PAPER 22

Commissioning of the Intensive Cyanidation Plant to treat Concentrate from the Selene Mine at the Ares Mill

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ABSTRACT

A number of silver producers have identified a need for a system to recover silver and gold from base metal flotation concentrates on site rather than sending the concentrate to third party smelters to improve mine economics. Historically intensive cyanidation has only been used for coarse gold gravity concentrates in batch machines but Gekko have applied the InLine Leach Reactor (ILR) to these difficult to leach concentrates.

The ILR's unique ability to operate at various solid to solution ratios, high mass capacity, the ability to handle fines, the use of peroxide to aid silver leach kinetics and simple operation has resulted in significant economic benefits to Hochschild PLC's Selene and Arcata operations. This paper describes the commissioning phase of the ILR5000BA intensive cyanidation reactors on concentrates from the Selene mine at the Ares Concentrator.

INTRODUCTION

Intensive leaching of high grade concentrates in gold ore treatment is now commonplace and is considered an essential feature of most gold circuits (Lane, Fountain and LeBrooy, 2008). The devices commonly used for intensive leaching (InLine Leach Reactor, Acacia Reactor, etc) are specifically designed for the typical coarse nature of the concentrate.

In some of these intensive leach applications, significant amounts of silver are co-recovered with the gold. In fact, the intensive leaching conditions of 1 to 2% NaCN in solution and high dissolved oxygen levels, overcome the issue with silver's slow dissolution rate in traditional CIL/CIP circuits and avoids the formation of insoluble silver sulphide minerals on the surface of the gold (Marsden, 2006).

There are a significant number of mine operators producing silver in the form of mixed base metal sulphides flotation concentrates. Typically the mine operators are paid for the silver after processing of the concentrate by the base metal smelter whom recovers the silver during the refining process.

The disadvantages with recovering silver in this fashion have been (Hochschild, 2009):

- Silver is only paid for after processing through the smelter which could be 60 days compared with a typical 10 days turnaround for doré.
- Higher transportation, handling and shipping expenses.

Both disadvantages can have a significant affect on a mine's cash flow and Net Present Value.

Intensive cyanidation, typically using cyanide levels of 2%, requires no exotic chemicals or materials and uses standard process operations. At these levels of cyanide the safety procedures currently used around a CIP/CIL circuit are readily applicable with only minor modifications making it a relatively simple addition to most mine sites already using cyanide.

In 2006, Hochschild Mining Plc approached Gekko with the intension of leaching a flotation concentrate and producing Silver Doré on site which could then be sold to precious metal refiners rather than the base metal refiners.

Hochschild Mining Plc

Hochschild Mining Plc (Hochschild) is a leading precious metals company listed on the London stock Exchange with a primary focus on the exploration, mining, processing and sale of silver and gold. In 2008, Hochschild had attributable production of 26.1 million silver equivalent ounces from five underground mines (four in Peru and one in Argentina) and one open pit mine in Mexico.

Hochschild's Selene and Ares Plants

The Selene mine site is located in the Department of Apurímac in southern Peru, at an altitude of 4,600 metres above sea level and approximately 180 kilometres away from Hochschild's Ares processing plant (see
Figure **1**).

The Selene plant processes silver ore with associated gold to produce silver/gold bulk concentrate by flotation and is currently operating at a capacity of 3,000 tonnes per day. Selene was an operating mine until May 2009 and produced 3,201 tonnes of concentrate with 1.6 million ounces of silver and 1.9 thousand ounces of gold in 2008. Selene's plant continues to process the ore from Hochschild's Pallancata mine which is located 22 kilometres from Selene.

The Ares mine site is situated 4,900 m above sea level in the Andes Mountains, approximately 275 km from the city of Arequipa in southern Peru (see
Figure **1**).

Figure 1: Hochschild's Peruvian Mine Site Locations

INTENSIVE CYANIDATION

As discussed previously, the chemistry of cyanidation is proven and well known with the majority of gold and silver operations around the world using the process. Cyanidation as a process had been used for the extraction of gold since 1890. The reaction for the leaching of silver is:

$$4\ Ag + 8\ NaCN + O_2 + 2H_2O \Leftrightarrow 4\ NaAg(CN)_2 + 4NaOH$$

Oxygen is an indispensable reagent in the reaction and is provided either from atmospheric oxygen, hydrogen peroxide or a production oxygen facility. The level of oxygen addition required is determined from the initial test work and/or during plant commissioning.

