile is good. The prediction of the carbon profile is not good, although the predicted value for the loaded carbon was again correct.

It was noted during the sampling of the five-stage configuration that significant carbon leakage was occurring. It was possible to make rough estimates of this leakage based on estimates of the leakage rates of the coarser fractions. Taking this into account, the carbon and solution profiles were re-estimated. As can be seen in Fig. 5, the predicted carbon profile was remarkably good, but that for the solution was a little higher than usual. In view of the difficulties resulting from the erratic plant operation and the uncertainties about the actual slurry flowrates and carbon-leakage rates during the sampling period, the degree of agreement between the predicted and the actual solution and carbon profiles lends confidence to the ability of the simulator to describe the performance of CIP and CIL operations.

Simulation Case Studies

The simulator that was developed is described in detail in paper two of this series[2]. A number of case studies are presented here to demonstrate the capabilities of the simulator.

There are many variables that influence the performance of an adsorption plant, and several of these have been studied using relatively simple models[4,5]. In this paper, attention will be focused on some effects that have received relatively little consideration in simulation studies.

Many of the CIP or CIL simulation studies that have been reported in the literature consist of extensive (in terms of the number of variables examined) studies using 'typical' data. General conclusions are then drawn from the results. Although this approach provides insight into the complexities of CIP adsorption performance, each plant is different and should be treated accordingly during simulation studies. The ready availability of a CIP or CIL simulator as part of a user-friendly simulation package for the personal computer[2], as well as the development of techniques for the estimation of parameters for full-scale plants, enables all metallurgists to carry out sophisticated and meaningful simulation studies for their particular plants. This section of the paper merely illustrates the kinds of complex simulation studies that can be performed, and the results are not intended as a general guide to the operation of such plants.

In this study the following operating parameters were used:

Flowrate of ore	= 700 t/h (500 kt per month)
Head grade of ore	= 1,0 g/t
Density of ore	= 2,7 t/m^3
Water: solids ratio	= 1:1 (by mass)
Number of adsorption stages	= 6
Volume of adsorption stages	= 960 m^3
Concentration of carbon	= 15 g/l (base case)
Flowrate of carbon	= 14,4 t/d (base case)
Loading on eluted carbon	= 50 g/t (base case).

The Dixon rate expression was used to quantify the rate of adsorption:

$$R = k_1 C(y^+ - y) - k_2 y,$$

with the constants having the following values:

k_1 = 0,017 g/(t solution) per hour
k_2 = 0,005 h^{-1}
y^+ = 11 650 g/(t carbon).

It was assumed that the plant was a CIL plant, and leaching was modelled using the Mintek expression:

$$R_l = -k_p (S - S_m)^2,$$

with values for the constants as follows:

S_m = 0,13 g/t
k_p = 0,9 (g/t) per hour.

These parameters were chosen as typical of a large-tonnage low-grade CIL operation such as those used to process reclaimed dump material. It should be stressed that the results presented are in no way intended to provide general guidelines for CIL operation or design. As noted earlier, each plant is different and should be treated accordingly.

Case Study 1: The Effect of Carbon Transfer

One aspect of CIP performance that most of the models described in the literature have not been able to simulate is the effect of the carbon-transfer scheme; most models simply assume that a certain fraction of the carbon (and pulp) is transferred countercurrently in an instantaneous manner. This is not a good approximation of real plant operation, where carbon may be transferred continuously over a period ranging from a few to 24 hours.

Simulations for the following four transfer schemes were carried out.

Mode A: Carousel operation. A carousel plant is engineered so that carbon transfer takes place by the rotation of the pulp feed to each tank in the circuit. During transfer, the carbon is separated from the pulp, and all the carbon in each tank is transferred forward to the next tank. The carbon is transferred in discrete batches, with no mixing taking place. This is a most efficient way of operating an adsorption plant since there is no backmixing of pulp or carbon from different stages during the transfer.

Mode B: Continuous transfer, in which carbon is transferred countercurrent to the pulp flow for 24 hours a day. This mode of operation implies that the plant will operate at true steady state (ignoring process disturbances).

Mode C: Sequential transfer, in which carbon is first transferred from tank 1 to elution. The sequence then proceeds with transfer of carbon from stage 2 to 1, stage 3 to 2, stage 4 to 3, stage 5 to 4, stage 6 to 5 and, finally, regenerated carbon is added to stage 6. The convention followed is that stage 1 is the tank into which the pregnant pulp is fed.

