The evaluation of the AAC Pump-Cell circuits at Anglogold's West Wits operations

by J. Rogans* and D. McArthur†

Synopsis

This paper discusses the comparative performances of the three activated carbon adsorption circuits at the West Wits operations of Anglogold. These circuits consist of two pump-cell circuits (at Two Plant, formerly Elandsrand and at Three plant) and a conventional counter-current adsorption circuit (at Mponeng plant). The implications of the improved performance of the pump-cell plants are discussed.

Introduction

Recent developments in Carbon-in-Pulp (CIP) adsorption circuit technology have centred around the use of tanks arranged in a carousel mode of operation. The carbon is not transferred between stages, rather, feed and discharge points in each tank are moved to achieve counter current transfer[1,2].

One of the more successful developments is the Anglo American (AAC) Pump-Cell adsorption circuit[3–5]. In its initial applications, Pump-Cell circuits were applied to recovering gold from low grade materials such as scavenging from filtration plant tailings and slime dam re-treatment. The application of AAC Pump-Cell technology to high grade gold circuits is recent and the evaluation of these plants is covered in this paper. Anglogold undertook a detailed trade off study[6] to evaluate to best practice for this conversion of their outdated plants in the West Wits region:

- ➤ West Wits Two plant (formerly Elandsrand)—Filtration plant
- ➤ West Wits Three plant (formerly Western Deep Levels No.2)—Filtration plant.

It was decided to install AAC Pump-Cell circuits at West Wits Two and Three plants and to expand the elution facility at West Wits Mponeng plant, to cater for all three plants. The two Pump-Cell plants were completed at the end of 1999 and were commissioned on head grade soon thereafter.

Since the three gold plants had similar head grades, and shared an elution facility, comparison between Pump-Cell and CIP technology in terms of performance and cost was undertaken. This study was carried out for the calendar year 2000, after the three operations had been optimized.

West Wits operation project

Anglogold investigated the conversion of the three plants of the West Wits organization[7,8].

This involved the following:

- ➤ Converting the filtration plant at West Wits Two plant to a Pump-Cell plant CIP circuit capable of handling 220 000 t/m
- ➤ Converting the filtration plant at West Wits Three plant to a Pump-Cell CIP circuit capable of handling 280 000 t/m.

Enlarging the elution facility at West Wits Mponeng plant, to handle 35 tons per day of activated carbon. The elution plant utilizes the AARL method of elution.

The Pump-Cell CIP plants at Two and Three plants are similar in that they are satellite adsorption circuits, with the carbon being eluted at the centralized elution facility. Loaded and eluted carbon is moved to and from the Pump-Cell plants in road tankers. The project was completed in 1999, with all three plants operating on head grade by December 1999. The optimization of the three plants was carried out during the calendar year 2000. By the end of the year the plant personnel could make value judgements on how their plant could operate under most favourable conditions.

The operating conditions for the optimized plants are given in Table I.

* *Kemix (Pty) Ltd, P.O. Box 39441, Bramley, 2018.*

† *Anglogold Limited, Private Bag X5010, Vaal Reefs, 2621.*

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Table I

Operating data of the West Wits operations, CIP plants after optimization (last quarter 2000)

Parameter	Mponeng (Western Deep Levels No.1)	Two (Elandsrand)	Three (Western Deep Levels No.2)
Type of plant	Conventional CIP	Pump-Cell	Pump-Cell
Throughput (t/m)	135 000	147 000	227 000
Throughput (t/d) Average:	4 500	4 900	7 600
Range :	Continuous	Continuous	2 000–12 000
Head grade (mg/l)	7.5	6.25	10
CIP vessel size (effective m^3)	212	90	110
Average residence time of pulp per tank (mins)	50	19	15
No. of cells (operating)	8 (8)	8 (7)	8 (8)
Soluble loss (mg/l)	0.011	0.006	0.008
Washed residue (g/t)	0.148	0.179	0.270
Carbon consumption (g/t)	45	40	45
Pulp density	1.48	1.44	1.46
Gold on loaded carbon (g/t)	6 000	12 250	16 200
Carbon eluted per day (t)	5.6	2.5	4.7
Upgrade ratio	800	1 960	1 620
Gold lock up (kg)	83	41 (max)	90 (max)
Carbon inventory (adsorption circuit only) (t)	45	35	44