In 1997 Gekko Systems Pty Ltd (Gekko) introduced the InLine Leach Reactor (ILR). The ILR is produced in a number of sizes and in two operating modes – Batch or Continuous. The batch units will treat up to 27,000kg per cycle (nominally 24 hours), whilst the continuous units treat from 150kg per hour up to 7,000kg per hour.

Batch ILR Design Features

The batch models of the ILR have been developed to treat high-grade, low volume gold and silver bearing concentrates (Longley, McCallum and Katsikaros, 2002). The ILR has a number of special features as described below.

Well Mixed Reaction Zone

The ILR operates on a semi-submerged bed principle. A partially closed medium aspect ratio drum is filled with concentrate to the overflow level and rotated. The rolling drum technology closely resembles common bottle roll technology but with added features. The solution carrying all reagents is cycled through the drum at relatively high flow rate to ensure a constant supply of cyanide and oxygen.

The action of the drum ensures a high level of solution shear at the particle surface, which removes chemical passivating products that may form at the particle surface. This also guarantees that there are no "Dead Spots" in the solution/solid interface and the solid particles see fresh solution continuously.

Flexible Reagent Regime

Due to this relatively high shear and intense reagent environment, exceptionally rapid reaction kinetics are seen. Oxygen utilisation is maximised and surface passivation is minimised. The effective mixing allows a wide variety of oxidants to be used to maximise recovery and minimise operating costs.

Coarse and Fine Gold and Silver Leaching

Both coarse and fine gold and silver are targeted with no physical losses to tails of fines through short circuiting or clarification. During drum loading all solids are retained within the leaching system. Any fines that overflow the drum, including hydrophobic gold fines, are retained in the solution storage cone and form part of the leaching solution. This solution is recirculated through the drum during leaching. In this way all solids are contacted with leach solution.

Clarification Step

A separate step is used to clarify the pregnant solution prior to transferring to electrowinning. This process gives good control of clarification. The solids are returned to the drum and flocculant addition is used as required. This means all types of concentrates can be treated. This includes concentrates where slimy precipitates are formed as part of the leaching process.

Batch ILR Operation

The concentrates from the primary recovery device report to the feed cone for de-watering, with the water overflowing and returning to the mill circuit. Solids are stored in the feed cone until the beginning of each leach cycle.
Figure **2** and
Figure **3** show a typical Batch ILR.

Figure 2: InLine Leach Reactor (ILR2000 model shown)

The Batch ILR works on the principle of the laboratory bottle roll to keep the solids in contact with the liquor. The ILR consists of a horizontal drum rotating at low speed with a set of specially designed baffles and aeration system for maximum leach performance, a feed cone to contain the feed material, a solution cone to contain the leach solution and a recirculating pump and hopper (see
Figure **4**). During leaching, solution is continually recirculated through the solids from the solution storage tank to ensure a fresh supply of reagents, including oxygen, is always available for leaching. This also results in an effective low density leach being achieved.

The reactor drum rotates around a horizontal axis. The drum is rotated only fast enough to ensure that fresh solution is mixed through the solid. The action of the rotating drum also draws oxygen from the contained atmosphere within the drum into the slurry, which ensures no portion of the solids can become oxygen depleted; therefore re-precipitation of gold onto steel particles does not occur.

Residence time is predicted in the laboratory and controlled by the leach cycle time. At the completion of the leach cycle the pregnant solution is clarified then pumped to the electrowinning circuit. Barren solids are emptied by reversing the drum rotation and pumped to the mill circuit. The barren solution from electrowinning is pumped to the CIL/CIP circuit (optionally to the ILR) to reuse the residual cyanide.

