Increased Recovery from Preg-Robbing Gold Ore at Penjom Gold Mine

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ABSTRACT
The Penjom Gold Mine is one of the world’s worst preg-robbing gold ores, yielding very low recoveries from traditional CIL methods. Gold recovery from the cyclone underflow was targeted to recover as much gold as possible in the absence of the fine preg-robbing carbon.

Gold is recovered by intensive cyanidation and tabling of a gold concentrate produced by gravity from the cyclone underflow. The circuit was designed together with Gekko Systems and uses their InLine Pressure Jig and InLine Leach Reactor technology to reject the preg-robbing carbonaceous material and obtain high recoveries from the gravity concentrate before over grinding the carbon and sulphides.

The gravity and intensive cyanidation circuit now recovers almost 50% of gold in new mill feed, with unit recovery in intensive cyanidation of up to 90%, the highest unit recovery in the plant. Operating costs for the gravity and intensive cyanidation circuit are under US$2.50 per oz, while the cost to recover gold from the cyclone overflow is ~US$200 per oz. (not including common costs of milling, stripping and electrowinning).

Figure 1 shows the increase in gold recovery due to the gravity and ILR circuit coming on line at Penjom.

INTRODUCTION
The Penjom Gold Mine is the largest gold mine in Malaysia. The Penjom ore is high grade, with head grades to the plant ranging between 6 g Au/t and 10 g Au/t, but has been benchmarked as one of the world’s worst preg-robbing ores.

Before the Penjom Gold Mine finished treating oxide ore it was known that the transition and primary zones contained highly preg-robbing carbonaceous ore. The naturally occurring finely divided carbon in the ore acts in the same manner as the carbon introduced in the adsorption process with traditional Carbon In Leach (CIL) systems.

Cyclone Underflow Circuit
Testwork carried out at site showed the recovery of coarse gravity/sulphide concentrates from the grinding circuit offered many benefits. It was considered essential to maximise gold recovery from these concentrates if total recovery was to be increased to an economic level. There were several options available to maximise gold recovery from this part of the circuit, however operating experience with Penjom oxide ores suggested the conventional Knelson bleed from the cyclone underflow circuit followed by tabling yielded only mediocre recoveries of around 30%. Any gold associated with the sulphides or of a very fine free nature was not recovered on the tables. A substantial portion of Penjom ore was believed to be in this category.

Testwork showed any gold not recovered prior to the cyclone overflow was likely to give relatively low recovery because of the high level of organic carbon in the downstream circuit. The InLine Pressure Jig (IPJ) offered a means of continuously recovering sulphide and free gold concentrates from the entire cyclone underflow stream. Gold trapped in the grinding circuit would either pass through the existing 30” Knelson or through one of three jigs, which had the capacity to treat the balance of the entire recirculating load. The InLine Leach Reactor (ILR) was chosen to scavenge the high grade portion of the jig product after cleaning the concentrates with spirals and tables. The gravity/ILR system at present recovers almost 50% of the total gold in new mill feed. After the free gold is removed (12-15%) the ILR alone recovers 35% of the total new mill feed gold at a unit recovery of over 80%. This is the highest unit recovery in the plant.

FIGURE 1
Breakdown of Gold Recovery at Penjom Mine.
Cyclone Overflow Circuit

The process route for the cyclone overflow stream was never going to be straightforward. Conventional wisdom suggested desliming, and possibly concentrating the deslimed product before leaching using the existing leach circuit. This process was attempted with poor results. A full scale continuous discharge centrifugal gravity concentrator was trialed on cyclone overflow but the upgrade, recovery and carbon rejection were poor. Kerosene poisoning and conversion from CIL to continuous Resin in Leach (RIL), using a commercial strong base resin, also produced only mediocre recoveries. This was despite successful testwork in the laboratory. Other options such as roasting the whole ore to oxidise the carbon were explored but pyrometallurgical solutions were considered unattractive from both a financial and environmental point of view. Furthermore, capital was difficult to raise due to the uncertain mine life at the time.

Fortunately, a flotation circuit had been incorporated into the design of the plant, to enable carbon rich concentrates to be at least stockpiled for later processing, either onsite or offshore. It was utilising this circuit, together with the construction of a small batch leaching plant that gave best results for the cyclone overflow. Resin responded well to the batching process, and unit recoveries ranging between 30 and 50% have been achieved to date. This circuit was low cost to implement because the flotation cells were already in place and the design and engineering work for the batch plant was done on site. Construction of the new batch facility was completed using Malaysian sub-contractors.

