Gravity Leaching With the ConSep ACACIA Reactor — Results From AngloGold Union Reefs

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ABSTRACT

The ConSep ACACIA Reactor is a device, which utilises a high intensity cyanidation process to achieve very high, usually near total, recovery of gold from gravity concentrates. The process utilises a fluidised bed and a chemical oxidant to enhance the gold dissolution kinetics to the point where the bulk of the dissolution occurs in a few hours. For convenience and security, most plants operate a 24-hour turn around. The product from the process is in the form of cathode gold ready for smelting by traditional means.

The ConSep ACACIA Reactor performs a two-fold role. Firstly it increases gravity gold production, leading to a decreased CIP feed grade. Secondly, it removes slow leaching components from the plant leaching circuit. This two fold benefit leads to the following efficiencies: enhancement of the dissolution kinetics; enhancement of the adsorption kinetics; reduction of the gold load reporting to the carbon; a significant reduction of the 'gold in circuit' lockup; and removal of slow leaching entities which can also result in a lowering of the required cyanide concentrations in the leaching circuit and a subsequent reduction in overall cyanide consumption.

The above benefits are discussed in this paper, with a particular focus on the ConSep ACACIA Reactor's role in removing slow leaching components, with data generated over a 21-month period.

Improvement in overall plant recovery via removal of slow leaching gold species is achieved in two ways. Firstly, some of the slow leaching entities, successfully leached under intensive cyanidation, are not always fully leached under plant conditions. This results in a lowering of the solid tailing. Secondly, the faster leaching kinetics achieved in the plant as a result of the removal of slow leaching entities results in faster and more complete adsorption of the dissolved gold onto activated carbon. This results in a lowering of the solution tailings.

The construction and operation of the ConSep ACACIA Reactor is simple. Apart from the reactor body, which is a proprietary design, all components of the system are 'off the shelf' or specific to the site's requirements. In operation of the fully automated version, a PLC controls a series of valves and pumps but except for a daily changeover process the only operating component for the bulk of the time is a relatively small solution pump. The process can be totally automated giving the security of a 'hands free' concentrate handling process up to the point where the product is presented as cathode gold.

The ConSep ACACIA Reactor was developed by Anglogold Australia (formerly Acacia Resources) for Union Reef's Gold Plant and has been in production since February 1999. It has proven to be a low cost, high recovery, mechanically reliable method for the processing of gold concentrates. Such has been the success of the plant, as of June 2003 there are eighteen full installations of the processing plant installed at mines owned and/or managed by Anglogold, Newmont, Placer Dome, Independence (formerly Lonrho), Sons of Gwalia and Harmony.

INTRODUCTION

Gravity Recoverable Gold (GRG) is that portion of the gold, which can be recovered from a gold bearing ore by physical rather than chemical processes. It is expressed as a percentage of total gold contained in the ore. Traditionally this was free gold which was recovered or concentrated by virtue of gold's high specific gravity giving higher settling rates when acted on by gravitational forces. A vast array of devices have been invented utilising this principle.

Since the mid 1980s accelerated concentrators have been developed giving far higher gold recovery efficiencies than traditional devices. Centrifugal concentrators, such as the Knelson Concentrator, develop accelerating forces many times that of gravity thereby accentuating the gold recovery effects.

The improved performance is manifested in two ways, firstly much finer gold now reports to the concentrate stream as the settling force (F = m*a, in which G forces can be 60 or more) overcomes the buoyancy effects of surface tension on fine particles. The increased settling force also causes other particles with elevated specific gravities to report to the concentrate stream.

With the development of intensive cyanidation techniques this latter group has taken on a significant importance. Many of these particles have a higher specific gravity due to attached or encapsulated gold inclusions and it is these inclusions which the new technology is able to recover. Traditional concentrate treatment devices return these heavy sulfides to the process stream as table, or secondary concentrator tails.

The following photomicrographs of Knelson concentrate particles, taken from AngloGold Union Reefs Gold Plant, illustrate examples of the nature of the gold species reporting to a gravity concentrate stream.

While these photomicrographs show the range of encapsulation situations encountered each site will be different, having its own sulfide species and encapsulation occurrence, frequency and nature.

The identification of this potential advantage of intensive cyanidation in terms of increased gravity recovery, led to an Australian gold plant, then Acacia Resources Union Reefs, to undertake the development of treating concentrates. The process and product they developed has become known as the ConSep ACACIA Reactor.

The process involves leaching of gravity concentrate using an up-flow reactor. Clear pregnant solution is produced which can be directly electrowon. The process is high recovery, security and safety, can be fully automated, and uses equipment not dissimilar to an elution circuit, with the result that gold room staff are already well equipped to understand and operate the process.

The actual process steps of the ConSep ACACIA Reactor has been covered in other papers (Lethlean and Smith, 2000; Watson and Steward, 2002).

DEVELOPMENT OF THE CONSEP ACACIA REACTOR

Identifying the need

The ConSep ACACIA Reactor was developed in response to a shortfall in the recovery of gravity gold in the circuit at Union Reefs. Pre-production test work indicated recoveries of approximately 30 per cent should be achieved but in practice the recovery started at approximately 25 per cent when the mill commenced operation at the end of 1994 and gradually decreased to a minimum of approximately 11 per cent prior to the installation of the reactor in February 1999.