West Wits Mponeng plant (Western Deep Levels No.1 gold plant) adsorption circuit

This adsorption circuit is a traditional cascade CIP circuit in which the counter current flow of activated carbon is carried out by physically pumping the carbon up the adsorption circuit. The central elution facility is situated next to this adsorption circuit. The adsorption circuit consists of eight 212 m^3 tanks (effective volume) with MPS interstage screens (submerged mechanically swept vertical screens similar to those employed in the Pump-Cell plants). At a throughput of 135 000 t/m, the residence time of the pulp per contactor is 50 minutes.

Prior to the commencement of the optimization of the Pump-Cell plants, the CIP plant at Mponeng was operated like most other traditional CIP plants in South Africa, namely, operated to minimize gold lock up in the adsorption circuit at the expense of an optimized operating cost. The optimization of the Pump-Cell plants of West Wits operations demonstrated that it is possible to reduce operating costs by moving the carbon slower, without penalizing solution gold loss. An optimization programme was undertaken at Mponeng plant, consisting of reducing a number of elutions per day then monitoring the performance of the plant in terms of solution profiles and residue, and operating costs. The change in key parameters is given in Table II.

As the carbon movement rate is reduced, the gold content on loaded carbon increases, increasing the upgrade ratio. The upgrade ratio is the ratio of gold in the solution feed to the adsorption circuit to gold on loaded carbon. A higher up grade ratio means that the carbon in the adsorption circuit is able to load gold to higher gold loadings thus, less carbon is required. Moving less carbon reduces elution costs as elution costs are based on volume irrespective of gold loadings on carbon. A similar way of describing upgrade ratios is using operating or pseudo equilibria determined by relating gold on carbon to gold in solution at steady operating state graphically[9]. During the course of the year 2000, Mponeng plant optimized carbon movement rate towards a point where solution gold residue was not penalized. This was achieved at an upgrade ratio of 800. The plant did achieve a best case scenario of an upgrade ratio of 1000, but this was not regularly achieved due to lock up constraints. Other Anglogold CIP adsorption circuits (Vaal River No.8 and No.9, Freestate No.1) all achieve upgrade ratios of between 800 to 900. All the plants would operate at an upgrade ratio of 1000 to 1200 if there were no lock up constraints. Thus, the best case scenario for the Mponeng plant was set at 1000 (for a CIP plant treating pulp with a gold grade of between 6 to 12 mg/l).

West Wits Two plant (Elandsrand) adsorption circuit[10,11]

During the course of the year 2000 the Two plant went through an optimization similar to that of the Mponeng plant adsorption circuit, in that the circuit was optimized in terms of operating costs balanced against maximizing gold on carbon loadings without penalizing gold losses. The changes to key parameter areas are given in Table II.

The monitoring of the gold on carbon and gold in solution profiles demonstrated an under-utilization of carbon. The movement of carbon was thus slowed down to a movement cycle of one elution batch every two days from an initial daily cycle.

During the period when the cycle time was every two days, the variation of the gold on carbon and gold in solution profiles were evaluated. The daily average gold on carbon variation is given in Figure 1, and for gold on solution profiles in Figure 2.

The profiles demonstrate the differences between carousel and cascade CIP plants in terms on how the plants operate.