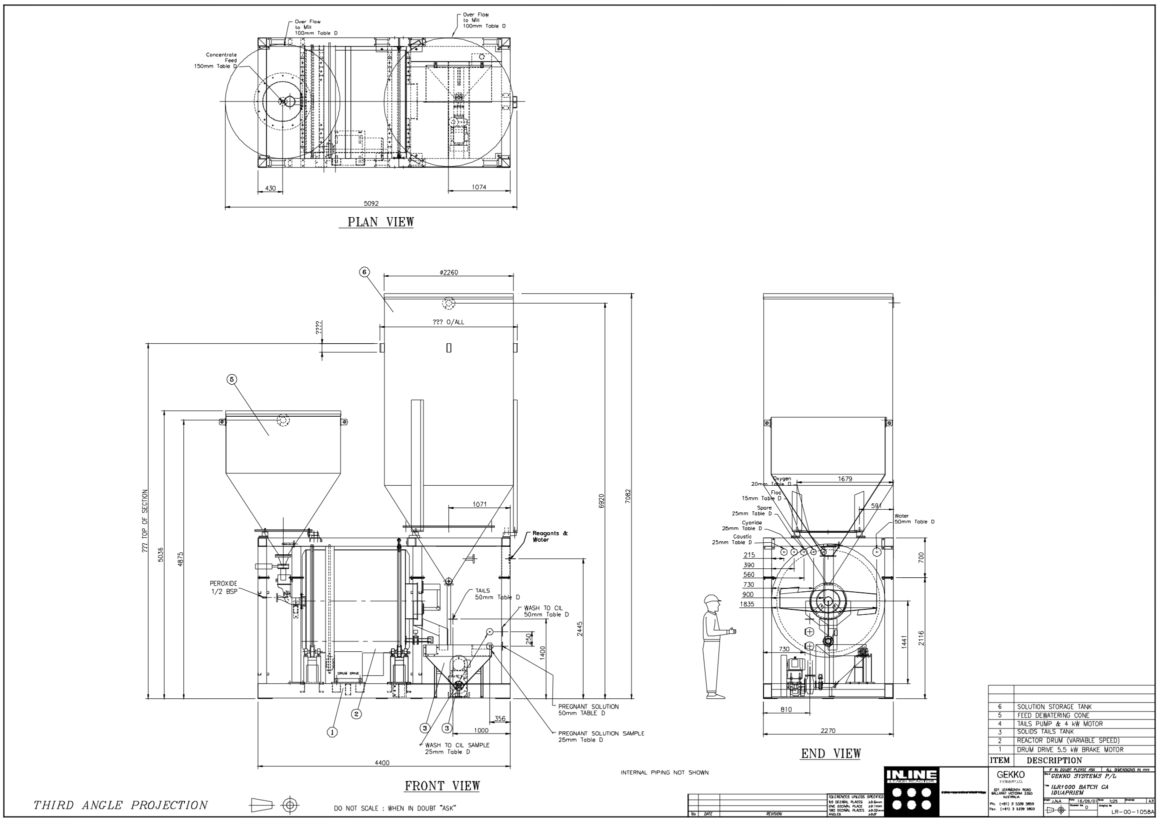

Figure 3: Drawing of Gekko Systems Batch InLine Leach Reactor ILR1000BA

Wash water can be added to the drum to wash entrained pregnant solution from the solids.

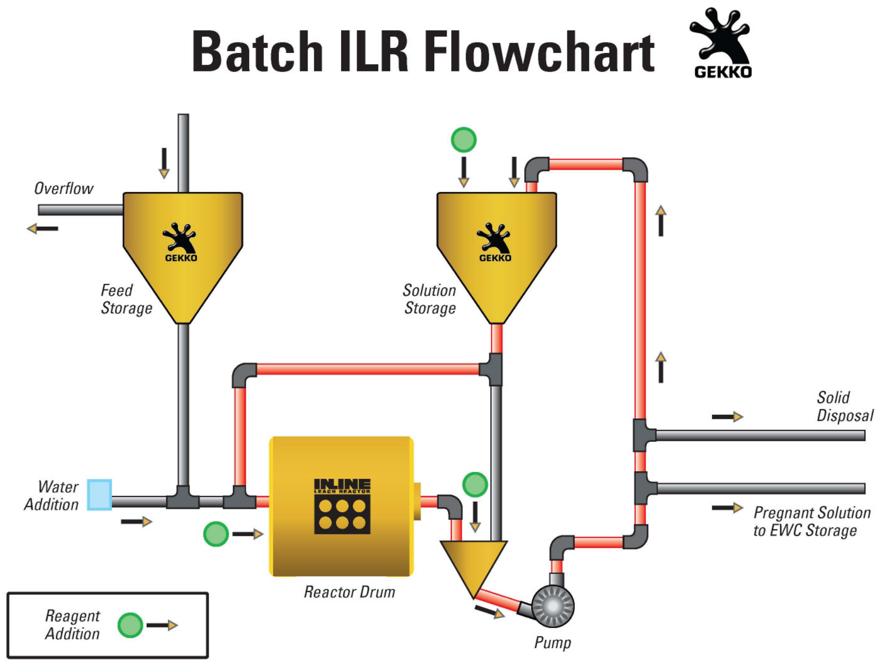

Figure 4: Batch InLine Leach Reactor Flowsheet

If electrowinning is not metallurgically feasible, other options include Activated Carbon, AuRIX®100 resin and Merrill Crowe interfaces.