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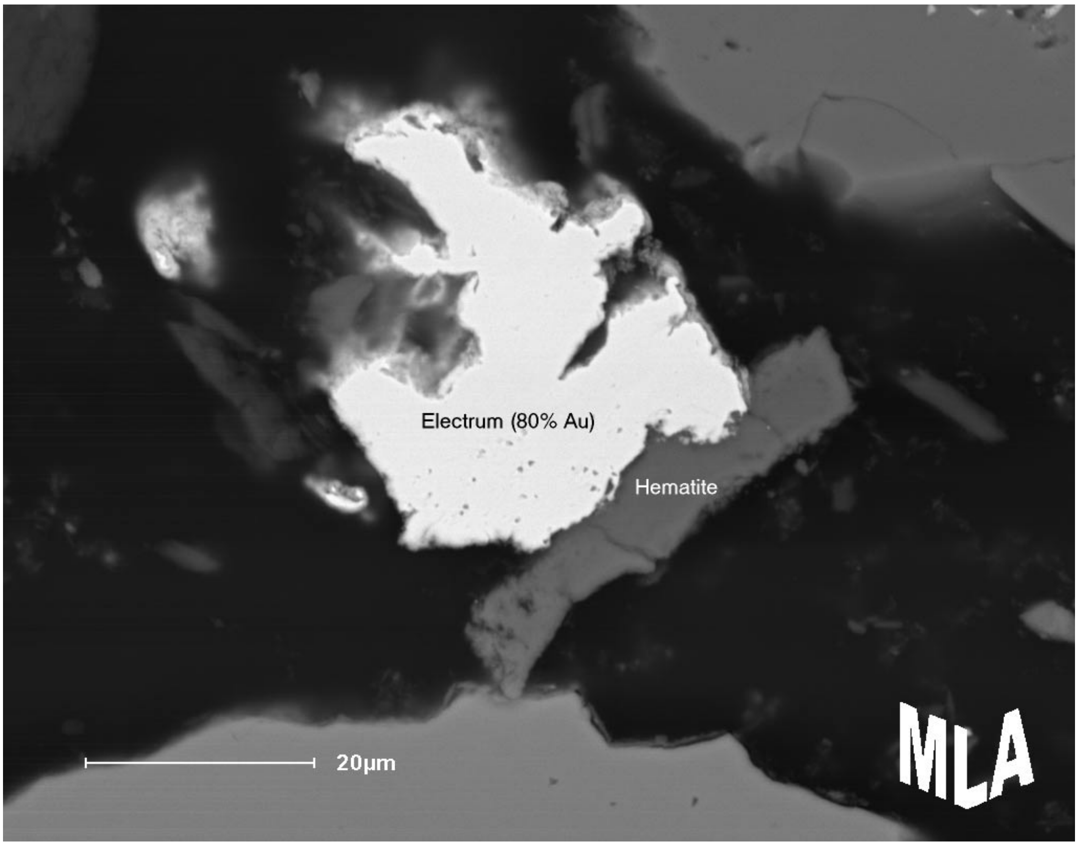

FIG 1 - Photomicrograph of Knelson Concentrate at Union Reefs - the bulk of the gold particle is free but some is attached to a Hematite crystal.

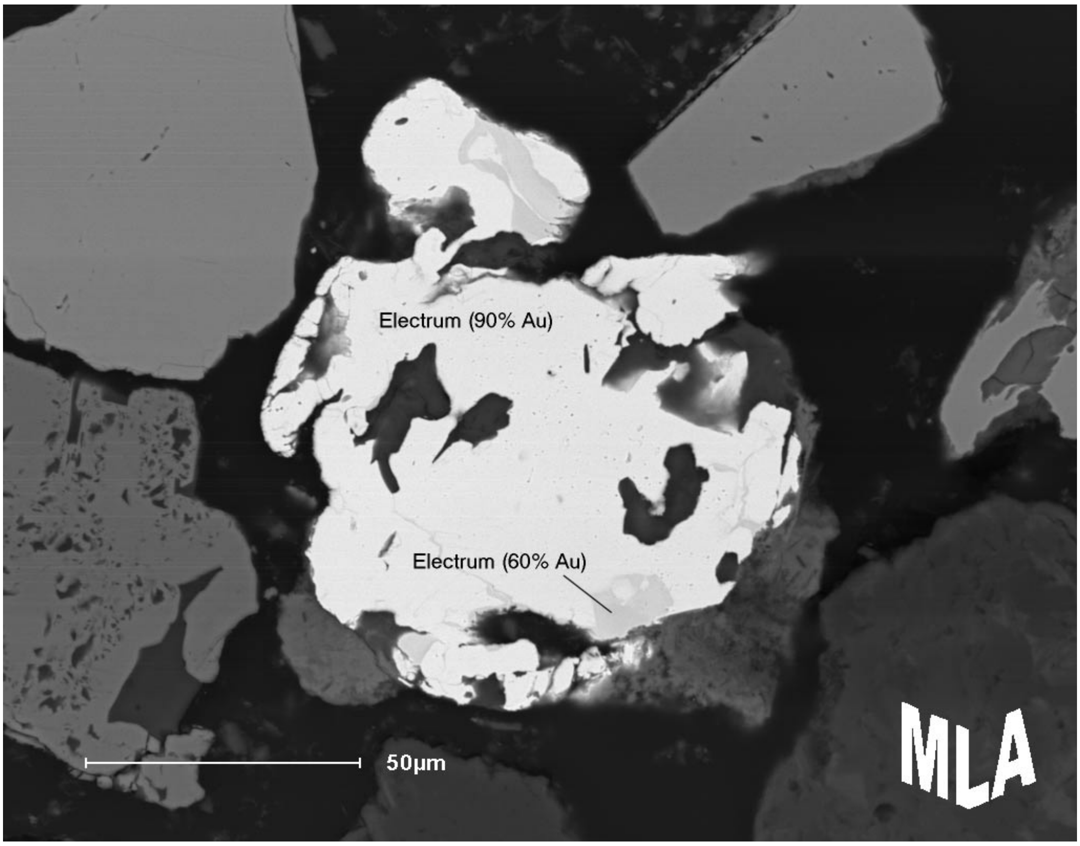

FIG 2 - Photomicrograph of Knelson Concentrate at Union Reefs - the gold particle has the bulk of its surface area covered by sulfide crystals.