Mode D: Sequential transfer in a direction opposite to that described in C. Regenerated carbon is first added to stage 6, and transfer proceeds up the train until, as the last step, carbon is moved from stage 1 to elution.

The simulations to investigate the effect of carbon transfer method were carried out as follows.

- The carbon flowrates ranged from 14,4 to 4,8 t/d. For the carousel system, all the simulations were run at a carbon concentration of 15 g/l, and the carbon flowrate was varied by adjustment of the adsorption cycle period. At a carbon concentration of 15 g/l, each contactor would contain 14,4 t of carbon. If the inventory of each tank were moved every 24 hours, the carbon flowrate would be 14,4 t/d, and 14,4 t would have to be eluted. Moving the inventory of each tank every 48 hours resulted in a carbon flowrate of 7,2 t/d. For this case, 14,4 t of carbon had to be eluted over a period of 2 days.
- For transfer modes B, C, and D, the required carbon flowrate was obtained by adjustment of the carbon-transfer pumping rates. As the highest carbon transfer

rate (14,4 t/d) implied that all the inventory in each tank (at a concentration of 15 g/l) had to be transferred, the plant was assumed to operate on a 12-hour cycle, i.e. 7,2 t would be transferred every 12 hours. This made it possible to transfer all the inventory even when in sequential mode C.

- It was assumed that there would be 4 pre-leaching stages for all simulations in this section.
- As the carousel configuration proved to be the most efficient manner for the transfer of carbon of the methods examined, the carousel operation was used as a basis for comparison. The gold tenors of the plant effluent for modes B, C, and D were compared with that for the carousel plant (mode A) at the same carbon flowrate. If necessary, the carbon concentrations for modes B, C, and D were adjusted to give the same solution tailings as predicted for carousel operation. The relative performances of the various transfer schemes could then be evaluated for carbon inventory and gold lock-up at the same tailings tenors.

The results are presented in Table I. The average loading reported is the arithmetic mean of the loadings in all 6 stages averaged over the adsorption cycle period. This quantity is reported because it is likely that the carbon lost from the circuit will have a gold loading close to this value[6]. Some indication of the relative amounts of gold lost from the circuit in this manner can be obtained from this value. It should also be noted that the loading on the batch of carbon actually sent to elution will be the same for each operating mode. This is because the carbon flowrate and the solution tenor of the tailings are constant for each set of simulations. This loading will obviously be a function of the carbon flowrate and can easily be calculated by mass balance.

As expected, the carousel mode results in better performance over a wide range of carbon flowrates than any other mode of operation. If carbon is transferred continuously (mode B), an increased carbon inventory (compared with mode A) is required only after the carbon flowrate has decreased by a factor of 2. However, the gold lock-up, as well as the average carbon loading, is significantly higher (from 36 to 84 per cent) for all the conditions investigated. There is also a sharp increase in lock-up and average loading at the lowest carbon flowrate.

For mode C, an increase in carbon inventory (over that in A) is required for all carbon flowrates. This is because there is a substantial drop in the mass of carbon present in the circuit of C when transfer takes place. There is also a substantial increase in the gold lock-up and average carbon loading.

Mode D is similar to mode B in that an increase in carbon inventory to maintain an effluent value equivalent to that of the carousel mode is required only after the carbon flowrate has dropped substantially. This is because this method of carbon transfer results in an increase in the amount of carbon in the adsorption circuit during transfer.

There are interesting similarities between modes B and D, the lock-up and loadings being similar and generally greater than for mode C. This is probably because the manner in which transfer is carried out for modes B and D results in an increase in the carbon loadings in each stage owing to the severe mixing of carbon that takes place in these transfer modes. This is illustrated in Fig. 6, where the time-averaged gold loadings on the carbon in each stage are plotted for each transfer mode. Fig. 6 shows the data for the lowest carbon flowrate, where the effect is most pronounced. It can be seen that the profiles for B and D are very similar and higher than for both A and C.

