

The absorption of gold cyanide onto activated carbon. II. Application of the kinetic model to multistage absorption circuits

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SYNOPSIS

A relatively simple rate equation for the kinetics of the absorption of gold from cyanide solutions onto activated carbon was used as the basis in the development of a model for multistage carbon-in-pulp and carbon-in-leach absorption circuits.

The model was used in the prediction of both the steady-state and the transient behaviour of the absorption process, and the results were found to be in reasonable agreement with those observed in an extended pilot-plant campaign. A number of practical implications of the model are discussed, and an assessment is made of the economic consequences of the various process options available for the design of a carbon-in-pulp plant.

SAMEVATTING

'n Betreklik eenvoudige tempovergelyking vir die kinetika van die absorpsie van goud uit sianiedoplossings op geaktiveerde koolstof is gebruik as grondslag vir die ontwikkeling van 'n model vir veeltrapkoolstof-in-pulp- en koolstof-in-loogabsorpsiekringe.

Die model is vir die voorspelling van sowel die vastetoestand- as die oorgangsgedrag van die absorpsieproses gebruik en daar is gevind dat die resultate redelik ooreenstem met dié wat in 'n uitgebreide proefaanlegkampaanje waargeneem is. 'n Aantal praktiese implikasies van die model word bespreek en die ekonomiese gevolge van die verskillende prosesopsies wat vir die ontwerp van 'n koolstof-in-pulpaanleg beskikbaar is, word geëvalueer.

Introduction

A previous paper¹ describes a relatively simple kinetic model for the absorption of gold from cyanide solutions and pulps onto activated carbon, and illustrates the use of the rate equation in predicting the performance of single-stage continuous and batch absorption tests. The application of this kinetic model to the description, design, and optimization of multistage carbon-in-pulp (CIP) absorption circuits is developed in this paper.

As suggested in the previous paper, the rate at which activated carbon absorbs gold is the most important property of the carbon used in this application because this factor determines the operating efficiency of a CIP plant, in which true equilibrium between the carbon and the solution is seldom achieved in any stage. The well-known McCabe-Thiele approach to the description of multistage countercurrent extraction circuits cannot be expected to yield adequate results when applied to CIP circuits because it is based on an equilibrium description of the system. For this reason, workers at the United States Bureau of Mines, in the only published work on this topic², adopted a modified McCabe-Thiele approach in which pore diffusion was coupled to a Freudlich isotherm to describe the equilibrium between silver cyanide and activated carbon.

Continuous Countercurrent Extraction

In the simplest approach to the modelling of a CIP circuit, the assumption is made that the flow of pulp and carbon is continuous but countercurrent, and that a steady-state condition is reached in which the concentrations of gold in the solution and on the carbon are constant in each stage of the absorption circuit. It is further assumed that each contactor can be treated as a perfectly mixed reactor with a constant residence time for both the pulp and the carbon.

In the previous paper it was shown that, under conditions of constant gold concentration in solution, the following equation can be used to describe the rate of absorption of gold onto carbon:

$$d[Au]_c/dt = k(K[Au]_s - [Au]_c), \dots \dots (1)$$

where $[Au]_c$ is the concentration of gold on the carbon at any time t , $[Au]_s$ is the concentration of gold in solution, k is a rate constant, and K an equilibrium constant. Both k and K can be obtained from batch absorption tests as described in the previous paper.

This rate equation can be combined with mass-balance equations to yield an overall model for a circuit consisting of N stages (shown schematically in Fig. 1) in which pulp (at an equivalent solution flowrate of V_s) enters the first stage with a gold concentration of $[Au]_s^0$ and carbon (at a flowrate of V_c) enters the last stage with a gold concentration of $[Au]_c^N$. As shown, the concentrations of gold in solution and on the carbon in any stage i are represented by $[Au]_s^i$ and $[Au]_c^{i-1}$ respectively.

The overall mass balance of gold across the circuit requires that

$$V_s ([Au]_s^0 - [Au]_s^N) = V_c ([Au]_c^0 - [Au]_c^N) \quad (2)$$

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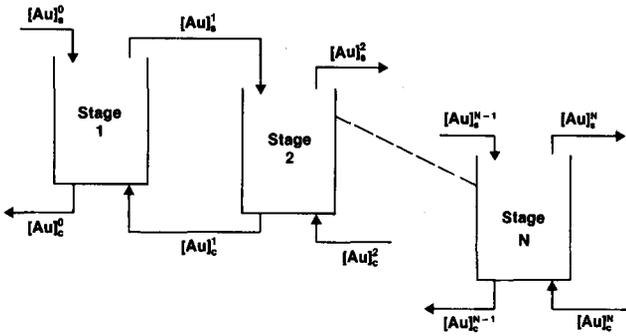


Fig. 1—Concentrations of gold in the solution and on the carbon

In general, $[Au]_s^N \ll [Au]_s^0$ and $[Au]_c^N \ll [Au]_c^0$ so that this equation can be simplified and rearranged to give

$$V_c = V_s[Au]_s^0/[Au]_c^0, \dots \dots \dots (3)$$

which specifies the rate at which carbon must be moved for the desired loading, $[Au]_c^0$. Experience has shown that a value of 1500 for the ratio $[Au]_c^0/[Au]_s^0$ is a reasonable expectation. This can be seen from the data for actual operating plants shown in Fig. 2. It is interesting to note that the results obtained from pilot-plant investigations invariably predict better performance than is generally achieved during full-scale operation. The only variable left that can be adjusted if the desired performance is to be achieved is the mass of carbon (M_c) in each stage. This determines the average residence time of carbon per stage ($t_c = M_c/V_c$).

The following iterative procedure has been found useful for the derivation of the required amount of carbon.