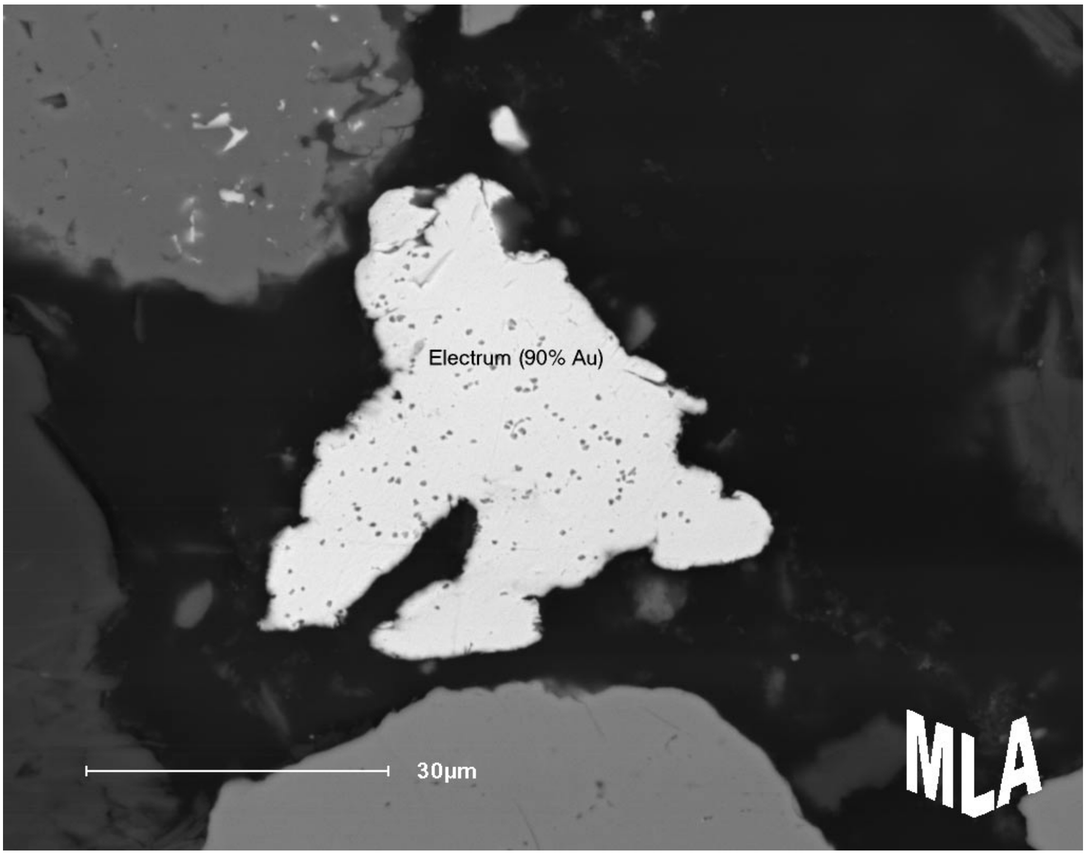

FIG 3 - Photomicrograph of Knelson Concentrate at Union Reefs - small particles of gold can be seen comprehensively encapsulated in sulfide crystals next to a large particle of free gold.

Analysis of the circuit showed that while the gold was reporting to the Knelson Concentrators (four KCCD30 Knelson Concentrators) concentrate, it was not being recovered in the bullion, due to low table efficiencies. Traditional methods of upgrading gravity concentrate, such as tables, typically have low efficiencies. Laboratory test work demonstrated that intensive cyanidation of the concentrates substantially improved the gold recovery.

The concept of the fluidised bed reactor was conceived as a means of achieving this dissolution in a practical manner on a plant scale. Laboratory scale equipment was devised and successfully tested thereby demonstrating the practicality of the concept and at the same time helping to define the process parameters and controls required.

The Union Reefs Gold Mine (URGM) plant underwent an expansion in late 1997 and as the mine matured and the plant throughput was increased to around 2.7 mtpa through 1998 the transition was made from predominantly oxide to primary ore. As the year progressed the gravity recovery decreased and metallurgical problems increased. Late in the year a decision was made to go ahead with the construction of a 1 m^3 transportable reactor which could be utilised at all Acacia Resources sites. As the instigator of the process, Union Reefs was chosen as the first site and commissioning of the plant commenced in mid February 1999.

Reactor development stages

From the outset, the transportable reactor's performance exceeded expectations and its beneficial effect on the rest of the circuit quickly became evident. By the end of March 1999 the design concept for the permanent installation was completed and detailed design for its construction and modifications to the Gold Room were underway. Construction of the permanent fully integrated gold room installation started in August and it was ready for commissioning on 22nd September 1999.

A review of the reactor's performance was carried out in July and at this stage it became evident that the reason the reactor was having such a significant effect on the circuit was that it was doing a lot more than just dissolving the free gold in the concentrates. Photomicrographs of the tailings from the early commissioning work showed particles of gold being dissolved from agglomerated sulfide particles and it was while studying these that the probable source of the extra gravity gold became evident and the following hypothesis was proposed:

> *Under the concentrated cyanide, highly caustic and strongly oxidative conditions present in the reactor, not only is free gold dissolved but also that present within agglomerated particles and that deposited within the crystalline lattice of the sulfides.*

Consideration of this concept indicated several ramifications, which were consistent with observations of the plant's performance.

OPERATIONAL EFFECTS OF THE CONSEP ACACIA REACTOR

After consideration of the hypothesis above the following points should produce measurable variations in the plant's performance:

1. The gold rich sulfide species which report to the KCCD30 concentrates will leach more slowly than the free gold due to the need for the solutions to penetrate the structures containing the gold. Their removal should speed up the dissolution of the solids reporting to the CIP circuit.

2. More rapid dissolution of the solids allows the carbon to more effectively adsorb the gold in solution thereby reducing the final solution tenor, ie improved overall recovery.
3. Intensive cyanidation of these species recovers gold which would not be recovered by leaching conditions in the CIP plant. This lowers the grade of the final solid tail, ie improved overall recovery.
4. More efficient dissolution and adsorption of the gold in circuit reduces the Gold In Circuit (GIC) inventory.
5. By removing the slow leaching species the cyanide concentration in the circuit can be lowered without producing a soluble tail. The result is a reduction in the overall cyanide consumption.

In considering these points the plant's operation will be examined in three different time frames:

- Pre ConSep ACACIA Reactor - October 1998 to January 1999 (inclusive). This four-month period was chosen as it provided a consistent ore feed type and blend prior to the operation of the first ConSep ACACIA Reactor.
- Portable Plant - February 1999 to September 1999 (inclusive). This was the period in which the transportable reactor was in operation.
- Fixed Installation - October 1999 to June 2000 (inclusive). This was a period for which the author was present on site and can vouch for the consistency of the feedstock and operation of the plant.

Improvements in the CIP circuit Leach profile

The CIP leach dissolution curves in the three time frames outlined above are presented in Figure 4. In this chart the plots for the Pre-ACACIA and, to a far lesser extent, the Portable Reactor show anomalous readings at the Tank 200 and 201 discharges. This was due to a systematic sampling error, due to incorrect sampling procedures from inter-tank launders, which was corrected in March 1999.

Apart from the anomaly at Tank 200 and 201 discharges the curves show a distinct improvement in the rate of gold dissolution, which diminishes with time. The reduction in gold grades throughout the leach train are evident, including a reduction in the final grade in Tank 7.

Improvements in the CIP adsorption profile

With a reduced gold loading in the adsorption circuit the carbon is in a better position to reduce the gold tenor of the solution. In most instances this will also result in a lower dissolved tail. Figure 5 illustrates the adsorption profiles that accompany the Figure 4 dissolution profiles.

These curves are precisely what would be expected from the dissolution curves in Figure 4. The improvement introduced by the ConSep ACACIA Reactor enables the carbon to adsorb the gold faster, keeping it closer to the head of the circuit. The final solution tenor is also improved.