This shows that the manner in which carbon is transferred on a CIP or CIL plant has an important effect

TABLE I

EFFECT OF TRANSFER SCHEME ON CIP PERFORMANCE*

Simulation	Carbon flowrate, t/d					
	14,4	12,2	10,1	7,9	5,8	3,6
	Tenor g/t	Tenor g/t	Tenor g/t	Tenor g/t	Tenor g/t	Tenor g/t
Solution tailings, g/t	0,005	0,005	0,005	0,005	0,006	0,006
Carbon, t/stage						
Carousel	14,4	14,4	14,4	14,4	14,4	14,4
Mode B	14,4	14,4	14,4	16,3	16,3	18,3
	(1,0)	(1,0)	(1,0)	(1,13)	(1,13)	(1,27)
Mode C	15,4	15,4	15,4	16,3	16,3	17,3
	(1,07)	(1,07)	(1,07)	(1,13)	(1,13)	(1,20)
Mode D	14,4	14,4	14,4	15,4	15,4	18,3
	(1,0)	(1,0)	(1,0)	(1,07)	(1,07)	(1,27)
Gold lock-up, kg						
Carousel	18,3	20,5	24,2	30,1	40,8	62,9
Mode B	24,9	27,8	32,9	47,5	62,3	115,6
	(1,36)	(1,36)	(1,36)	(1,58)	(1,53)	(1,84)
Mode C	24,0	26,4	31,8	47,8	57,1	98,2
	(1,31)	(1,29)	(1,31)	(1,59)	(1,40)	(1,56)
Mode D	27,8	28,7	33,8	44,9	57,9	113,7
	(1,52)	(1,40)	(1,40)	(1,49)	(1,42)	(1,81)
Average loading, g/t						
Carousel	212	238	280	349	472	728
Mode B	289	322	381	485	636	1056
	(1,36)	(1,35)	(1,36)	(1,39)	(1,35)	(1,45)
Mode C	261	287	345	486	584	948
	(1,23)	(1,21)	(1,23)	(1,39)	(1,24)	(1,30)
Mode D	322	332	391	487	628	1039
	(1,52)	(1,40)	(1,39)	(1,40)	(1,33)	(1,43)

* The values in brackets indicate the lock-up, average loading, or carbon inventory for the particular transfer scheme relative to the carousel-transfer scheme

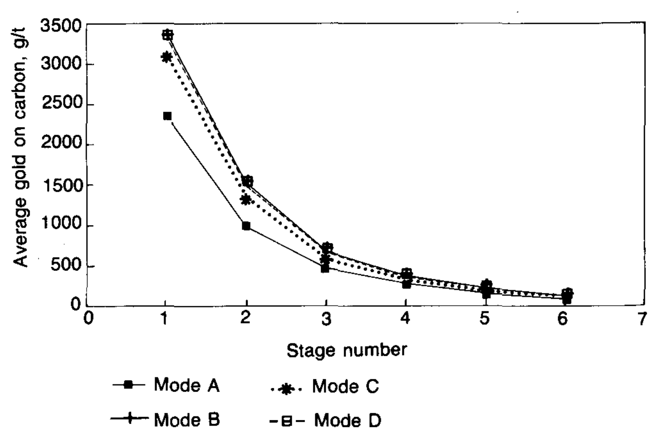


Fig. 6—Carbon profiles for various modes of transfer

on the efficiency of the plant, and therefore on plant economics. The simulator described in this paper can be used effectively to identify the most appropriate carbon-transfer scheme either at the plant design stage or once operations are under way.

Case Study 2: The Effect of Leaching

A number of simulations were carried out to show the influence of concurrent leaching on overall plant performance. For the simulations reported in this section, it was assumed that the carbon is transferred continuously, and that 60 per cent, or 8,64 t of carbon, is transferred per day. Although it is not usual to operate plants in this way, i.e. with continuous transfer, this was done to make the results of different simulations more directly comparable. When intermittent transfer is simulated, more variables change owing to the effects of carbon concentration and pump capacity on the flowrate of the carbon being transferred. For intermittent transfer, the carbon concentration is time-dependent, while for continuous transfer the carbon concentration in each contactor does not change.

Number of Pre-leaching Stages

The concurrent leaching that takes place in a CIL operation has a serious effect on the overall performance of the system. Previous modelling studies[5] show that there is an optimum number of pre-leaching stages.