Consideration of the mass balance and reaction according to equation (1) occurring in Stage 1 yields the following well-known form of equation for the performance of a stirred-tank reactor:

$$[Au]_c^0 = \frac{[Au]_c^1 + K[Au]_s^1 kt_c}{1 + kt_c} \dots \dots \dots (4)$$

It should be pointed out that, because of the form of equation (1), it is identical whether homogeneous or segregated reaction is assumed in the stage. (This can be shown quite simply by substitution of the integrated form of equation (1), which applies to a batch reactor, into the expression for a stirred-tank reactor, which incorporates the exit age distribution function for the segregated phase, i.e. the carbon). An initial estimate (say 10 hours) is made for t_c , which is used in the calculation of $[Au]_c^1$ and $[Au]_s^1$ from equation (4) and the mass balance across the first stage (equation (2) with $N = 1$). The values of $[Au]_c^1$ and $[Au]_s^1$ can then be used in the calculation of the corresponding quantities for the second stage, and so on until the values of $[Au]_s^N$ and $[Au]_c^N$ are obtained. If $[Au]_s^N$ thus obtained does not match the desired barren solution, t_c is adjusted accordingly and the iterative procedure is repeated until the calculated value

of $[Au]_s^N$ converges to the desired value.

The use of this rate equation in simulating the performance of a typical CIP circuit is illustrated in the following example, which is based on kinetic data and operating parameters pertaining to the operation of the Mintek pilot plant at Western Areas Gold Mine under conditions of low (400 l/h) and high (800 l/h) pulp flowrate. The following parameters are common to both tests:

No. of stages	5
Gold on carbon to CIP	0 g/t
Rate constant (k)	0,027 h ⁻¹

Equilibrium constant (K) 10850.

From Table I it can be seen that, although the predicted and observed solution and carbon profiles were similar, the amounts of carbon calculated as necessary for the observed performance were considerably less than those actually employed. One of the reasons for this lack of agreement is the fact that gold from the ore is dissolved or desorbed during CIP absorption. This can, in certain cases, significantly influence the performance of a CIP plant, and this aspect will be discussed later. Another possible reason is sensitivity to small changes in the barren solution. Thus, a decrease in the gold concentration of the barren solution from 0,03 to 0,02 g/t in Test 2 resulted in an increase in the predicted amount of carbon required from 6,4 to 8,3 kg per stage.

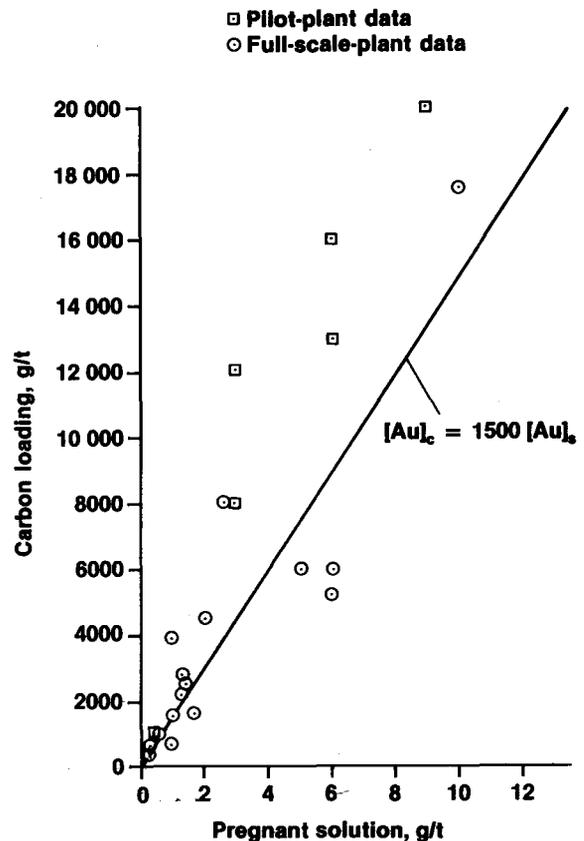


Fig. 2—Observed performance of full- and pilot-scale CIP plants

TABLE I
PREDICTED AND OBSERVED OPERATION OF PILOT PLANT AT WESTERN AREAS GOLD MINE

Stage	Test 1, 400 l/h				Test 2, 800 l/h			
	Gold in solution, g/t		Gold on carbon, g/t		Gold in solution, g/t		Gold on carbon, g/t	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
Feed	2,02	2,02	0	0	2,26	2,26	0	0
1	0,76	0,52	3092	3097	1,12	1,00	6503	6512
2	0,24	0,13	1600	793	0,39	0,44	3693	2835
3	0,039	0,034	168	201	0,15	0,19	1972	1196
4	0,015	0,009	40	49	0,08	0,08	550	467
5	0,002	0,002	18	10	0,03	0,03	189	141
Carbon per stage:	Observed	10 kg	Predicted	6,6 kg	Observed	10 kg	Predicted	6,4 kg

Periodic Transfer of Carbon

In practice, carbon is not transferred continuously countercurrent to the flow of the pulp. Instead, a fraction of the carbon inventory in each stage is removed at fixed time intervals and transferred to the preceding stage by means of airlifts or pumps. In the extreme case, all the carbon in any one stage is transferred during a cycle. If it is assumed that this transfer is accomplished in a very short time compared with the time that the carbon spends in each contactor between transfers, then the following simple analysis enables the periodic performance of an absorption section to be modelled.