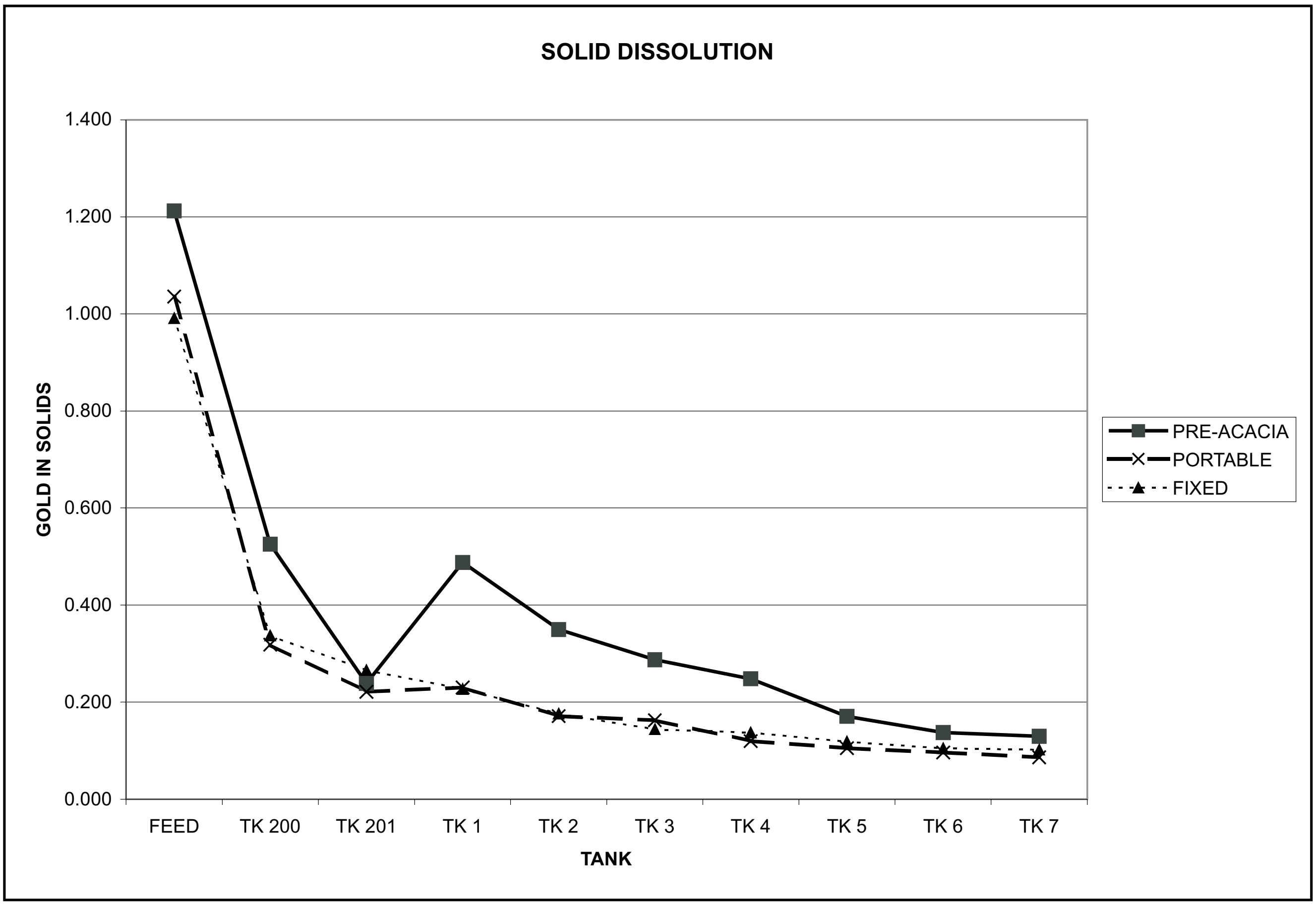

FIG 4 - Gold Dissolution Profiles in the Union Reefs CIP plant.