A series of simulations was carried out on the effect of the number of pre-leaching stages on adsorption performance. The results are summarized in Figs. 7 and 8, which depict the profiles for average solution tenor and carbon loading with 1, 2, and 4 pre-leaching stages. As the number of pre-leaching stages increases (i.e. as less leaching takes place in the adsorption section), the adsorption performance increases significantly. Profiles become steeper and the solution tenor in the plant effluent is reduced. As the number of pre-leaching stages increases, the solution tenor in the adsorption feed rises, causing higher loadings in the first stages of the adsorption plant. Even though more gold is leached from the ore as the number of pre-leaching stages increases, the amount of gold leached into solution in the last few stages is decreased. This results in lower loadings in the last few stages, and thus better scavenging of low-tenor solutions.

It can be seen that separating the leaching plant from the adsorption circuit results in two beneficial effects (on the assumption of a 'normal' situation in which the gold is not adsorbed or precipitated onto the ore).

- The overall extraction of gold from the ore is increased owing to increased residence time in the leach.
- The increase in solution tenor in the adsorption feed, combined with the fact that little leaching takes place in the last few stages in the plant, results in improved adsorption performance and an overall increase in gold recovery.

Carbon Distribution

Simulation studies carried out by Nicol, Fleming, and Cromberge[5] indicated that the optimum distribution of carbon in a CIP plant is an even distribution, i.e. the carbon concentration in the vessels should be the same. The present simulation studies indicate that, although this appears to be the case for plants in which no leaching takes place, it is definitely not true for CIL plants.

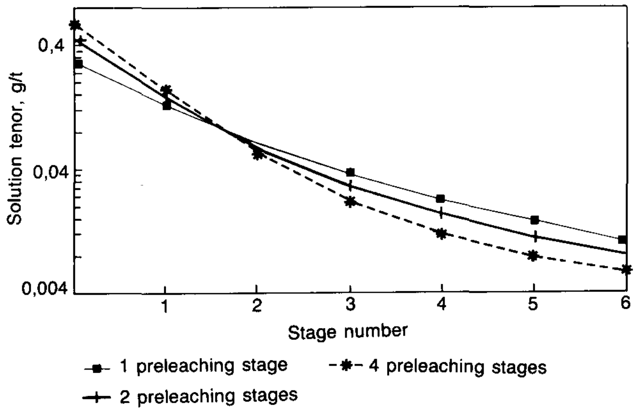


Fig. 7—Solution profiles for different numbers of preleaching stages

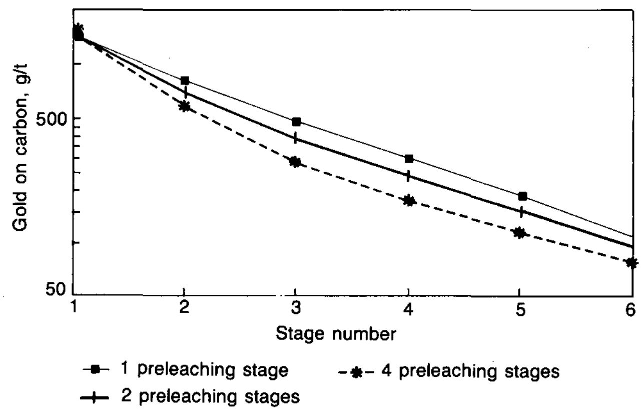


Fig. 8—Carbon profiles for different numbers of preleaching stages

Three simulation runs were carried out. For the base case, an even distribution of carbon (15 g/l per stage) was used. For the second and third runs, the distribution of carbon was weighted to either the top (feed end) or the bottom of the circuit. Specifically, for the second simulation run, stages 1 and 2 contained 22 per cent of the total inventory in each stage, stages 3 and 4 contained 17 per cent of the carbon in each stage, and stages 5 and 6 contained 11 per cent per stage. For the third run, stages 1 and 2 contained 11 per cent of the total inventory in each stage, stages 3 and 4 contained 17 per cent of the carbon in each stage, and stages 5 and 6 contained 22 per cent per stage.

For this study, the first run (in which the carbon was evenly distributed) was used as a basis for comparison. For the second and third runs, the carbon inventory was increased or decreased (while still maintaining the relative proportions of carbon in each stage) until the same tailings as predicted for run 1 were obtained. The relative performances could then be judged using inventory and lock-up in a manner similar to that used in case study 1. The exercise was carried out for 1, 2, and 4 pre-leaching stages. The results are shown in Table II.