A cascade CIP circuit, in which the carbon is continuously transferred up the circuit against the flow of pulp (which may

Table II

Changes to key performance areas on the three West Wits operations, CIP circuits during year 2000 (With interpolation into best case scenario)

	Mponeng	Two	Three
Mid-year operation (not optimized)			
Throughput (t/m)	140 000	140 000	220 000
Head grade (g/t)	6.9	6.25	11.2
Gold on loaded carbon (g/t)	4920	6400	14 100
Upgrade ratio	713	1024	1260
Carbon eluted per day (t)	7.4	4.8	5.83
Gold lock up (kg)	71	80	86
Late-year operation (optimized)			
Throughput (t/m)	135 000	147 000	227 000
Head grade (g/t)	7.5	6.25	10.3
Gold on loaded carbon (g/t)	6 000	12 250	17 000
Upgrade ratio	800	1962	1650
Carbon eluted per day (t)	5.6	2.5	4.7
Gold lock up (kg)	83	50	87
Best case scenario—(no lock up constraints—continuous operation)			
Throughput (t/m)	140 000	150 000	230 000
Head grade	7.5	6.25	10.5
Gold on loaded carbon (g/t)	7 500	14 000 (19000)	20 600
Upgrade ratio	1 000	2 200 (3040)	1 970
Carbon eluted per day (t)	5	2.5 (1.7)	3.9

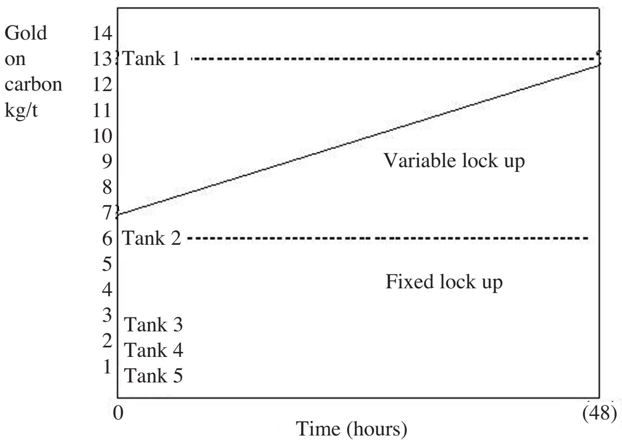

Figure 1—Variation of gold on carbon in lead cell of the Pump-Cell circuit at West Wits No. 2 gold plant. (Averaged for November 2000)

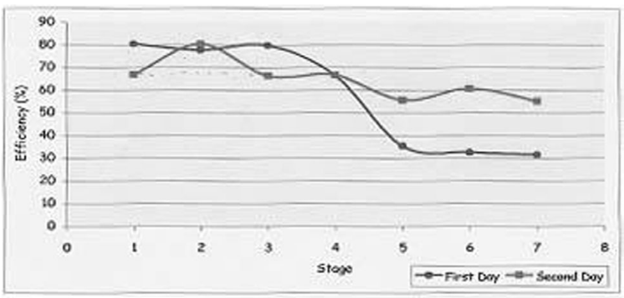

Figure 2—Average stage efficiencies for decreased carbon movement rates

be over a certain period per hour, or continuously), the gold-on-carbon and gold-in-solution profiles form pseudo equilibrium profiles. In other words, whenever the samples are taken over a twenty-four hour period the profiles will be similar (assuming consistent gold grade and throughput). This is even achieved in the lead contactor, as a higher concentration of carbon is generally utilized in the top tank to minimize gold slipping down the circuit when the loaded carbon is removed for elution. Thus the profiles can be measured at any time, and a change in the profiles would indicate that an unwanted process problem has arisen that requires rectification. The measurement of profiles thus becomes an important tool to manage an operating cascade CIP circuit. Since the cascade CIP circuit has achieved a pseudo equilibrium the measurement of gold-on-carbon is directly extrapolated into gold locked up in the circuit.