The rate of loading of gold onto a batch of carbon (mass M_c) transferred into a contactor (containing a mass M_s of solution) through which pulp containing gold at a concentration of $[Au]_s^{in}$ is passed at a flowrate V_s can be derived if the expression for the mass balance across the contactor is combined with a suitable rate equation. Thus, for the mass balance,

$$M_c \frac{d[Au]_c}{dt} = V_s([Au]_s^{in} - [Au]_s) + M_s \frac{d[Au]_s}{dt} \quad (5)$$

As shown in the previous paper¹, the concentration of gold in solution increases with time, but the term $M_s d[Au]_s/dt$ is small in relation to the others for reasonable concentrations of carbon. This equation can then be simplified to

$$\frac{d[Au]_c}{dt} = \frac{V_s}{M_c} ([Au]_s^{in} - [Au]_s) \quad (6)$$

Equation (1) can be combined with this equation to yield the following expression for $[Au]_s$:

$$[Au]_s = \frac{M_c k [Au]_c + V_s [Au]_s^{in}}{M_c k K + V_s} \quad (7)$$

Substitution in (6) yields

$$\frac{d[Au]_c}{dt} = k_A (K[Au]_s^{in} - [Au]_c), \quad (8)$$

where $k_A = kV_s/(M_c kK + V_s)$.

For the first stage of a multistage circuit with a constant feed concentration $[Au]_s^{in} = [Au]_s^0$, equation (8) can

be integrated to yield the following expression for the concentration of gold on the carbon as a function of time in the first stage:

$$[Au]_c^0 = K[Au]_s^0 - \exp(-k_A t) (K[Au]_s^0 - [Au]_c^1), \quad (9)$$

where $[Au]_c^1$ is the concentration of gold on the carbon added to the contactor. Substitution of equation (9) into equation (7) yields the following expression for the concentration of gold in solution in the first stage as a function of time:

$$[Au]_s^1 = [Au]_s^0 - \frac{k_A M_c}{V_s} \exp(-k_A t) (K[Au]_s^0 - [Au]_c^1). \quad (10)$$

As shown in the previous paper, these expressions can be simplified if the absorption reaction is far from equilibrium. The resulting equations predict a linear dependence of both $[Au]_c^0$ and $[Au]_s^1$ with time in the first stage after carbon has been transferred into the contactor.

This procedure cannot be followed for the second or subsequent stages because the feed to each stage is not constant and the equation (written for the second stage)

$$\frac{d[Au]_c^1}{dt} = k_A (K[Au]_s^1 - [Au]_c^1) \quad (11)$$

cannot be simply integrated. The simplest approach has been found to be the following.

- (i) $[Au]_c^0$ and $[Au]_s^1$ are obtained as a function of time by the procedure previously outlined.
- (ii) The values of $[Au]_s^1$ thus obtained are used in a numerical integration of equation (11) to give $[Au]_c^1$.
- (iii) Values for $[Au]_s^2$ are then obtained by use of equation (7).
- (iv) This procedure can be repeated for each subsequent stage.

Simulation of the start-up and approach to the steady-state operation of a circuit can be made if it is assumed that fresh carbon is added to each stage at the start and all the carbon is transferred at fixed time intervals. This calculation procedure can be carried out after each transfer, and Fig. 3 shows the approach to steady-state conditions predicted for the first and fourth stages of the Mintek pilot plant as detailed in Table I.

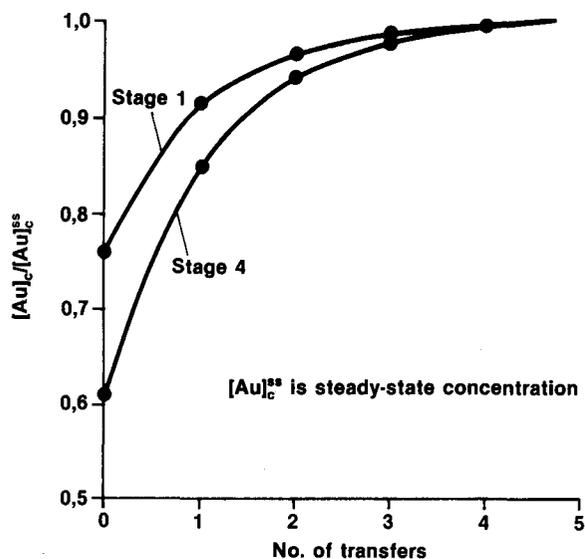


Fig. 3—Approach to steady-state operation

Actual plant data are shown in Fig. 4 for the gold on the carbon over four cycles in the first stage, and the solid lines were calculated according to the above procedure. The agreement between observed and calculated performance is seen to be reasonably good and, if the inaccuracies associated with the sampling and analysis of both the solution and the carbon are taken into consideration, the results demonstrate that the model can adequately describe the performance of a CIP circuit operated in this periodic-transfer mode. The calculated periodic variation in the concentration of gold in solution is also shown in Fig. 4.