The 'weighted to top' row refers to the situation in which stages 1 and 2 contained the highest concentrations of carbon, while 'weighted to bottom' refers to the situation in which the highest concentrations of carbon were

TABLE II
INFLUENCE OF CARBON DISTRIBUTION ON PERFORMANCE*

Parameter	No. of pre-leaching stages		
	1	2	4
Solution tailings, g/t	0,010	0,008	0,006
Total carbon inventory, t			
Evenly distributed	86,4	86,4	86,4
Weighted to top	115,0	115,0	115,0
	(1,33)	(1,33)	(1,33)
Weighted to bottom	63,0	63,0	63,0
	(0,73)	(0,73)	(0,73)
Gold lock-up, kg			
Evenly distributed	48,1	43,9	40,1
Weighted to top	70,8	68,4	63,1
	(1,47)	(1,56)	(1,57)
Weighted to bottom	28,7	27,6	25,2
	(0,60)	(0,63)	(0,63)
Average loading, g/t			
Evenly distributed	556	508	464
Weighted to top	514	489	444
	(0,93)	(0,96)	(0,96)
Weighted to bottom	563	550	514
	(1,01)	(1,08)	(1,11)

* The values in brackets indicate the lock-up, average loading, or carbon inventory for the particular carbon-distribution scheme relative to the even distribution scheme

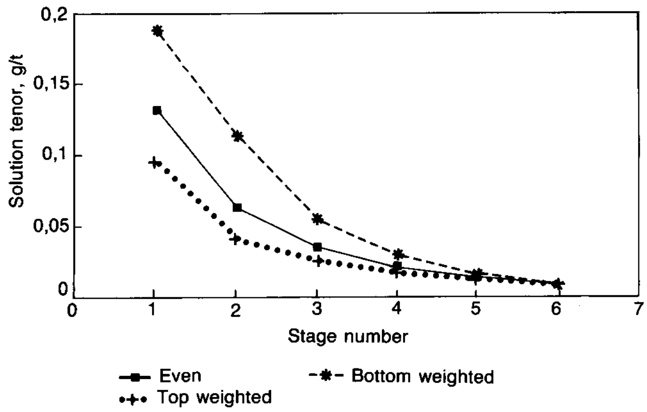


Fig. 9—Effect of carbon distribution on solution profile

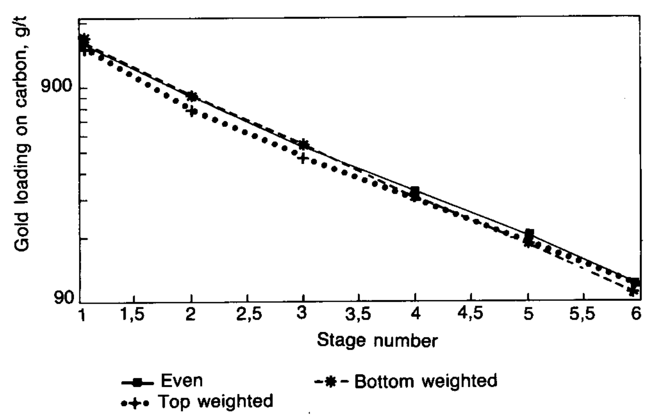


Fig. 10—Effect of carbon distribution on loading profile

in stages 5 and 6. The numbers in parentheses are again the quantities relative to the base case (even distribution of carbon concentration).

It is clear from Table II that, for the situation simulated, it is highly advantageous to distribute the carbon so that the stages at the pulp effluent end of the cascade contain more carbon than the stages at the feed end. For this particular situation, 27 per cent less carbon is required to produce the same tailings as the evenly distributed case if the carbon is distributed in this manner. In addition, the gold lock-up is 40 per cent smaller.

It is probable that, for a given total carbon inventory and given leaching behaviour, there is an optimum distribution of carbon (based on economic criteria). This distribution will obviously be a function of the leaching profile. It can also be seen that, as the number of pre-leaching stages is increased, the solution tailings, the gold lockup, and the average loadings decrease, i.e. the performance improves.