This paper focuses on the success of the cyclone underflow circuit recovery, because without the InLine Pressure Jigs and the InLine Reactor concept, the mine would have struggled to survive. With the on-going optimization of both the cyclone underflow and overflow circuits, Penjom has become a low risk operation, with cash costs averaging well below US$200 per ounce.

CYCLONE UNDERFLOW CIRCUIT OPTIMISATION

Any process chosen for the cyclone underflow circuit needed to satisfy two basic criteria - simplicity to retrofit and low capital cost.

The original gravity circuit consisted of a Knelson concentrator and a Gemini table, which produced varying quantities of free gold ranging between 10% and 35%. Targeting gold recovery from the cyclone underflow (CUF) was logical in that this stream had the lowest carbon level, with most of the fine carbon already removed by the primary cyclones. Furthermore, there was a high gold loading in the re-circulating load because of the high feed grade, ranging between 2,500 gm/hr and 10,000 gm/hr.

The fact that low carbon concentrates can be further upgraded (at even lower carbon levels) suggested that the use of jigs could produce a leachable product, consisting of both free gravity gold and sulphide associated gold.

Test Program

Gekko Systems were engaged to test the potential for increasing the recovery from the gravity circuit. Gekko Systems, based in Ballarat Australia, specialise in gravity recovery and intensive concentrate leaching systems with their InLine Pressure Jig and InLine Leach Reactor technologies.

The InLine Pressure Jig (IPJ) is an advanced gravity separation device developed by Gekko Systems and described in detail by Gray.67 The InLine Leach Reactor (ILR) is an intensive cyanidation reactor developed by Gekko Systems to obtain high recoveries from concentrates and is described in detail by Gray.8 Both units offer significant advantages in high gold recovery, ease of installation and low capital.

Testwork Carried Out On Site

The testwork on site was carried out in several stages. This work was designed to show potential for increased recovery utilising the IPJ and the ILR in combination.

As the potential target was a circulating load it was difficult to predict the overall recovery. When liberated mineral is recovered from the circulating load the gold grade is reduced. As gold grade is reduced, so is the feed grade to the recovery device. Equilibrium is reached and if the circuit is efficient the grade of this equilibrium can be lower than new mill feed grade. Without installing a full scale circuit, it is not possible to accurately predict the equilibrium grade and hence final concentrate grade and recovery.

In order to estimate the likely equilibrium and concentrate grade a test program based on liberation and recovery was carried out. The following parameters were investigated:

⇒ The upgrading of cyclone underflow to produce a high grade gravity concentrate.
⇒ The production of low carbon (low activity) concentrates.
⇒ Investigation of the quantity of free gold present.
⇒ Investigation of liberation size and gold upgrade in the various fractions.
⇒ Leachability and kinetics of the cyclone underflow without upgrade.
⇒ Leachability and kinetics of the concentrates.
⇒ Size by size leach recovery of concentrates.

Outcomes

Several important observations were made from the results of the testwork:

- The concentrate leached rapidly to an acceptable recovery (75%)
- The coarse concentrates (p80=1000μm) did not need grinding to achieve relatively high recoveries.
- Gravity concentration alone produces a low carbon product, unlike flotation which produces a high carbon product.
The carbon was not as active in the coarse high-grade gravity concentrates; regrinding the concentrates increases the activity of the carbon in the ore and reduces leach recovery.

A relatively high-grade concentrate (100-200 ppm Au) could be made with very little free gold visible.

**Interpretation of Results**

From these results the outcome of the final circuit was predicted. The predicted results were:

- >45% of total gold could be recovered by a combination of gravity and ILR.
- CUF grade of 15 g Au/t.
- IPJ concentrate/ILR feed grade of approx. 40 g Au/t.
- ILR feed rate of <5 mtph.
- ILR residence time of 15 mins.
- ILR unit recovery of >75%.

**THE INSTALLED CIRCUIT**

Three IPJ1500s were installed in the grinding circuit. Each unit is fed cyclone underflow with the tails being returned to the mill feed. At the same time, the original bleed stream from the cyclone underflow is fed to the 30” Knelson concentrator. The jigs therefore receive about 200 tonnes per hour between them. The IPJ concentrates report to spirals in the gold room. The spiral and Knelson concentrates are tabled with any coarse free gold removed for direct smelting. All table middlings are sent to the ILR feed. This product is a high-grade sulphide concentrate. The grade of this material ranges from 300 to 1500 g Au/t. The ILR solid tail is pumped to a separate storage area, where prolonged leaching trials are being conducted.