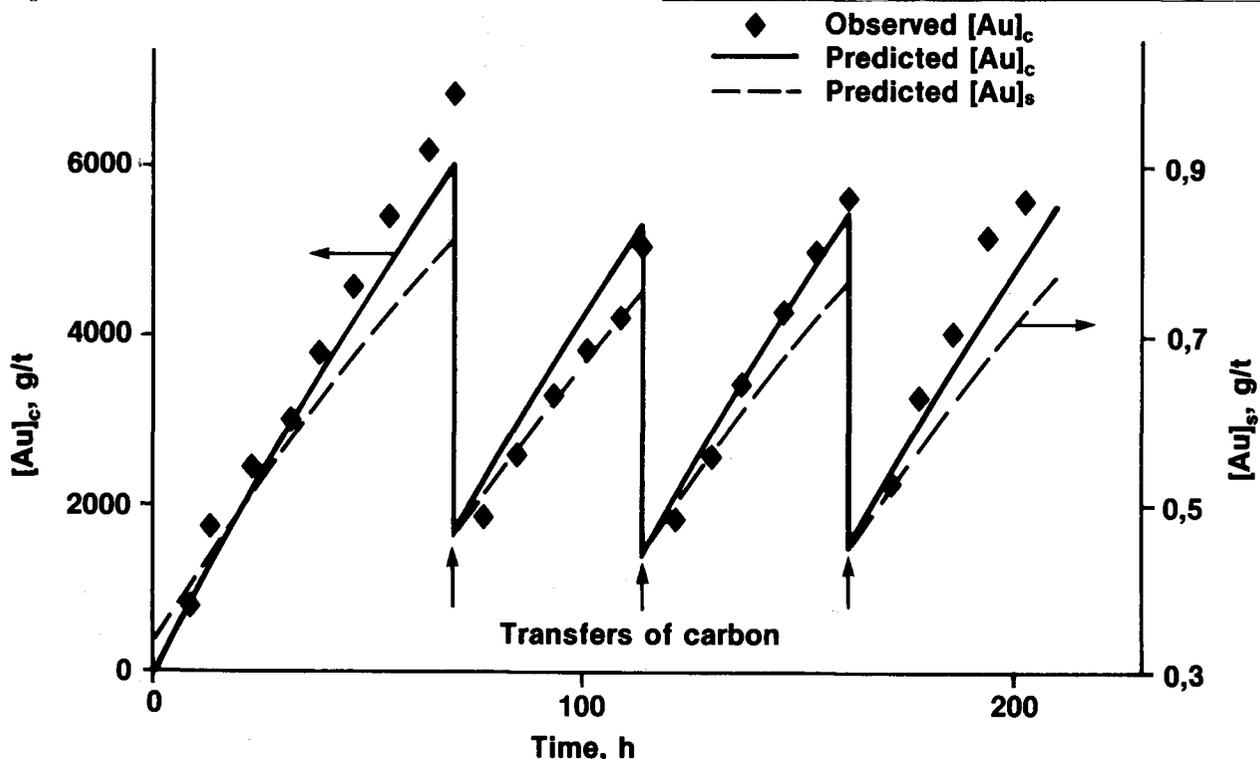


Fig. 4—Cyclic behaviour of the CIP pilot plant

Some Practical Implications

A number of conclusions regarding the design and operation of an absorption circuit can be made as a result of the application of this model.

Transfer of Carbon

A comparison of the data calculated from the predicted curves in Fig. 4 with those in Table I shows that there is very little difference in the expected performance of an absorption circuit with continuous transfer of carbon, or with periodic complete transfer of all the carbon, from stage to stage. A full analysis of the relative performance for the transfer of various fractions of the carbon inventory of each stage during each cycle produced the values given in Table II. It should be emphasized that these values are for an ideal case and do not allow for possible 'poisoning' of the carbon or other similar effects.

Amount of Carbon per Stage

It has often been suggested, without explanation, that more carbon should be added to the latter stages of an absorption circuit than to the early stages. This is sup-

TABLE II
ANALYSIS OF RELATIVE PERFORMANCE FOR THE TRANSFER OF VARIOUS FRACTIONS

Fraction transferred per cycle	Relative performance
1,00	1,00
0,50	0,95
0,25	0,92
0,10	0,90
Continuous	0,88

posed to result in a more effective operation with reduced concentrations of gold in the barren solution. The predicted effects of such a non-uniform distribution of carbon in the Mintek pilot plant at Western Areas are shown in Fig. 5. It can be seen that, if the carbon is distributed uniformly throughout the plant, the gold in solution decreases exponentially with the number of stages, i.e. each stage extracts the same fraction of gold as that which enters the stage. It should be noted that a non-uniform distribution of the carbon in the direction of a greater fraction in either the first or last two contactors results in a higher concentration of gold in the barren solution. The practical implication of this finding is obvious in that, for a given performance, the minimum carbon inventory is realized when the carbon is distributed uniformly throughout the absorption circuit. It is interesting to note, however, that the amount of gold 'locked up' in the carbon in a plant has a bearing on the optimum distribution of carbon.

This can be seen from Table III. The amount of carbon required and the gold lock-up in the four-stage plant were calculated from the model for the following possibilities:

- a uniform distribution of carbon throughout the plant,
- three times as much carbon in stages 1 and 2 as in stages 3 and 4, and
- three times as much carbon in stages 3 and 4 as in stages 1 and 2.

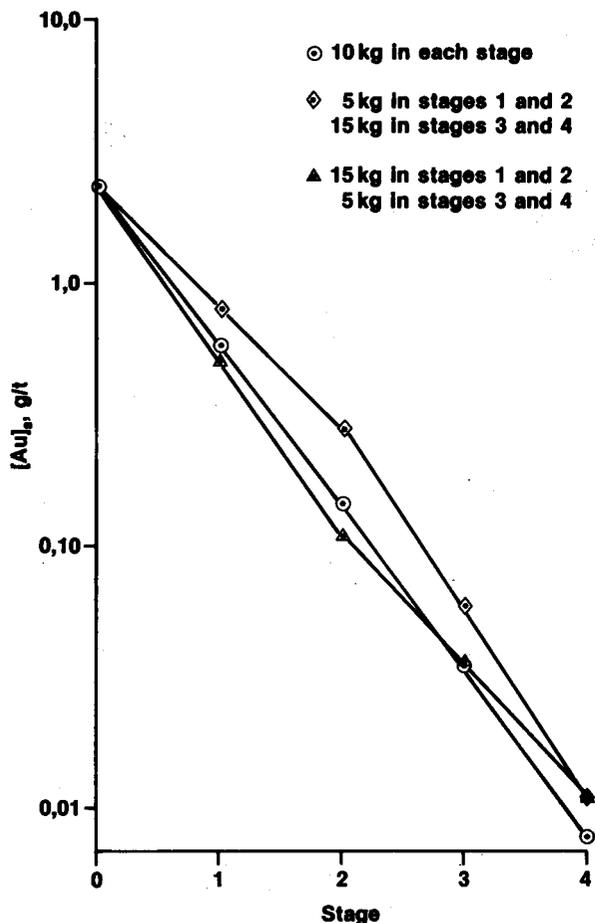


Fig. 5—Effect of carbon distribution on CIP performance

TABLE III
EFFECT OF NON-UNIFORM DISTRIBUTION OF CARBON

Example	Relative carbon inventory	Relative gold lock-up
(a) Uniform	1	1
(b) Stages 1, 2 > Stages 3, 4	1,19	1,68
(c) Stages 1, 2 < Stages 3, 4	1,19	0,77