In the Pump-Cell plant, since the carbon is maintained in discrete batches, the carbon behaves dynamically. In other words, as the pulp moves through the cell the carbon in the Pump-Cell removes gold increasing the content of gold on the carbon with time. As shown in Figure 1, the increase in gold loading is linear with time over a complete cycle. At the end of the cycle the carbon in the lead cell is isolated and the carbon removed. The second cell becomes the lead cell. The gold-on-carbon in the lead cell starts from a loading base equal to the second cells gold loading of the previous cycle. This dynamic change occurs throughout the circuit, throughout the cycle. A gold-on-carbon profile taken at any time during a cycle will be different. In terms of gold lock up in the adsorption circuit, the gold adsorbed in the first cell is removed from the circuit prior to completion of the cycle (the first cell is always taken off line before the second cell becomes the lead cell). Thus the gold loaded in the first cell is a variable lock up that is easily removed whereas the gold in the rest of the circuit will take at least two cycles to be removed. As shown in Figure 1, about half the gold-on-carbon is a variable lock up. Comparing gold lock up to a cascade CIP (which has no variable lock up), the Pump-Cell plant has a much lower true gold lock up.

The gold-on-carbon solutions profiles shown on Figure 2 also demonstrate a variation in the profiles with time. At the beginning of the cycle higher extraction efficiencies were achieved in the first three cells with very little gold travelling down the circuit. This results in low extraction efficiencies in the last three cells (because there is too little gold). In the second day of the cycle the extraction efficiencies have evened out.

During the period when the carbon movement rate was decreased, the effects of carbon concentration on stage efficiencies were investigated. This was undertaken to evaluate which of the following scenarios were most effective for Two plant Pump-Cell plant:

- Maintain a five-ton batch of carbon per contactor and move every two days. A carbon concentration of 50 g/l would be achieved
- Maintain a two-and-a-half ton batch of carbon per contactor and move the carbon every day. A carbon concentration of 25 g/l would be achieved.

Carbon concentration data was collected for the months when solution profiles were available. A graph of carbon concentration versus CIP stage efficiency was plotted (see Figure 3). The results show that stage efficiencies increase linearly with increase in carbon concentration. The slope of the line is 1.3, implying that an increase in 1 g/l will increase stage efficiency by 1.3%. A matrix of tail residues was then simulated covering varying head grades and carbon concentrations. This simulation demonstrated that lowering carbon concentrations to below 40 g/l would negatively impact residue filtrates, making the option of moving a five-ton batch of carbon every two days the more suitable option for the No. 2 gold plant.

After the optimization period, the plant was evaluated to find out how far the Pump-Cell plant could be pushed in terms of upgrade ratio. For a two-week period the upgrade ratio was pushed to 3000 by slowing elution rate. This is equivalent to achieving loadings of 20 000 g/t from a head grade of 6.5 g/t.

Currently the plant has managed to achieve an upgrade ratio of between 2000 and 4000, achieving a solution residue of less than 0.01mg/l on a continuous basis. This is achieved by moving carbon three times per week. The variation in upgrade ratio is caused by increasing the rate of carbon elution to satisfy month end gold lock up requirements.

West Wits Three plant[11]

The West Wits Three plant is the oldest gold plant in the West Wits region, the original Western Deep Levels plant was built in the 1960's. The replacement of the two filtration plants by a single 8-stage Pump-Cell plant was completed in the latter half of 1999. The optimization programme for this plant could not have been more different than that of the Two Plant, (Elandsrand). While the Two plant was consistently steady and thus easy to optimize, the Three plant was inconsistent. The main reason is that no ore is hoisted on Sunday from the shafts feeding the gold plant. The daily tonnages typically varied as follows :

Sunday—1500 tons treated per day
Monday—4000 tons per day
Tuesday—5000 tons per day
Wed to Sat—10 000 per day.

Other variables that complicated the operation of the plant was variability in pulp density (1.6 to 1.38) and inconsistent mill gradings.

It was not possible to optimize the West Wits Three plant to the same extent as the West Wits Two Plant, because even under consistent operating conditions a batch of activated carbon always went through a cycle of high and low tonnage, as both tonnage cycle and carbon batch cycle were of similar durations.

The West Wits Three Plant was commissioned with a carbon movement rate of 15 tons per day. This was reduced to 5.5 tons per day for 6 days a week, which was the rate of carbon movement during the majority of the optimization period. It was felt that the carbon movement rate could be improved upon, but this was not attempted due to the variability of the operation of the gold plant.