Flotation Concentrate Specific Modifications

Flotation concentrates are typically 100 µm or less and as such the solids bed is less dense and there is more carryover of fines with the solution circulating through the drum. This has some impacts on the capacity and performance of the Batch and Continuous ILR's.

The Batch ILR drum capacity is affected by the finer concentrate sizing. At the end of the cycle all the solids including any solids in the solution are flocculated and returned to the drum. As is well known, flocculated solids have a lower bulk density than un-flocculated solids and therefore the drum capacity needs to be designed based on this density rather than the feed density to avoid solids overflowing during the final decant step.

Similarly for the continuous ILR the finer particle size will reduce capacity because the finer solids do not form as dense a bed of solids in the rotating drum. This requires a reduction in drum throughput, typically between 20 and 30%. During leaching, the fine particles behave and are handled differently in the batch and continuous ILRs.

For the Batch ILR, the finer solids are carried by the solution into the solution cone but remain within the leaching system. The solids settle to the bottom of the solution cone and are returned to the reactor drum with the recirculating solution. The higher level of solids in the recirculating solution can sometimes cause increased wear in the ILR system. In these cases special wear liners are employed in the high wear areas.
For the Continuous ILR, some of the finer solids again flow with the recirculating solution but they flow to the ILR tails thickener and are not recycled.

However this effect is minimised by the design of the drum. Firstly the baffles in the continuous ILR drum divide the reactor into up to four discrete volumes which are only connected once per revolution. Secondly the solution and the fine solids carried with it are continually mixed into the bed of coarser solids at the bottom of the drum. This means that a fine particle entering the feed cannot bypass directly to the exit. It is “kneaded” into the bulk of the solids in the drum at least four times before exiting the drum.

The effect of reduced residence time for fines is further reduced because the solid to liquid ratio is generally higher when treating flotation concentrates compared to gravity concentrates. This reduces the maximum difference in residence time between the solids and solution in the drum. This is because the gold grades treated in continuous ILRs are generally lower and because the solubility of silver in cyanide solution is very high; 15000ppm has been achieved in practice. Therefore solution saturation is not generally a limiting case.

In Gekko’s experience the small reduction of residence time for the finest size fractions has no significant affect on recovery as the very fine minerals have large surface areas and very fast leach rates.

Conversely, the coarser fractions of the concentrate have an increased residence time in the drum which can aid recovery from this fraction.

Reagent selection also needs careful thought when dealing with fine sulphide concentrates. High oxidant addition can have two very different affects. In some cases high levels of peroxide have been found to increase silver recovery due to the breakdown of sulphides and liberation of silver. In other cases the affect has been the opposite with certain silver minerals forming slow leaching product layers or being converted to other silver minerals which leach more slowly in cyanide solutions. Detailed test work is required to determine the optimum oxidant and dosage rates but as the ILR can be easily simulated by rolling bottle tests this is not difficult.

METALLURGICAL TESTWORK

In 2006 Hochschild Plc approached Gekko Systems to leach precious metals from a flotation concentrate produced at the Selene concentrator. The proposed method was to construct an ILR facility at the Ares processing plant, to simplify the requirements for recovery of metal from solution (Merrill Crowe), and truck the concentrate from Selene to Ares (approximately 180 km).

The Selene concentrate contained 15,500 g/t Ag, 18 g/t Au, 0.54% Cu, 20.5% Fe, 0.56% Pb and 0.78% Zn. Initial lab trials at Gekko and testwork carried out by Hochschild on Selene flotation concentrate showed that 96 to 98% gold and silver recovery was obtainable from the flotation concentrate in 48 hours leach residence time.

The final conditions chosen from the test work were 2% NaCN, Hydrogen Peroxide to bring the O_2 levels to 10ppm and Lead Nitrate with a leaching time of 48 hours.

Due to the long leach time, two ILR 5000BM units were chosen to perform the leach on Selene concentrate. The units were loaded on alternating days and each ran for 48 hours to gain the maximum recovery benefit.