Stage Efficiency

The stage efficiency, i.e. the percentage of gold extracted in each stage, is usually constant if the concentration of carbon in each stage is the same. This has generally been found to be the case on both pilot and full-scale plants. However, there are exceptions, as shown by Table IV.

TABLE IV
SOLUTION PROFILE FOR PLANT TREATING A CALCINE AT THE PRESIDENT BRAND GOLD MINE

Stage	Gold in solution g/t	Stage efficiency %
Feed	6,14	
1	4,09	33
2	2,91	29
3	2,09	28
4	1,40	33
5	0,86	39
6	0,47	45
7	0,15	68

The decreasing stage efficiency as the carbon progresses through the plant is indicative of a cumulative 'poisoning' effect, and an investigation with a scanning electron microscope revealed the presence of a layer of fine hematite that had built up on the carbon particles and was hindering the mass transport of gold to the carbon surface.

Carbon Inventory

As in most multistage processes, the total amount of absorbent material (in this instance carbon) decreases as the number of stages increases. Calculations similar to those for Table I for conditions pertaining to the pilot plant at Western Areas Gold Mine produced the values that were plotted in Fig. 6. Here, the carbon inventory and gold lock-up were normalized to the case in which an infinite number of stages are used. It is apparent from the curves that there is a significant advantage to be gained in terms of reduced inventories of both carbon and gold (on the carbon) by the use of a large number of stages. This is obviously offset by the higher capital and operating costs associated with each additional stage, and it can be expected that there will therefore be an optimum number of stages for each individual application. This aspect is treated later in more detail.

Application to Carbon-in-Leach

The addition of carbon direct to a gold-leaching circuit is an attractive alternative to a separate carbon-in-pulp

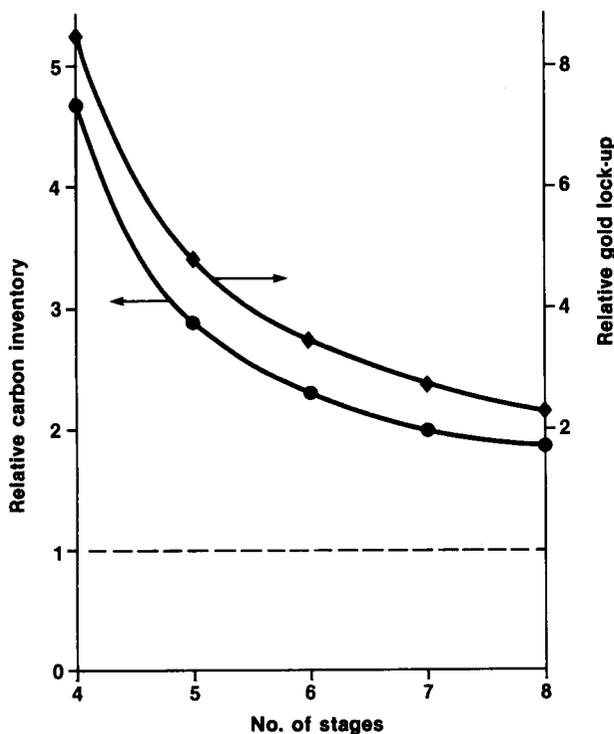


Fig. 6—Influence of the number of stages on carbon inventory and gold lock-up

absorption circuit. This approach has obvious advantages from the point of view of capital costs, but at the same time presents a number of operational problems. These are not discussed here, but the application of the CIP model for the absorption process to a typical carbon-in-leach (CIL) application is useful in an assessment of the technical feasibility of such an option and the identification of some of the more important design and operating parameters. Such a model should also be of value in an estimation of the effects of the additional gold leaching that can occur during absorption in a conventional CIP circuit. The derivation of such a model requires that a suitable rate equation should be obtained for the leaching of gold. This equation can then be combined with the rate expressions for absorption and the relevant mass-balance equations.

Kinetics of Leaching

The rate of gold leaching from ores such as those encountered in the present example is a complex kinetic problem involving a number of chemical, mass-transport, and mineralogical factors. However, a relatively simple expression has evolved from experience at Mintek with the leaching of a number of local ores. This rate expression has the following form:

$$-\frac{d[Au]_{p,t}}{dt} = k_p ([Au]_{p,t} - [Au]_{p,e})^2 \quad (12)$$

where $[Au]_{p,t}$ is the concentration of gold in the ore at time t and $[Au]_{p,e}$ is the corresponding quantity at infinite time (i.e. the minimum achievable residue grade), while k_p is a rate constant.