Thus the achievable performance for this plant was set at :

	Operating	Ideal Optimization
Throughput (tons per month)	230 000	230 000
Daily Tonnage (tons per month)	2 000 to 10 500	7 667
Head Grade (g/t)	10	10
Carbon Inventory (tons per tank)	5.5	4.5
Gold on loaded carbon (g/t)	12 000 to 16 000	18 000 to 20 000
Movement rate (batches per week)	6	6

The value of the optimization programme at West Wits Three plant demonstrated the importance of consistency of operation in cost efficiency. The extra ton of carbon per batch is the penalty of inconsistency.

Operating costs

In today's metallurgical climate, the aim on every plant manager's mind is to reduce operating costs as far as possible without comprising performance and safety. All the West Wits plants share a common elution facility, hence, the operating cost differences between the two technologies (cascade CIP versus carousel Pump-Cell) could be evaluated.

Once all three plants had been optimized (latter half of 2000) their operating costs were evaluated. The operating data in Table I covers the period after the plant has been optimized. A complete cost breakdown per elution at the West Wits Mponeng plant is given in Table III. The operating costs for the plants are given in Table IV. The costs are based

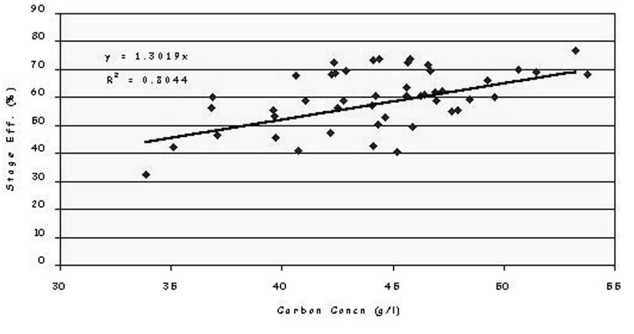

Figure 3—Effect of carbon concentration on stage efficiency

Table III

Elution plant operating costs for West Wits operations' No. 1 gold plant (year 2000 averages, for elution, regeneration and smelting)

Item	Type of unit	No. of units	Cost per elution (South African Rands)
Fixed Costs			
Labour	Hours	-	1 604.00
Assay costs	Analysis	27	452.00
Smelt reagents	-	-	166.00
Spare parts/repairs	-	-	1696.00
Major eplacement items	-	-	276.00
		Total fixed cost	**R4 194.00**
Variable costs			
Reagents:			
Caustic	Kg	648	2 738.00
Sodium cyanide	Kg	145	998.00
HCL	Kg	204	278.00
Water	Kilo litre	46	90.00
Electricity:			
Boiler (elution heater)	KWhr	8959	1 156.00
Kiln (regeneration)	KWhr	8959	1 156.00
Smelt furnace/pumps	KWhr	4480	578.00
		Total variable costs	**R 6 994.00**
		Total (for 5 tons)	**R11 188.00**
		Total (per ton)	**R 2 237.60**

Table IV

Operating costs for the three West Wits operations' CIP plants (year 2000)
Cost—SA Rand per ton of dry ore milled

Plant	Mponeng	Two	Three
Daily Tonnage (average)	**4 500**	**5 000**	**7 666**
CIP circuit costs:			
Activated carbon	0.510	0.495	0.510
CIP screens	0.070	0.067	0.076
Power	0.088	0.088	0.088
Maintenance	0.050	0.050	0.050
Labour *1	0.131	0.129	0.081
Total CIP	**0.849**	**0.829**	**0.805**
Elution daily tons treated	5.7	2.5	4.7
Elution Plant costs *2	2.834	1.119	1.372
Total	**3.683**	**1.948**	**2.177**
Differences (from most expensive)	0	- 1.735	-1.506
Notes *1	Labour costs are R18 400 for 4 operators per month costs divided by tonnage.		
*2	Determined by elution cost per ton carbon (Table III) x carbon eluted per day ÷ daily tonnage.		

on the average daily tonnage throughput and daily carbon movement rates.