PLANT COMMISSIONING

The plant was constructed and the initial commissioning was attempted in October 2006, although soon cancelled to allow final work to be completed on the plant. In December 2006 the plant was fully ready for commissioning and the team was brought back in. Over a 2 week period, the ILR was commissioned and optimized to the leach testwork performed earlier.

Four trials were undertaken with conditions as summarised in Table 1.

Table 1: ILR Trials during Commissioning

Batch #	Oxidant	Oxidant Addition Strategy	Regrind Conditions
4	Peroxide	Set addition rate	Process water
5	Oxygen	Addition to DO level	Process water
6	Peroxide	Addition to DO level	Barren cyanide solution
7	Peroxide/ Oxygen	Peroxide for 11 hours. Oxygen for total time to DO level.	Barren cyanide solution

Batch 4, shown in
Figure **5**, was performed on flotation concentrate that was reground in process water and then leached using 2-3% NaCN with peroxide as the oxidant. The final results did not achieve the >96% Silver recovery that was expected.

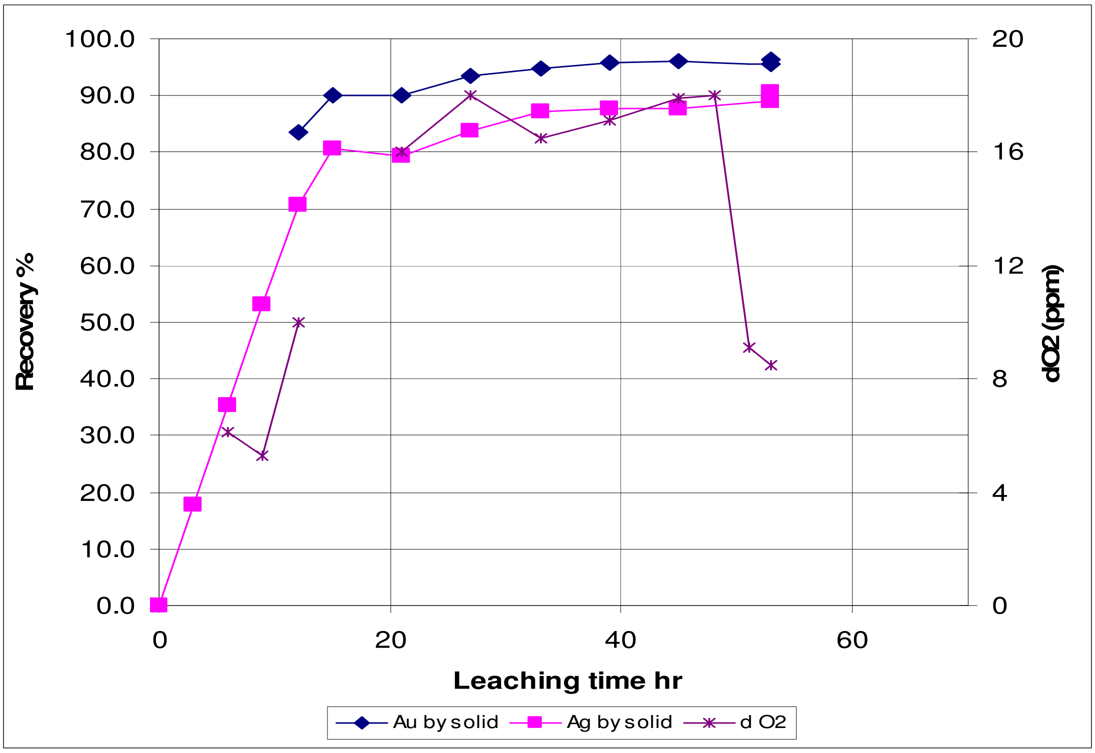

Figure 5: Batch 4 – Fixed Peroxide Addition - Leach Results

It was suspected that the peroxide caused a slow leaching silver mineral to form as an outer layer to the precious metal grain and ultimately reduced the dissolution rate.

For batch 5, the flotation concentrate was reground in process water with gaseous oxygen used as an oxidant to minimize the potential passivation problem noted above.

As can be seen in

Figure **6** the leach kinetics were initially slower than in Batch 4 which suggests that there was not enough oxygen in solution to allow leaching to progress at it's maximum rate in the initial stages. The slope of the silver dissolution curve at the end of the leach test suggests that with more time, a higher recovery could be achieved.