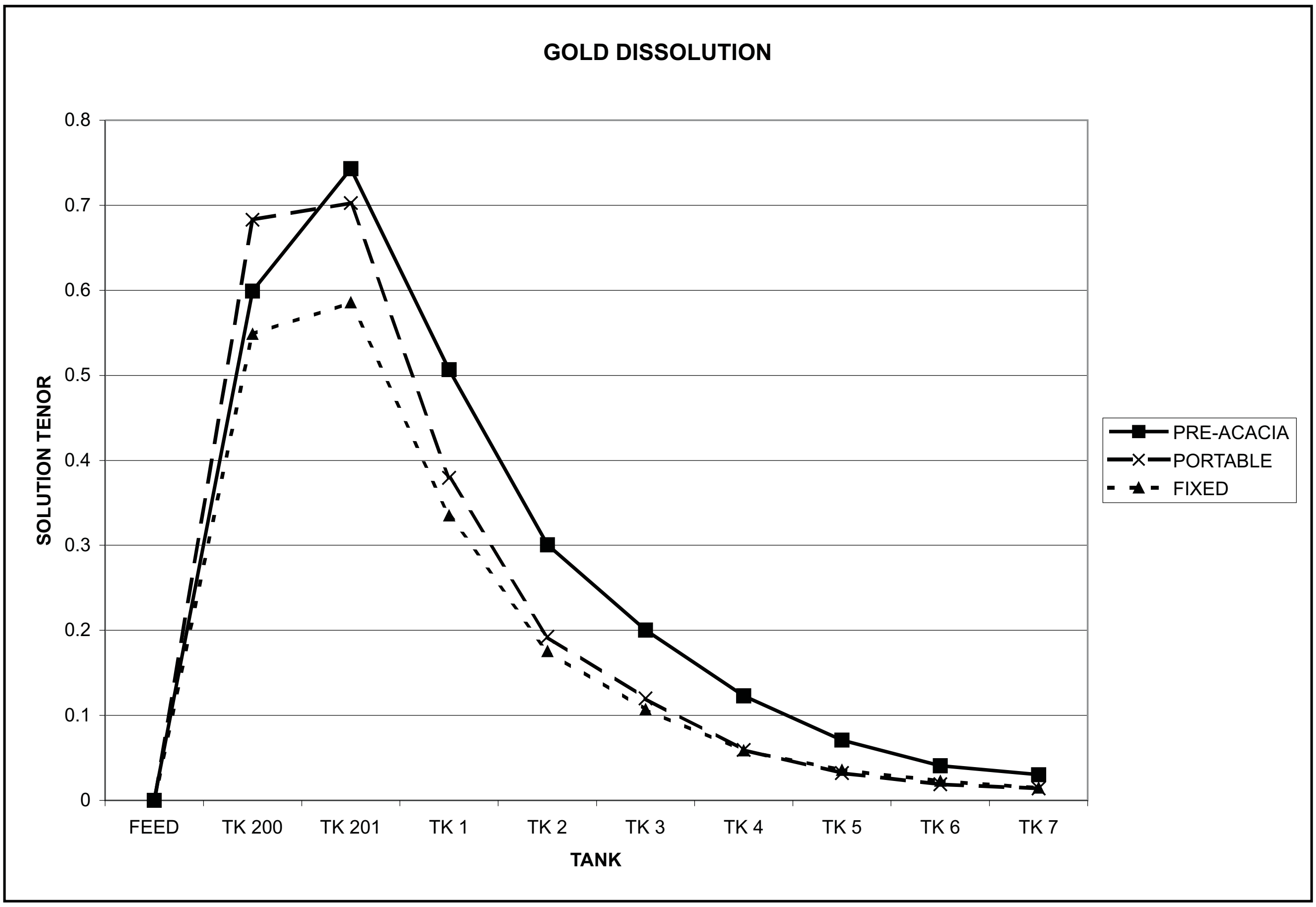

FIG 5 - Adsorption Profiles in the Union Reefs CIP plant.

Slow leaching concentrates

Ten consecutive dissolution curves within the ConSep ACACIA Reactor are given in Figure 6, which were carefully monitored in December 1999. Each curve presented within Figure 6 clearly show the occurrence of sequential dissolution events at different dissolution rates.

The hypothesis proposed to explain this process was that the first, most rapid and largest of these events was the dissolution of free gold. The following events resulted from the dissolution of gold, which because of its physical size or attachment to other mineral particles, was less accessible to the dissolving solution.

The following photomicrographs were taken before and during a production run in January 2000 and illustrate some of the situations, which could hinder the dissolution process resulting in the curves presented above.

In Figure 7 the dominant feature is a large particle of free gold, which will present a straightforward path to dissolution, the duration of which will be dependent on the overall size of the particle. To the upper right of this particle a large number of smaller particles have been deposited within a relatively porous mineral structure. To recover the gold in the porous mineral structure the solution must first diffuse into the pores of the structure, dissolve the gold and then diffuse back into the bulk solution. This process will obviously take place at a slower rate than the previous scenario.

In Figure 8 the gold particle has the bulk of its surface area covered by iron oxides. To dissolve this material the solutions have ready access to a substantial portion of its surface area and some hindered access, via the porosity of the particle, to some of the encapsulated surface. Whilst this particle will be readily dissolved in the reactor, its rate of dissolution will be substantially slower than that of fully liberated gold.

Figure 9 was taken three hours into a leach cycle. The photo shows partial erosion of the iron oxides encapsulating the gold. Evidence shows that particles of this nature are all dissolved by the reactor, but clearly the process is a slow one.

In normal milling practice composite particles such as those shown in Figures 7 and 8 would be returned to the comminution circuit as table tailings. Ultimately they would report to the leaching circuit where the much milder leaching conditions would not necessarily complete the gold dissolution before they reported to the circuit tailings.

Reduction in gold in circuit inventory

Over the 21-month period being analysed the plant feed grade remained steady. For reasons not associated with the ConSep ACACIA Reactor the mill feed rate significantly increased with peaks of 360 tph being achieved for extended periods. As shown in Table 1, the CIP feed grade dropped significantly with the introduction of the reactor and remained at the lower value. The tails solid and solution grades mimicked the CIP feed grade trends.

With the significant lowering of the load on the CIP circuit and some improvements in the carbon stripping efficiency, the GIC was significantly reduced through the operation of the portable reactor. This was followed by consistent performance in the operation of the fixed reactor, which resulted in an excellent overall recovery.

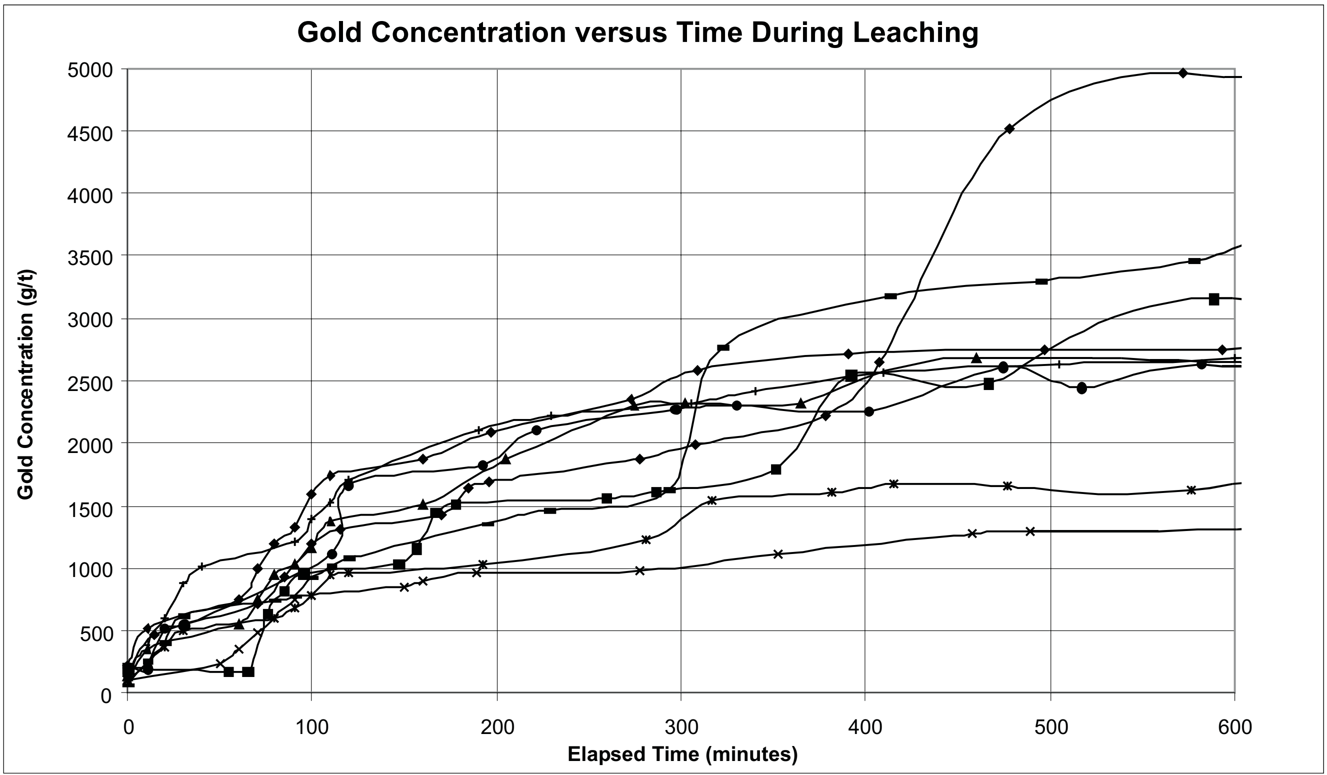

FIG 6 - ConSep ACACIA reactor dissolution curves.