Examples of the use of this expression to describe the kinetics during batch leaching are given in Fig. 7, in

which data for the leaching of a high-grade ore (7 g/t) and a low-grade residue (0.8 g/t) are plotted on a logarithmic scale. The lines were calculated from the integrated form of equation (12), and best-fit values for the parameters $[Au]_{p,e}$ and k_p were derived from a non-linear least-squares treatment of the data. The agreement can be seen to be good, and it is interesting that such an analysis of some six different ores yielded values for the rate constant k_p that vary in the rather limited range 0.4 to 1.0 h^{-1} . This suggests that most ores are leached at roughly the same rate, and that an average of 0.7 h^{-1} is a reasonable estimate for use in the absence of actual values. The finer grind that is necessary for CIL probably results in somewhat faster leaching, and the suggested value of 0.7 h^{-1} is probably a lower limit.

Model for the Multistage CIL Process

The methods outlined earlier for a multistage continuous CIP plant operating at steady state can be simply extended by the inclusion of the solids in the mass balance for each stage after the concentration profile for the solids has been calculated from equation (12) with the average residence time for the pulp in each stage; that is, the assumption is made that the rate of leaching is independent of the presence of activated carbon. Batch tests at Mintek have shown this to be the case. The application of this procedure to a typical low-grade ore (such as that used in the Mintek pilot plant at Western Areas Gold Mine) yields the following performance for a simulated CIL plant designed to achieve the same performance as the CIP plant operated under the conditions of Test 1 in Table I, viz a pulp flowrate of 400 l/h with a barren solution of 0.002 g/t gold and a carbon loading of approximately 3000 g/t from a head grade of 2 g/t. The CIL plant has 8 stages with a pulp residence time of 3 hours per stage, and the calculations were made on the assumption that activated carbon is present in all the stages or only the last seven, six, five, or four stages of

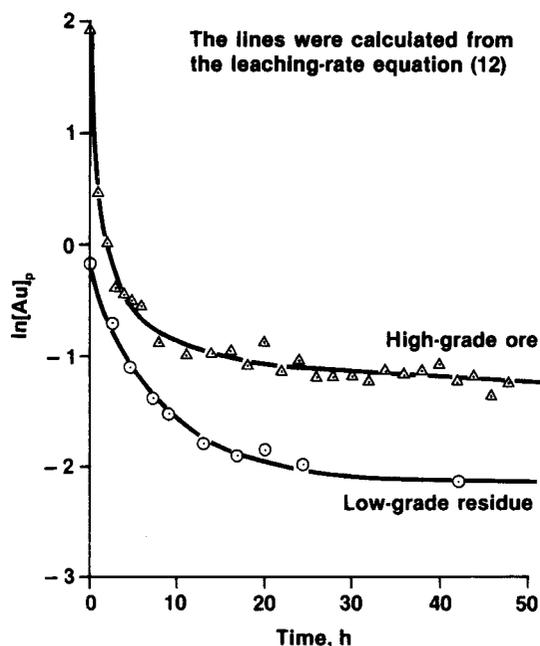


Fig. 7—Leaching rates of two ores from different localities

leaching, i.e. with varying numbers of preleaching stages.

The profiles calculated for the solution and solids (ore) in the example in which the first three stages do not contain carbon are shown in Fig. 8. It can be seen that almost 90 per cent of the gold is leached in the first stage, implying that carbon could be added to the first stage without affecting the achievable loading on the carbon while possibly reducing the gold in the barren solution. However, the calculations show that there is an optimum point for the addition of carbon. Thus, the amounts of carbon required to achieve the same performance and the gold locked-up in the plant (relative to the example where all the stages contain carbon) are plotted in Fig. 9, from which it is apparent that two stages of preleaching would be optimum. The point of addition of carbon will vary with head grade and the desired barren-solution value. However, only in very exceptional cases are more than 5 or 6 hours of preleaching required. Thus, calculations in which the desired barren solution in this application is increased to 0,01 g/t results in an optimum situation of one preleaching stage, and an increase of the head-grade to 8 g/t results in the prediction that carbon should be added to all the stages.

This model permits an assessment of the effect of so-called 'extra gold dissolution' during CIP absorption. Observations on both pilot-and full-scale plants have shown that the washed residues after CIP are invariably lower than those obtained by sampling of the feed to