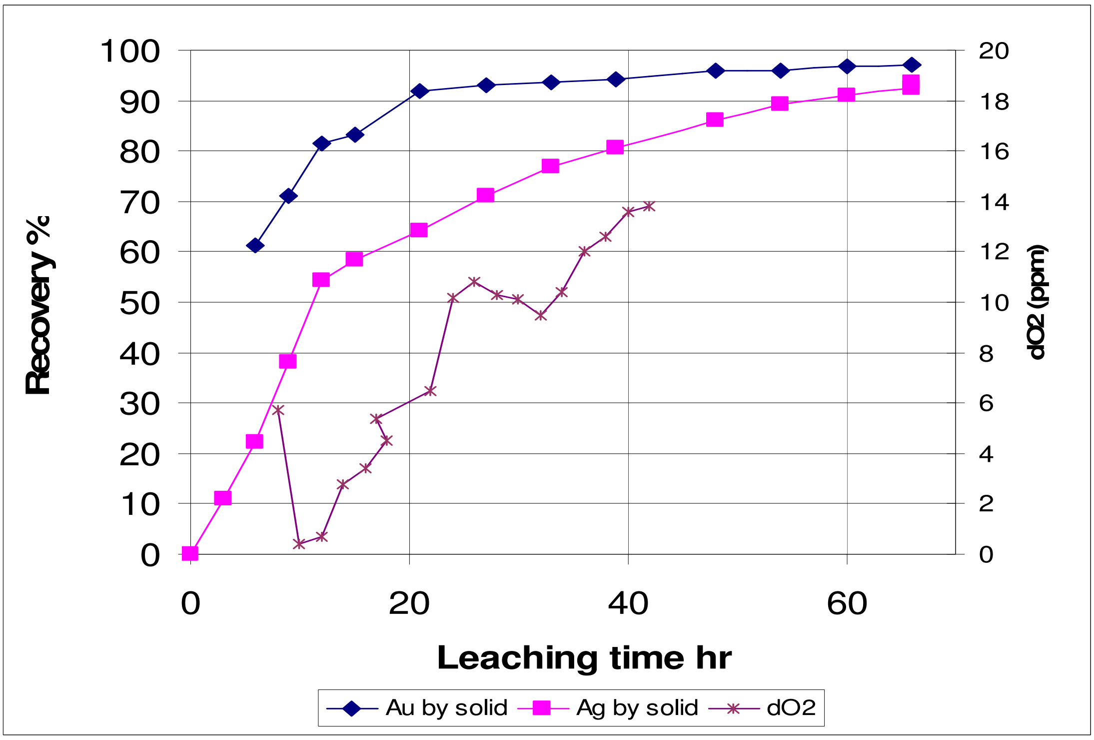

Figure 6: Batch 5 – Gaseous Oxygen - Leach Results

For Batch 6, the flotation concentrate was reground in barren electrowinning solution to increase leach time. The leach was carried out in 3-4% NaCN with carefully controlled peroxide as an oxidant.

The cyanide addition was also staged in an attempt to maintain consistent levels. The results for the Batch 6 can be seen in
Figure **7**.