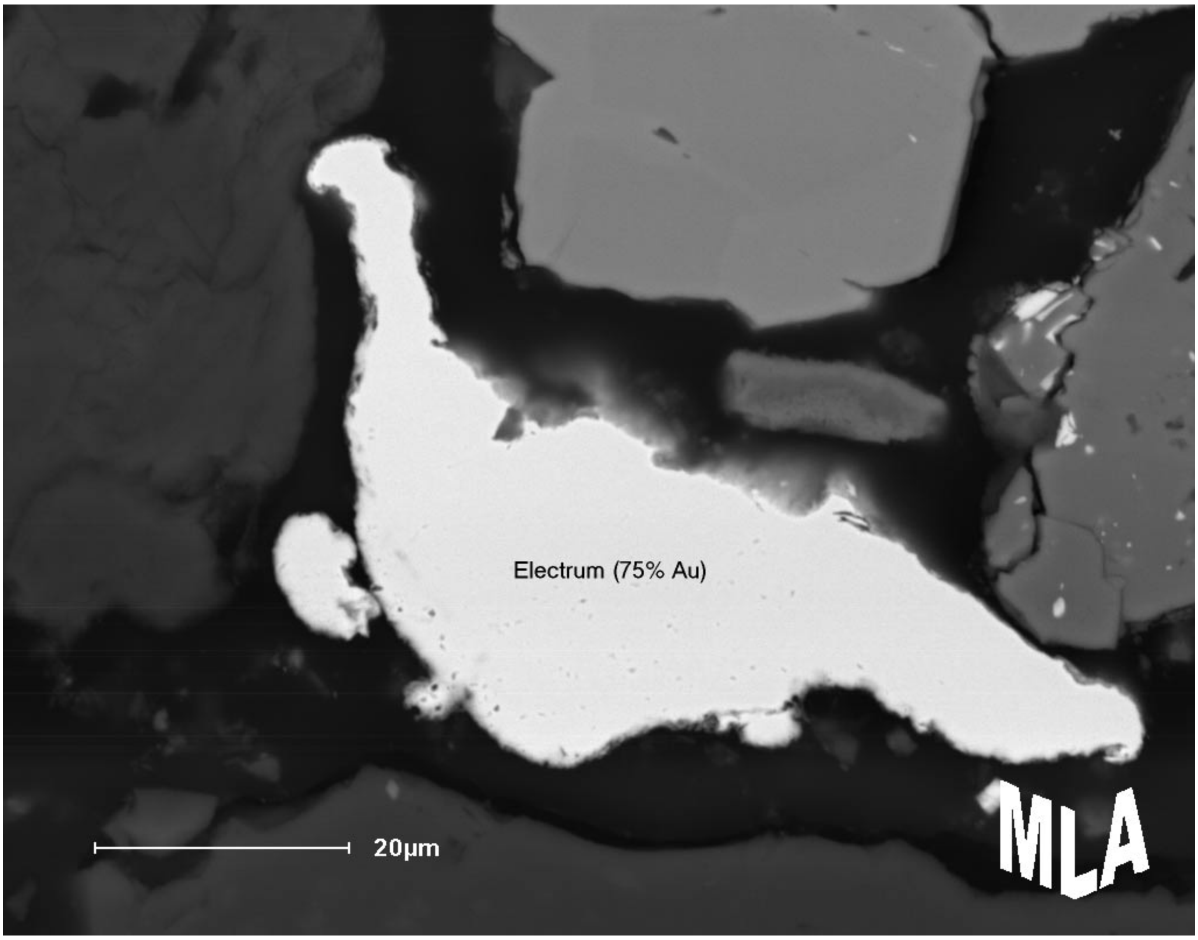

FIG 7 - Photomicrograph of Free Gold within the ConSep ACACIA Reactor prior to leach commencement.