Figs. 9 and 10 show the profiles of average carbon loading and solution tenor for the different methods of carbon distribution when 1 pre-leaching stage is used. The differences are more clearly seen in the graph for solution tenors than in that for carbon loadings.

Case Study 3: Effect of Eluted-carbon Loadings

Data collected during various sampling campaigns, as well as data presented in the literature[4], suggest that there is a correlation between the gold loading on carbon in the last stage and the gold tenor in the plant effluent. This is due to the reversibility of the adsorption reaction under the high pH conditions existing in a CIP plant.

The gold loadings in the last stage may be influenced by a number of factors. Firstly, if significant leaching is taking place in the last few stages of the cascade, the gold loadings on the carbon tend to be higher. This more highly loaded carbon is transferred to the upstream stages, leading to a general increase in the loadings in all stages. Because the loadings increase, the solution tenors in each stage also rise, resulting in a decrease in adsorption efficiency and an increase in gold lock-up. These effects were clearly illustrated in case study 2.

Co-current movement of carbon has much the same effect. Carbon of relatively high loading moves from stage 1 to the last stage, resulting in a general increase in the gold loading in each stage. This again leads to a drop in adsorption efficiency and an increase in gold lock-up. This effect was well illustrated with plant data in the model validation described earlier.

The most obvious factor influencing the gold loading in the last stage is that on the eluted and regenerated carbon, which is normally added to this stage. Several simulations were performed to examine the effect that various eluted-carbon loadings could be expected to have on the performance of the adsorption plant.

Evaluation criteria similar to those used in the previous simulation case studies were applied. It was assumed that there were 4 pre-leaching stages and that carbon transfer was carried out continuously so that 8,64 t of carbon was eluted per day. The base-case simulation assumed that the gold loading on the eluted carbon was 50 g/t, and that a carbon concentration of 15 g/l in each stage was used. For the simulations carried out using different eluted-carbon values, the carbon concentrations were adjusted in order to provide the same tailings as in the base-case simulation. The results obtained are summarized in Table III.

TABLE III
INFLUENCE OF ELUTED LOADINGS ON PERFORMANCE*

Parameter	Eluted-carbon loading, g/t			
	20 g/t	50 g/t (Base)	100 g/t	130 g/t
Solution tailings, g/t	0,006	0,006	0,006	0,006
Total carbon inventory, t	74,9 (0,87)	86,4 (1,0)	97,9 (1,13)	138,2 (1,60)
Gold lock-up, kg	32,2 (0,80)	40,3 (1,0)	47,0 (1,17)	73,3 (1,82)
Average loading, g/t	430 (0,92)	466 (1,0)	480 (1,03)	530 (1,14)

* The values in brackets indicate the lock-up, average loading, or carbon inventory for the particular eluted-carbon loading relative to that for the base case.

It is obvious from Table III that, for this particular case, the performance is very sensitive to the eluted-loading value. There is a sharp increase in the inventory, lock-up, and average loading at relatively low eluted-carbon values (130 g/t). Figs. 11 and 12 illustrate the effect of different loadings on the profiles for average solution tenor and gold loading on carbon. It can clearly be seen how even small increases in the eluted-carbon loading result in an upward shift in carbon-loading profile. It should be noted that the solution profile shifts downwards as the carbon inventory increases with the rise in eluted loadings to maintain the solution tailings value at 0,006 g/t. The solution profile shows a deleterious flattening of the profile as the eluted loading rises.

The results from this case study are not surprising when compared with data obtained from plant sampling. Fig. 13 is a plot of gold loading on carbon as a function of gold in solution (in the same stage) for the last few stages of two different CIP plants taken over a period of time. Plant A is a dump-treatment plant, while plant B treats mined ore. These data show a strong correlation between the carbon loading and the corresponding solution tenor for both plants. This strongly suggests that, in order to achieve low solution tenors in CIP effluent, the gold loadings on the carbon in the last stage must be low. One of the obvious ways of achieving this is to elute the carbon that is recycled to the circuit to low loadings. The experimental observations indicate a trend that agrees with the trend predicted by use of the simulator.