The operating costs show that the adsorption circuits costs are similar. This is not unexpected, as the carbon consumption is similar for the plants, and is the biggest cost contributor for the adsorption circuits. Where the Pump-Cell technology surpasses the cascade technology is in the elution costs. Elution costs are based on 'per ton of carbon', as the cost to elute activated carbon will not change irrespective of gold loading values on carbon. Increasing the upgrade ratio, the amount of carbon required to adsorb the gold is reduced. Less elution requirements will thus reduce costs. The most significant cost for CIP is the elution cost, thus the reduction of elution requirements will result in the most significant cost saving in any CIP circuit. Comparison between two similar plants operating at optimum efficiency shows that the Pump-Cell plant (West Wits No.2) demonstrates a cost saving of R1.74/ton ore against the cascade CIP plant (West Wits No.1). This is a significant saving when the total gold plant operating cost is typically R30/t ore milled in South Africa.

The use of modern technology (Pump-Cells) over an out-dated Technology (counter current CIP) is demonstrated on the cost savings, however, a number of questions are raised:

- ➤ Why the difference in performance?
- ➤ Is this a unique occurrence, or is it applicable worldwide?
- ➤ Can the use of a modern adsorption circuit (the Pump-Cell plant) have a direct implication on feasibility studies?

Theory of the practice

In order to explain why one circuit should perform so much better than another, the theory of adsorption of gold by activated carbon needs to be revisited. The adsorption of gold by activated carbon from cyanide solutions has been the centre of many studies over the years. It is generally accepted that the adsorption of gold by activated carbon is via physical adsorption of alkali/alkali earth-gold cyanide complexes. There are kinetic and equilibrium components.

- ➤ The residence time of the pulp per contactor in an adsorption circuit is at most one hour for CIP, thus the activated carbon must adsorb as much gold as possible in the limited time.
- ➤ The activated carbon is moved from contactor to contactor once a day at most. Thus, the activated carbon can load under steady state conditions (constant gold tenor, pH, pulp density, etc.). Activated carbon is allowed to establish a pseudo equilibrium (or operating isotherm).

Since the residence time of pulp in an adsorption circuit is short (one hour or less), adsorption kinetics plays a leading role in the recovery of gold by the CIP process. The role of adsorption by activated carbon has been frequently studied[12,13], with expressions from first order expressions and similar being applied. The rate of adsorption is either film diffusion controlled (diffusing from the bulk liquid phase through a hydrodynamic boundary layer or film surrounding the particle) or intra-particle diffusion controlled (diffusion within the carbon granule). Studies have shown[12] that since the solution concentrations of gold in typical gold plants is low, kinetic gold adsorption is film diffusion controlled. The rate of transfer of gold from a batch solution to the surface of carbon particles is given by:

$$R = k_F A\left(C - C^Y\right)^{13} \qquad [1]$$

Where :

R is the mass transfer rate through the film
k_F is the mass transfer coefficient
A is the external surface area of the carbon particles
C is concentration of gold in the bulk solution
C^Y is concentration of gold at the solution carbon interface.

The factors that affect the rate of gold adsorption are :

- External *surface area* of carbon, which is influenced by particle size of carbon (smaller particles have a higher external surface per unit mass) or concentration of carbon. A higher external surface will improve the rate of adsorption of gold
- A *higher concentration of gold* in bulk solution also improves rate. Hence carousel CIP circuits (such as the Pump-Cell plant) perform better than cascade CIP circuits because they do not utilize the reverse transfer of pulp to transfer carbon which dilutes the gold in solution in cascade CIP circuits
- The *mass transfer coefficient*; it is well known that an increase in intensity of mixing increases the film coefficient by increasing the connective component of mass transfer from the bulk solution to the surface of the carbon[13] (this is assuming that particles are fully dispersed). The agitation intensity may be expressed as power absorbed (in watts) per cubic metre of pulp[15]. The normal design for cascade CIP plants is an absorbed power of 20 to 30W/m^3.[9] The Pump-Cell plants are designed with an absorbed power in the 40 to 55W/m^3 range.