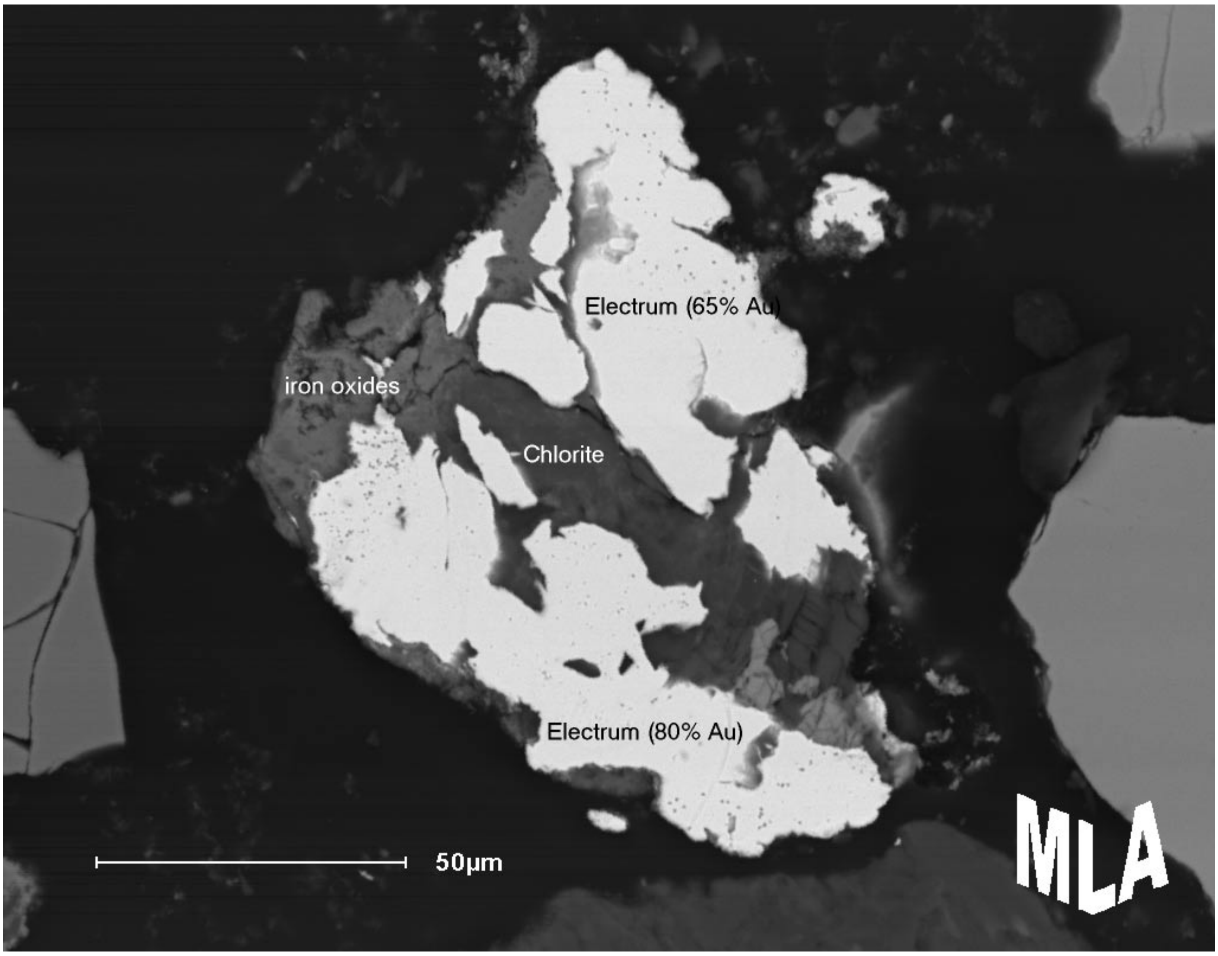

FIG 8 - Photomicrograph of Free Gold within the ConSep ACACIA Reactor prior to leach commencement.

TABLE 1
Plant performance around reactor installation.

	Feed grade (g/t)	Feed rate (tph)	CIP grade (g/t)	Tails grade solids (g/t)	Tails grade solution (g/t)	Gold in CIP (g)
Average from October 1998 to January 1999 - pre ACACIA reactor	1.394	277	1.212	0.130		106 583
Average from February 1999 to September 1999 - portable reactor	1.428	324	1.036	0.086	53% reduction	95491
Average from October 1999 to June 2000 - fixed reactor	1.416	327	0.991	0.102	50% reduction	69065

Improved cyanide consumption

One unexpected consequence of the operation of the ConSep ACACIA Reactor was a reduction in the overall consumption of cyanide, as shown in Table 2. From the commencement of production in December 1994 to the end of 1998 the annual consumption of cyanide has varied from a low of 0.24 kg/t to a high of 0.26 kg/t. In 1998 the average was 0.25 kg/t.

The lowering of cyanide consumption in this study period is a reflection on the fact that with the more difficult components removed from the dissolution process lower cyanide concentrations are required in the bulk leaching process. These cyanide savings outweigh the extra cyanide required for the intensive leaching. The savings were realised due to the gold in tailings and tails solution reduction, which allowed the plant to reduce cyanide additions. In fact, the decrease in cyanide consumption occurred against an increase in mill feed tonnes, and a decrease in CIP residence time.

Another process improvement resulting from treatment in the ConSep ACACIA Reactor is improved oxygen tenor throughout the CIP tank system. In the process of subjecting the more refractory mineral components to strong oxidisation their oxygen demand is satiated. At Union Reefs this meant that every time substantial amounts of E-lens ore (the biggest single gold bearing structure at Union Reefs) were fed to the system the oxygen supply did not have to be substantially increased. Instead the whole tank farm maintained its oxygen tenor that was generally higher than previously attainable.

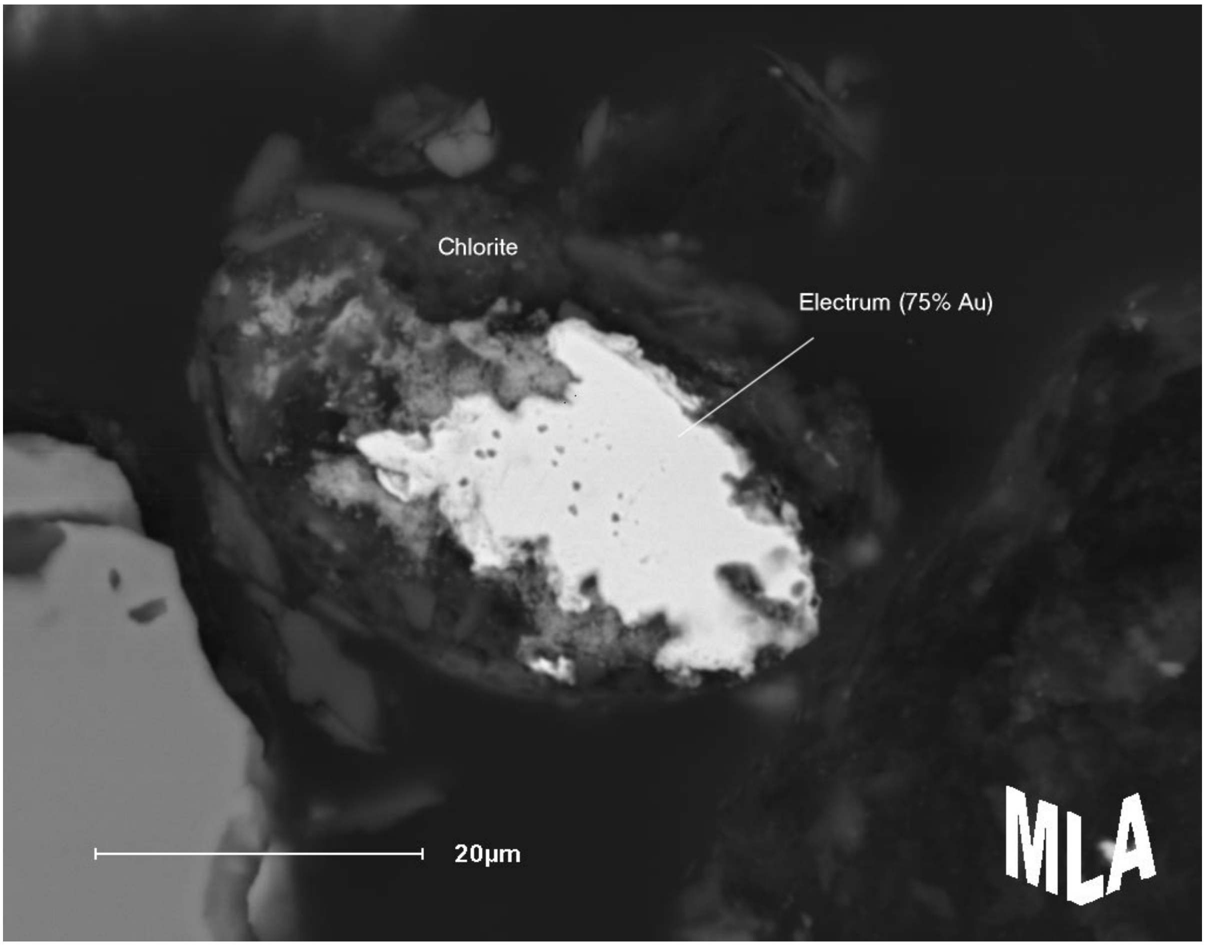

FIG 9 - Photomicrograph of Free Gold within the ConSep ACACIA Reactor after three hours of leaching.