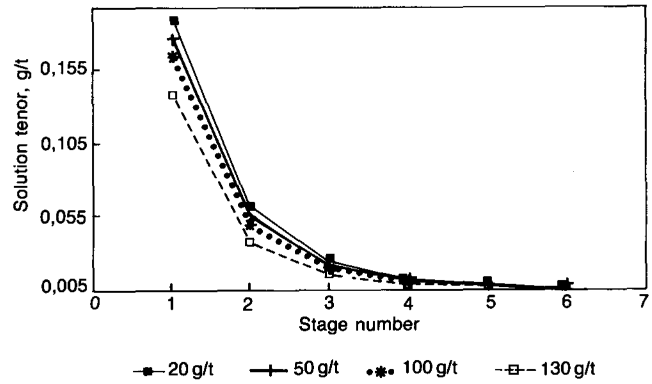


Fig. 11—Solution profile for various eluted loadings

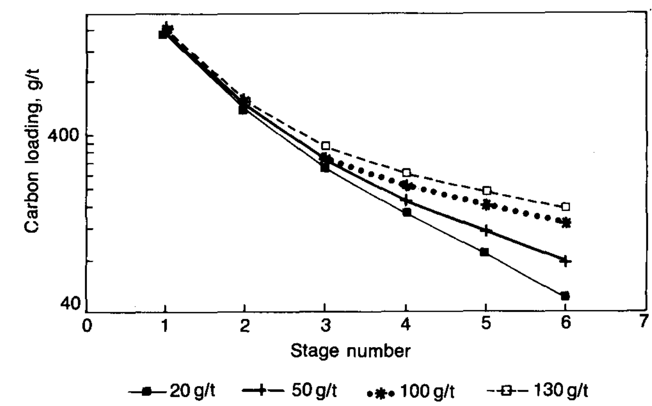


Fig. 12—Carbon profiles for various eluted loadings

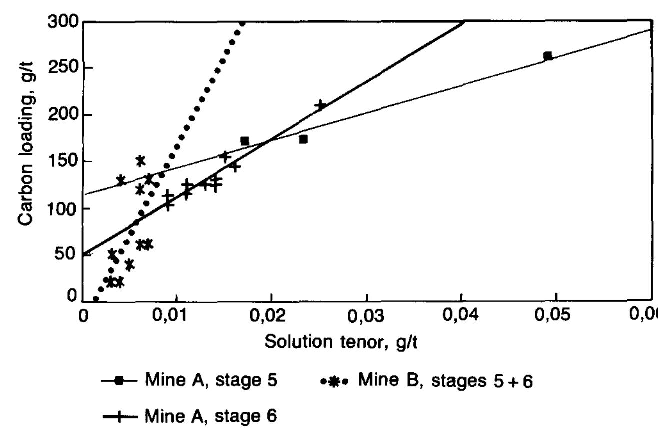


Fig. 13—Relationship between solution tenors and carbon loadings

The case studies demonstrate the ability of the simulator to model a wide range of operating conditions. The effects of carbon-transfer mode, concurrent leaching, and eluted-carbon gold loading on adsorption performance when simulated for specific conditions highlighted some interesting aspects of CIP or CIL plant behaviour.

The availability of the simulator, combined with the use of the parameter-estimation scheme developed by Stange, King, and Woollacott[2], makes the routine use of simulation in the design and optimization of CIP and CIL plants convenient for the metallurgist involved in these activities. The use of simulation allows many more options to be examined in detail, facilitating the optimum

Conclusions

The simulator is capable of simulating complex operational aspects of CIP and CIL plants as shown by the use of data collected from full-scale operating plants. Good agreement was obtained between predictions made by use of the simulator and experimental observations. The validation tests were carried out under conditions of significant carbon leakage and leaching, showing that the simulator can correctly model factors such as the carbon-transfer scheme used, co-current carbon leakage, and concurrent leaching.

design or operation of a plant. Because of the widespread use of CIP and CIL, this can have significant financial benefits for the South African mining industry.

During the course of the work described in this paper, the need for a more comprehensive simulation package became apparent. Such a package is currently being developed so that the interaction between adsorption and elution can be modelled. The package caters for parameter estimation, as well as the analysis and projection of capital and operating costs for CIP or CIL plants.