A combination carousel mode of operation, higher than normal carbon concentration and a higher agitation intensity allows the Pump-Cell circuit to achieve better film diffusion rates than cascade CIP plants. This has the effect of steepening circuit gold-in-solution and gold-on-carbon profiles, and allowing for a higher upgrade ratio in the first cell without sacrificing gold loss in the solution tails. This reduces the amount of carbon required per batch, reducing elution requirements and hence operating costs.

A unique South African phenomenon? Cost comparison on a world-wide basis

A common occurrence in the world-wide gold industry is the regionalization of ideas, if it works in one gold field, it won't work anywhere else. Considering that the South African gold industry is hamstrung by the need to minimize gold lock up, it is not surprising that this attitude is taken. A brief survey was undertaken on a number of gold producing areas to determine whether the Pump-Cell performance is indeed applicable world-wide, or just a South African phenomenon. The data collected are based on a comparison of upgrade ratios. The upgrade ratios are achieved when the plants have achieved steady states with respect to their gold-on-carbon and gold-in-solution profiles, (i.e. they are operating at psuedo-equilibrium, as in Rreference 10). From the information in Table V it can be clearly seen that only in South Africa is the constraint of lock up applied to operating gold plants. Overcoming the gold lock up constraint will allow the upgrade ratios to rise to similar levels achieved in the rest of the gold fields briefly surveyed. Allowing the Pump-Cell plants to operate outside of lock up constraints allows their upgrade ratios to be between 2500 and 4000. This is significantly higher than is being achieved in cascade CIP plants, (the best upgrade ratio is 1700).

The similarity of upgrade ratios achieved world-wide indicates that regionalization is based on how plants run, thus technologies like pump-Ccell plants do have world-wide applicability and the benefits obtained in South Africa is transferable world-wide.

A brief cost survey was undertaken, to establish costs to elute carbon in the various gold producing regions. As established previously, the elution costs are the biggest contribution to the CIP plant cost. The cost to operate the adsorption circuits have been ignored, because there is not much cost difference in the adsorption circuit cost, whether Pump-Cell or cascade CIP. The costs are given in Table VI (variable costs) and Table VII (elution costs). The costs are based on a 5 t AARL elution facility (and taken from Table III). The costs are divided into fixed and variable costs. The fixed costs should not vary from region to region, thus are a U.S. Dollar conversion of the cost established at West Wits Mponeng elution plant fixed cost (at a U.S. Dollar to S.A. Rand of 1:8). The variable costs (the major contributors to the costs) are actual costs in the regions. The values in Table VI show how prices for commodities can vary substantially

Table V

Typical upgrade ratio's (Ratio between gold in feed to gold-on-loaded carbon at operating equilibrium) rom a variety of gold producing areas

Area	Upgrade ratio	Typical gold grades
WW Mponeng	800 to 1000	
WW Two (Elandsrand)	2000 (to 3000*)	
WW Three (Western Deep Levels)	1620	
Typical Anglogold CIP (Vaal River/ Freestate operations)	800 to 900 (to 1200*)	6 to 12
Other CIP in South Africa (Witwatersrand region)	900 to 1000 (to 1400*)	4 to 8
Other pump-cells in South Africa (Witwatersrand)	1800 (to 2500*)	
Mali (Anglogold)	1600	
Western Australia	1000 to 1500	
South America	1700	0.8
North America		

Private communications with mines or Kemix agents (with permission)
* SA operations operating outside lock up constraint.