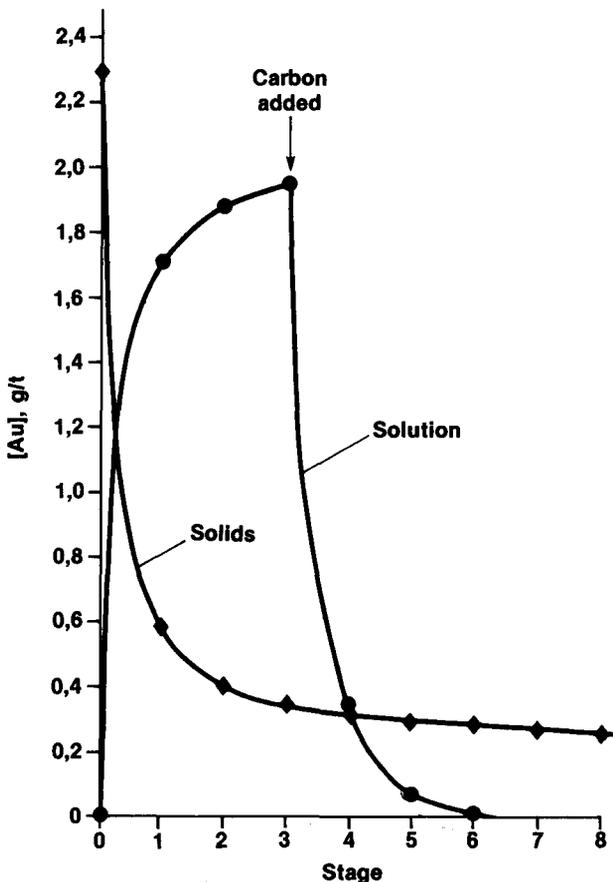


Fig. 8—Calculated solids and solution profiles for a CIL plant

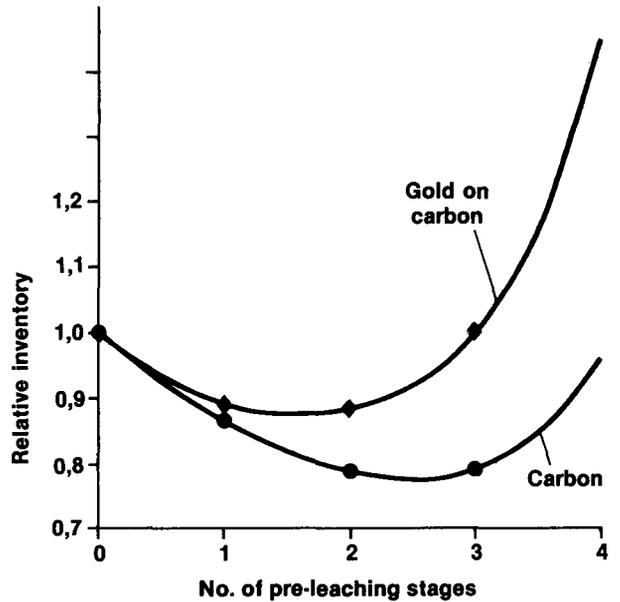


Fig. 9—Effect of number of pre-leaching stages on the relative performance of a CIL plant

CIP. This difference can in some instances amount to an additional gold recovery of as much as 1 to 2 per cent. However, continued slow leaching of the gold during CIP absorption can lead to apparent poor performance of the circuit, especially if low (less than 0,01 g/t) barren values are desired. This can be seen from the following fairly typical example in which the pulp produced by the leaching in 8 stages of 3 hours each as described above is subjected to CIP absorption. In the absence of additional leaching, five-stages of CIP would result in the predicted results shown in Table I (Test 1), in which 6,6 kg of carbon per stage would be required to produce a barren solution containing 0,002 g/t of gold. An allowance for continued gold leaching results in the predicted profiles shown in Table V.

TABLE V
PREDICTED EFFECT OF ADDITIONAL LEACHING OF GOLD ON CIP ABSORPTION

Conditions: The same as for Test I in Table I

Stage	Solids, g/t	Solution, g/t	Carbon, g/t
Feed	0,26	2,02	
1	0,25	0,43	3072
2	0,25	0,092	669
3	0,24	0,022	158
4	0,23	0,006	44
5	0,23	0,002	12

Table V can be compared with Table I and the results predicted for a CIL plant (Table VI).

It is apparent that the dissolution occurring during absorption can have a significant effect on the amount of carbon required, and this results in a higher carbon (and gold) inventory for a CIL plant than for a CIP plant. This would need to be taken into account in any economic evaluation of the alternative circuits.

TABLE VI
COMPARISON OF CIP AND CIL

Plant	Leaching stages	Head g/t	CIP stages	Residue g/t	Carbon inventory kg	Gold lock-up kg
Leach-CIP	8(3)	2,3	5(1)	0,26	32,9	0,027
*Leach-CIP	8(3)	2,3	5(1)	0,23	55,2	0,044
CIL	8(3)	2,3	0	0,26	68,5	0,055

The figures in parentheses represent pulp residence times

* Allowance was made for leaching during CIP absorption.

Application to the Economic Optimization of Design

It should be apparent from these considerations that the design of a CIP plant involves decisions on a number of process options, the most important of which are the desired extraction (i.e. the maximum concentration of gold in the barren pulp), the loading of gold on the carbon, and the number of stages to be employed. Having a knowledge of the kinetics of extraction and using this model, one can show that the correct decisions on these options can lead to economic optimization of the plant design. It should be emphasized that the approach suggested is a simplification of a complex economic-optimization procedure. However, it serves to illustrate how the models developed in this paper can be incorporated into such a cost-minimization procedure.

A major consideration is the value of the carbon and the gold absorbed on the carbon in the absorption circuit. As a first approximation, the value of the carbon and its associated gold was considered to be part of the capital cost of the plant. The following example was based on the operating characteristics of the Mintek pilot plant at Western Areas Gold Mine, which was fully described earlier. The calculations were made for a hypothetical plant to treat pulp containing 200 kt of solution per month, and the following assumptions were made:

	R
Value of activated carbon per ton	3 000
Value of gold per kilogram	15 000
Cost of elution and reactivation per ton of carbon	100
Cost of absorption vessel	150 000

As a result of the interdependence of the various parameters, an iterative procedure was employed in which, for example, the number of stages and the desired concentration of gold in the barren solution are fixed and an optimum gold loading on the carbon is calculated. This value can then be used in the calculation of the optimum number of stages, and in the estimation of the barren-solution value, which can then be used in another cycle of calculations. In this particular instance, the assumption was made that 6 stages are required to produce a barren solution containing 0,001 g/t of gold. These values were then substituted into the model, together with various possible gold loadings, and the necessary amounts of carbon and the gold locked up were calculated. The results are shown in Fig. 10, in which it can be seen that the optimum loading is 4000 g/t. The existence of this optimum is attributed to the oppo-

sing effects of lower operating costs associated with a higher gold loading (i.e. a slower movement of carbon through the plant) and the increase in the amount of carbon and gold in the absorption vessels. The interest on these values was calculated for a rate of 15 per cent per annum.

It has already been demonstrated that the amount of carbon required to achieve a desired extraction and the amount of associated gold decrease with increasing numbers of stages (Fig. 6). In this example, the decrease in capital associated with the carbon and loaded gold must be balanced against the cost of extra absorption vessels. The use of the optimum loading of 4000 g/t and a desired barren solution of 0,001 g/t in the model for various numbers of stages produced the results illustrated in Fig. 11, from which it can be seen that the previous estimated optimum of 6 stages is correct.