Acknowledgements

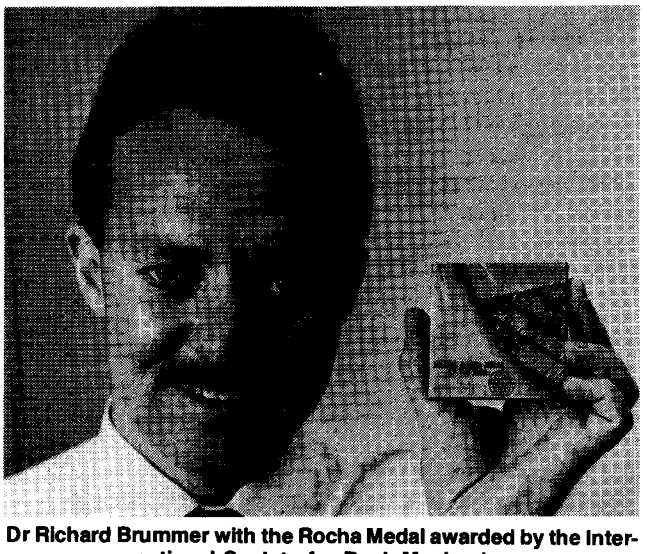
The authors thank the Anglo American Corporation for the generous financial support that made this work possible. The cooperation and assistance of staff of the Anglo American Research Laboratories and the Daggafontein division of ERGO in carrying out the experimental work are gratefully acknowledged. In addition, the authors are grateful for the facilities provided and the cooperation of Genmin in the investigations conducted at Grootvlei Gold Mine. The assistance of the 1987 and 1988 final-year extractive-metallurgy students of the Department of Metallurgy and Materials Engineering in the Grootvlei project is gratefully acknowledged.

References

1. Woollacott, L.C., Stange, W., and King, R.P. Towards more effective simulation of CIP and CIL processes. 1. The modelling of adsorption and leaching. *J. S. Afr. Inst. Min. Metall.*, vol. 90, no. 10. Oct. 1990.
2. Stange, W., King, R.P., and Woollacott, L.C. Towards more effective simulation of CIP and CIL processes. 2. A population-balance-based simulation approach. *Ibid.*, vol. 90, no. 11. Nov. 1990.
3. Davidson, R.J. Anglo American Research Laboratories, personal communication, 1988.
4. Bailey, P. Application of activated carbon to gold recovery. *The extractive metallurgy of gold in South Africa.* Stanley, G.G. (ed.). Johannesburg, South African Institute of Mining and Metallurgy, 1987. Chap. 9.
5. Nicol, M.J., Fleming, C.A., and Cromberge, G. The absorption of gold cyanide onto activated carbon. I. The kinetics of absorption from pulps. *J. S. Afr. Inst. Min. Metall.*, vol. 84, no. 2. Feb. 1984. pp. 50–54.
6. Sorensen, P.F. The origins and treatment of fine carbon in carbon-in-pulp plants. Presented at The Role of the Practical Metallurgist Symposium, Mine Metallurgical Managers' Association, Johannesburg, Jun. 1989.

Best in the world*

The International Society for Rock Mechanics (ISRM) has judged a Ph.D. thesis by a senior lecturer in the Department of Mining Engineering at the University of the Witwatersrand as the best in the world.



Dr Richard Brummer with the Rocha Medal awarded by the International Society for Rock Mechanics

* Released by Lynne Hancock Communications, P.O. Box 1564, Parklands 2121.

The winning thesis, by Senior Lecturer in Rock Mechanics, Dr Richard Brummer, was among entries for the annual Rocha Medal received from 30 countries. Named in honour of past ISRM President Manuel Rocha, the Rocha Medal has been presented annually for an outstanding doctoral thesis in rock mechanics or rock engineering since 1982.

Dr Brummer's thesis is entitled 'Fracturing and deformation at the edges of tabular gold mining excavations and the development of a numerical model describing such phenomena'. It was submitted to Rand Afrikaans University in 1987 while he was employed by the Chamber of Mines Research Organization.

In the thesis, a model is developed of the way in which a rock seam fractures and deforms under high stress. The model forms the basis for the development of stress-analysis packages that enable rock mechanics engineers to design mine layouts taking into account the finite strength of most mined reefs.

Dr Brummer, the first South African recipient of the Rocha Medal, won $1000 and a bronze medal designed by a Portuguese artist.

The ISRM is represented in 58 countries, of which South Africa has the fourth largest individual membership after Italy, Canada, and the UK.