TABLE 2
Total cyanide consumption at Union Reefs gold plant.

	Period	Cyanide consumption (kg/t)
Pre-ACACIA Reactor	October 1998 - January 1999	0.26
Transportable Reactor	February 1999 - September 1999	0.23
Fixed Reactor	October 1999 - June 2000	0.22

OPERATIONAL BENEFITS OF THE CONSEP ACACIA REACTOR

Metallurgical improvements

Metallurgical improvements at Union Reefs resulting from the installation of the ConSep ACACIA Reactor have been summarised below. At this point it should also be mentioned that while these effects were all noted at Union Reefs, different plants will react in different ways and where a plant is not suffering due to poor performance in a particular aspect it may not show an improvement in that aspect. The metallurgical improvements include:

- faster dissolution of the gold reporting to the CIP/CIL circuit;
- faster adsorption of the gold in the CIP/CIL circuit;
- improved recovery from the CIP/CIL circuit;
- reduction in Gold In Circuit inventory;
- improved overall plant recovery;
- reduction in overall cyanide consumption; and
- improvement in oxygen demand in the CIP/CIL circuit.

All of these improvements are a logical consequence of the ConSep ACACIA Reactors action and operational control.

Operational consistency

Table operation is a manual labour intensive process, with regular adjustment required by operators. Losses can occur if the process is not given a high level of attention, or the operator does not make the correct adjustments. Control of tabling is not easily automated.

The nature of the ConSep ACACIA Reactor's operation lends itself readily to automatic electronic process control that can be monitored remotely by the mill control room operator. This gives accurate, consistent and reliable process control.

Security improvements

In operating the ConSep ACACIA Reactor, human contact is removed from the concentrate treatment process. The only time manual handling is required is in the processing of the cathodes produced in the electrowinning step.

The operation of the reactor can be fully automated such that the operator does not even need to enter the gold room apart from tending to the electrowinning process.

OH&S considerations

One of the key considerations, outside of metallurgical performance, in justifying the expenditure on the reactor was its elimination of fumes that may be generated in roasting gravity concentrates prior to smelting. Whilst URGM employed environmental testing and appropriate PPE to address safety concerns associates with concentrate roasting, a more satisfactory solution was to engineer out the problem via the installation of the ConSep ACACIA Reactor.

Manpower savings

The fully automated plants currently produced can be operated wholly from outside the gold room by the control room operator. The fixed reactor at URGM did not have some of the features available now and management's hesitancy to leave such a new process unmanned, meant that the daily changeover of charges in the reactor and reagent mixing was carried out manually. After a familiarisation period the gold room operator was still able carry out all the duties required in the gold room in approximately 30 minutes.

With the 'two man policy' this occupied one man hour per day. When the tabling process was utilised it took at least four to five hours per day and again with the 'two man policy' this required up to ten man hours per day. This extra time spent in the gold room also had considerable security implications.

After four years operation at URGM the preventative maintenance schedule for the reactor consisted of an inspection every three months and possible change out of the filter assembly in the base of the reactor. This process takes approximately two hours, which is far less than the time spent over that period dressing the table surface or replacing broken springs in the table drive.

RESULTS FROM OTHER SITES

The ConSep ACACIA Reactor is being adopted worldwide as part of the desire of many gold plants to optimise and simplify gravity circuits. Through optimisation of gravity circuits, improvements in overall plant performance can and have been realised.

As of June 2003, there are eight installations in Australia, three in North America, five in Africa, one in Papua New Guinea, and one in Mongolia, for a total of eighteen installations. Twelve of these installations have been purchased or commissioned within the last 12 months.

All of these installations have recognised improvements in the performance of their processing plants. For instance one installation of a CS500 ConSep ACACIA Reactor in Zimbabwe has realised a three per cent increase in overall plant recovery, with the system running for nearly 12 months on 100 per cent availability, with an average recovery over 98 per cent. The installation has had a profound effect on the viability of the operation, and has had a payback period of less than one month, inclusive of their bulk order of 12 months of reagents.

A fully automated CS3000 ConSep ACACIA Reactor commissioned in May 2003 in Canada achieved leaching start up within six days of arrival of the equipment on site. The first day's results were over 97 per cent recovery, and since start up the unit has had 100 per cent availability and is averaging over 95 per cent recovery.

At Porgera Joint Venture, a fully automated CS3000 ConSep ACACIA Reactor was installed and operational within a four-week period on site. The unit has consistently produced recoveries above the 95 per cent expected from the plant. Recoveries since commissioning have been consistently above 98 per cent, often above 99 per cent. PJV estimate that the installation of the ConSep ACACIA Reactor has increased overall recovery by over one per cent with a project payback of approximately two months (Watson and Steward, 2002).

CONCLUSION

The development and utilisation of the ConSep ACACIA Reactor at Union Reefs Gold Mine was intended to improve gravity gold recovery thereby relieving the load on the CIP circuit, improve OH&S considerations in the gold room, reduce the security risk in handling gold concentrates and lower man power requirements in the gold room. From the time of commissioning the first full sized reactor on site, all of these objectives were achieved with some expectations substantially exceeded.

In addition to the expected improvements, other more subtle changes also took place. On realising that sulfide associated gold was responsible for a great portion of the improved gravity recovery the nature of this component was investigated.

Improvements in leaching and adsorption rates, which resulted in lower solution tails, were directly attributable to the removal of the slower leaching sulfide associated particles, as was the lowering of the cyanide soluble fraction of the tailing slurry. The improved leaching response in turn led to a lowering of the CIP cyanide concentration and a reduction in the overall cyanide consumption. The fluctuations in oxygen demand associated with certain ore types were also largely removed from the circuit.

ACKNOWLEDGEMENTS

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