Table VI

Variable costs for elution of activated carbon—all U.S. dollar based

Variable	South Africa	Western Australia	Mali	Tanzania	South America	North America
NaOH (metric ton)	527.0	820	711	751	423	369
NaCN (metric ton)	862.5	995	1219	1421	1130	1025
HCL (metric ton)	170	256.3	484	417	207	144
Water (kilolitre)	0.245	1.538	0.25	0.25	0.06	0.25
Electricity (kW/hr)	0.016	Diesel 0.067 Grid 0.038	0.084	0.13	0.034	0.037

Table VII

Elution costs in various regions surveyed (based on cost in Table) in U.S. dollars. Five ton AARL elution

Cost	Units per elution	South Africa	Western Australia	Mali	Tanzania	South America	North America
Fixed cost		524.25	524.25	524.25	524.25	524.25	524.25
NaOH	0.6484	341.7	531.70	461.0	986.75	274	239.3
NaCN	0.1447	124.8	126.10	176.4	205.64	163.5	148.3
HCL	0.2038	34.7	52.2	98.6	85.0	42.2	29.3
Water	46	11.27	70.0	11.5	11.5	2.8	11.5
Electricity	22398	358.40	Diesel 1501 Grid 850	1881.4 1 1	2911.7	1660	828.7
Total		1395.12	2805.95 to 2155.95	3153.2 (Diesel) (Grid)	4224.75	2666.75	1781.35
(5 tons of carbon eluted) Per ton carbon		279.02	431.19 (Grid)	630.64	844.95	533.35	356.27

Note* (1) Fixed costs are labour, assays, stores, and major capex items and equilized

from region to region. The elution costs in Table VII show how low elution costs are in South Africa when compared to the rest of the world, and that the cost of power contributes most to the variation.

Table VIII gives a comparison of the elution costs for the Pump-Cell and cascade adsorption circuits for the various regions. A US$ 0.4 million per year difference for a small plant (150 000 tons of ore per month), would be a typical saving when a modern Pump-Cell CIP adsorption circuit is chosen over a cascade CIP circuit.

A conceptual comparison of capital costs of a Pump-Cell and cascade CIP for the same duty in South African brownfield site was undertaken. This is based on estimates done during the feasibility study for the West Wits project and actual costs incurred by the Pump-Cell circuit at West Wits Two Plant (Elandsrand).

The study is for a plant designed to treat 200 000 t/m at a gold head grade of 8 g/t (for a life of 15 years).

Item	Cost (R millions) Pump-Cell CIP	Cascade CIP
Adsorption circuit	21.0	23.7
Elution/regeneration	14.4	20.0
Total	35.4	43.7

The elution requirements are :

Pump-Cell CIP: 4 tons per day

Cascade CIP: 7 tons per day

The benefit of achieving a higher upgrade ratio in the Pump-Cell plant results in a less expensive smaller elution plant. Therefore, significant capital cost savings can be achieved by building an elution plant suited to the requirements of a modern adsorption circuit (Pump-Cell plant). This, coupled with lower operating costs demonstrates how the use of modern technology is able to significantly lower the cost of building and operating carbon-in-pulp plants rather than using the conservative outdated cascade CIP approach. The approach of using new technology to lower costs in feasibility projects is being taken by Anglogold, to the extent that the use of Pump-Cell technology is standard practice within Anglogold plants.

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Table VIII

A comparison of cascade current CIP and Pump Cell CIP adsorption circuits in various regions, based on elution costs

Parameter	Counter current CIP		Pump cell CIP		Difference U.S. cents/ton ore	1 Year operating cost difference (U.S. millions)
Production (t/m)	150 000		150 000			
(t/d)	5000		5000			
Head grade	6.0		6.0			
Upgrade ratio[2]	1250		2500			
Carbon eluted per day (tons)	4		2			
Elution costs :	**US$/day**	**US$/tons of ore**	**US$/day**	**US$/tons of ore**		
South Africa	1176.08	0.22	558.04	0.11	11	0.20
Western Australia	1724.76	0.34	862.38	0.17	17	0.31
Mali (Grid)	2522.56	0.51	1261.28	0.25	25	0.45
Tanzania	3379.80	0.68	1689.90	0.34	34	0.61
South America	2133.40	0.43	1066.70	0.21	22	0.4
North America	1425.08	0.29	712.54	0.14	14	0.25

Note (1) Elution costs are from Table VII
Note (2) Upgrade ratios chosen based on data in Table V.
Note (3) The one year project cost is difference in operating cost for a 150 000 t/m plant for one year

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