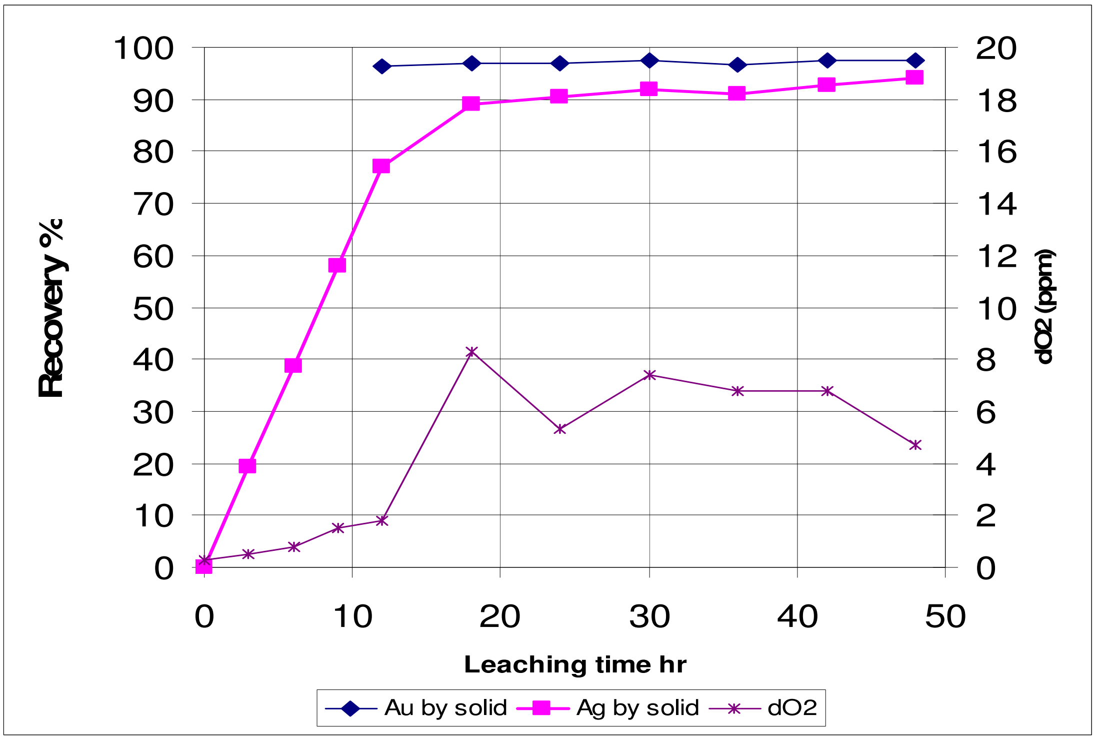

Figure 7: Batch 6 – Peroxide added to dissolved oxygen level - Leach Results

The flotation concentrate was ground in barren solution again for Batch 7. This time peroxide was used in conjunction with gaseous oxygen for the first 11 hours to help oxidize the high oxygen consumers that appear to be causing the leach reaction to progress slowly. Once dissolved oxygen levels were consistently above 6 ppm, the peroxide addition was stopped and gaseous oxygen addition maintained. This strategy ensured the precious metal surfaces were not passivated. The results shown in

Figure **8** can be seen to be superior to the previous leaches (

Figure **9**).

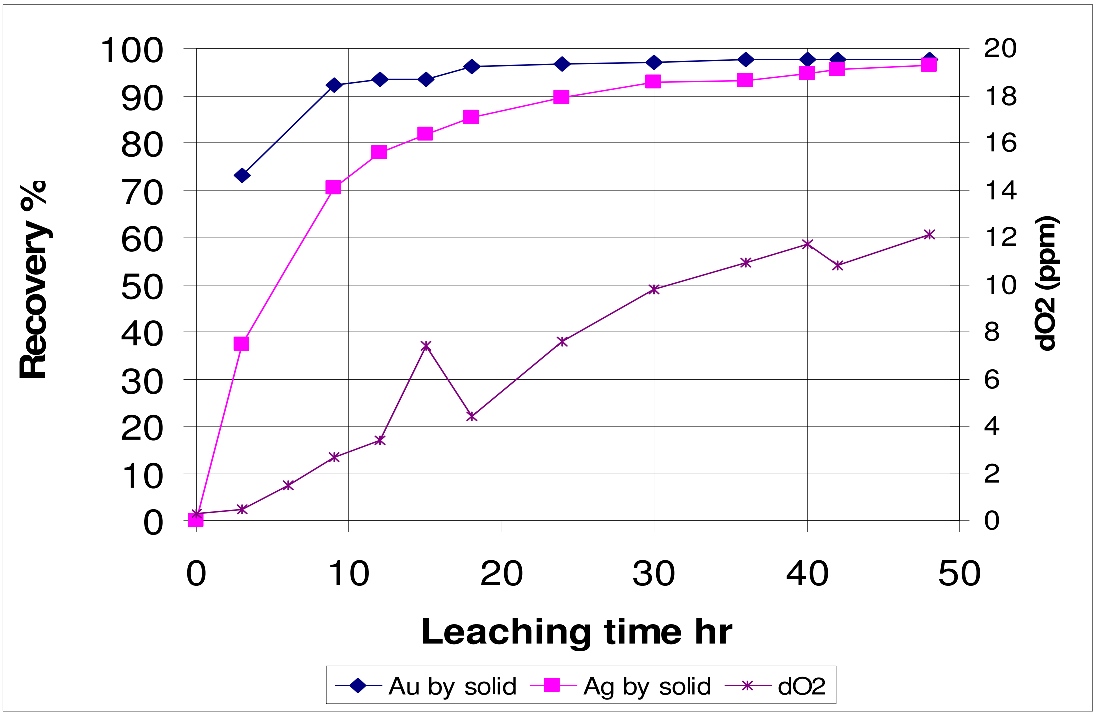

Figure 8: Batch 7 – Peroxide and oxygen added to dissolved oxygen level - Leach Results