Finally, these values of 4000 g/t loading and 6 stages can be used in a similar calculation to give an optimum value for the gold in the barren solution. In this case, increased recovery is offset by the need for the employ-

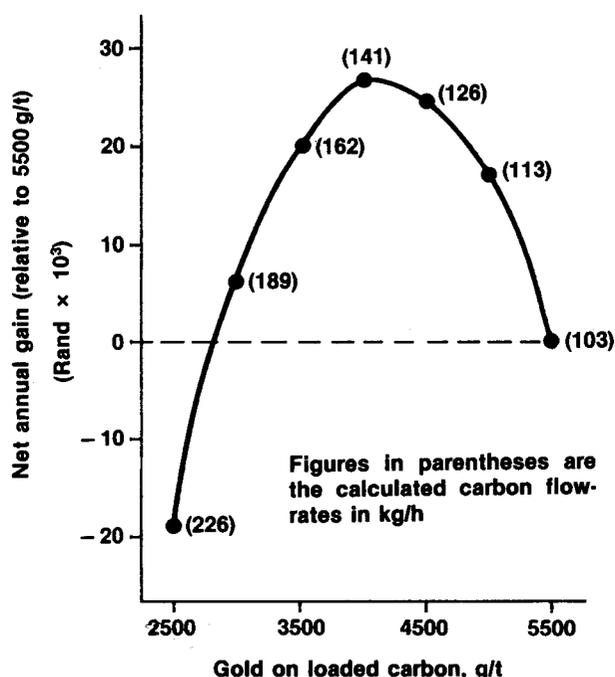


Fig. 10—Optimization of the carbon flowrate and the gold loading in a six-stage CIP plant

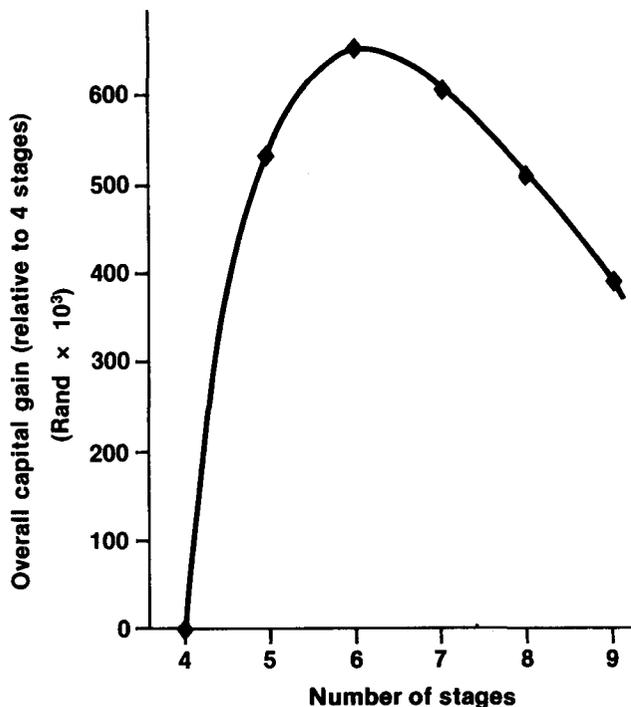


Fig. 11—Optimization of the number of stages in a CIP plant

ment of more carbon with its associated gold. The results of these calculations are shown in Fig. 12, from which it can be seen that the plant should be designed to produce barren values below 0,002 g/t. A comparison of the relative revenues in Figs. 10 and 12 shows that the loss of gold in the barren pulp is a more important consideration than the amount of gold locked up in the plant.

Conclusions

A relatively simple rate expression for the absorption of gold onto activated carbon was used as the basis for the development of a model for a multistage CIP absorption circuit. When the model was used in the prediction of both the steady-state and the transient behaviour of the absorption process, the results were in reasonable agreement with those observed in an extended pilot-plant campaign.

Extension of the model to the description of a CIL process was made possible by the inclusion, in the overall CIP model, of a suitable rate equation for leaching. This

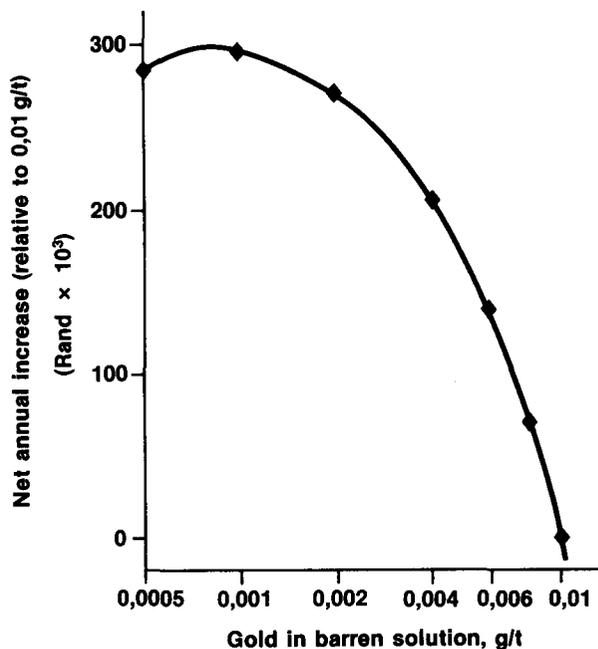


Fig. 12—Optimization of the extraction efficiency in a six-stage CIP plant

enabled the optimum point of addition of carbon to the leaching circuit to be identified, and also allowed for an assessment of the effects of gold dissolution during a normal CIP absorption.

Finally, a brief assessment was made of the economic consequences of the various process options available for the design of a CIP plant.

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