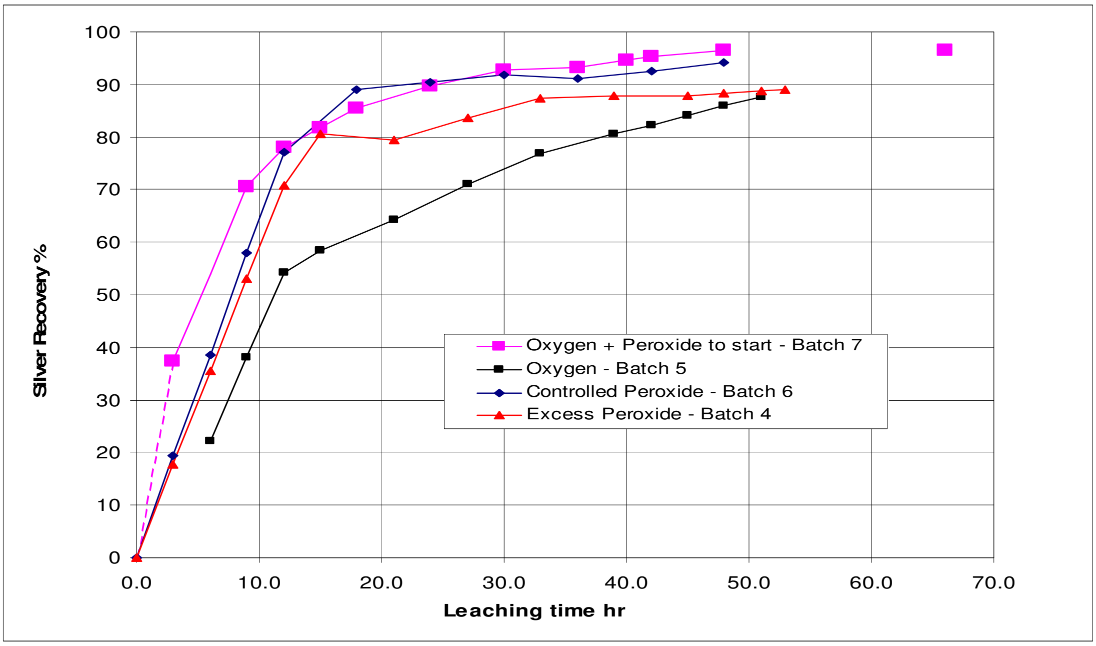

Figure 9: Comparison of the silver recovery all four batch leach tests

The optimisation program showed:

- It was not possible to add enough gaseous oxygen at the start of the leach to meet the oxygen demand and leach kinetics suffered,

- Peroxide addition overcame the initial slow kinetics but overall recovery was lower due to the suspected dissolution of sulphides and silver minerals to form slow leaching compounds, and

- Peroxide addition at the start of the leach in addition to gaseous oxygen produced the highest recovery in the shortest leach time. The peroxide overcame the initial high oxygen demand whilst the gaseous oxygen maintained high recovery in the later stages.

CONCLUSIONS

This paper has described the successful commissioning of the InLine Leach Reactor for leaching of the Selene flotation concentrates. The commissioning success is based on knowledge of the leach potential through testwork and a systematic approach to troubleshooting start-up problems.

The ILR's flexible design has also proved to be beneficial to the leaching of challenging silver concentrates due to the ability to optimise reagent additions and innovative solid/liquid contact within the unit.

Based on the above results, Hochschild Plc have recently announced (Hochschild, 2009) a $25 – 30 million (USD) project to convert 100% of Arcata's gold/silver production to dore'. The Arcata site is located approximately 25 km from the Ares site and produces approximately 20 000 tonnes per annum of silver/gold/base metals concentrate.

The project is expected to have a 2 year payback period. As part of this project, Hochschild ordered five more ILR5000 units.

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