The currently installed circuit differs from the original design in that instead of sending a high feed rate to the ILR, a cleaner, low tonnage sulphide rich stream is taken from the table middlings. This both avoids any threat from preg-robbing, and enables longer residence time in the reactor drum for leaching. Feed rates have recently averaged between 300 kg per hour and 600 kg per hour. Residence time of between 2 and 6 hours is now considered optimal for maximum leaching efficiency. The main features of the flowsheet are shown in figure 2.

From experience with the circuit so far, recoveries have been excellent at >90% on high grade feed, reducing to a low of 75% on feed grades of around 300 g/t.

Liquid/solid separation is achieved from the slurry leaving the reactor drum using a combination of settling cone and de-watering screen. Some flocculant addition has proven useful in the settling cone before the pregnant ILR solution is passed through two carbon columns for gold recovery. LeachWELL has also been used successfully to accelerate leach kinetics.

The existing circuit is being tested for the inclusion of a custom built ILR electrowinning system, manufactured by Gekko Systems, for ease of gold recovery, security and to bring forward inventory. The electrowinning system also increases dissolved oxygen levels in the return solution with the potential to further improve leach kinetics in the ILR.

**FIGURE 1**

Gravity and ILR Flowsheet at Penjom.

The current operating and performance parameters are summarised in the following table.

**ILR Process and Performance Parameters:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed rate</td>
<td>500 kg/hr (solid)</td>
</tr>
<tr>
<td>Feed grade</td>
<td>300-1500 g/t, 20 - 30%S</td>
</tr>
<tr>
<td>Tail grade</td>
<td>20 - 100 g/t</td>
</tr>
<tr>
<td>Average recovery</td>
<td>90%</td>
</tr>
<tr>
<td>Cyanide solution strength</td>
<td>&gt;2% NaCN</td>
</tr>
<tr>
<td>Solution flow rate</td>
<td>3 m³/hr</td>
</tr>
<tr>
<td>Gold solution grade</td>
<td>40 - 120 ppm</td>
</tr>
<tr>
<td>Carbon column</td>
<td>2 tonnes packed</td>
</tr>
<tr>
<td>Electrowinning cells</td>
<td>4 pressurised in series</td>
</tr>
<tr>
<td>Temperature of system</td>
<td>ambient</td>
</tr>
<tr>
<td>Residence time</td>
<td>3 hours</td>
</tr>
<tr>
<td>Reactor</td>
<td>ILR horizontal drum</td>
</tr>
<tr>
<td>Maximum capacity</td>
<td>unknown at present</td>
</tr>
<tr>
<td>Reactor solid tail density</td>
<td>&gt;85% w/w</td>
</tr>
</tbody>
</table>

**EFFECT ON PLANT PERFORMANCE**

The IPJ and ILR circuit has made a significant contribution to the viability of the mine. Figure 1 shows the gold recovery obtained in different parts of the plant. It clearly shows the increasing total recovery as the ILR came into full operation.

When the system was first installed total gravity gold recovery from the Knelson/Gemini table was expected to be in the 25 - 35% range. However, as the gold became finer at depth in the main pit, the gold recovery from this system alone decreased significantly. This finer gold was readily treated by...
the ILR, but would have proven to be difficult to separate using conventional gravity methods. The IPJ/ILR combination has maintained a high level of recovery from the cyclone underflow circuit, averaging between 30% and 40% of total recovery. If the plant had to rely on other less efficient processes only, then the cash cost of operating the mine would have exceeded the revenue obtained at recent gold prices.

The success of the ILR in this application highlights the potential of prioritising production from the cyclone underflow circuit, particularly when recovery problems exist at the back end of the circuit. The IPJs provide an inexpensive means of tapping into the sulphide stream in the recirculating load, and leaching the coarser fraction of these sulphides before any over-grinding can take place. The removal of sulphides also takes some load off the downstream processes, where sulphide treatment can be both difficult and costly.

ECONOMICS

The capital cost for the jig installation and complete leach reactor circuit was approximately US$180,000. This includes the three jigs, the complete reactor including reactor drum, settling cones, concentrate hoppers, barren solution tank, pinch valves, electrical control panels, de-watering screen, the two carbon columns, pumps and pipelines, and a cyclone to thicken the feed to the spirals. Detailed design work for the circuit was done in-house, and fabrication and construction was either completed by Penjom maintenance staff or subcontracted to local construction companies.

Operating costs were affected early by the frequent failure of expensive pressure bursting discs installed in the jigs. As operators have adopted correct operating procedures, and less blockages are experienced in the tails lines, costs have averaged less than US$6,000 per month. Most of this cost is in LeachWELL, pump maintenance and small circuit modifications. Longer term operating costs are expected to reduce further.

Given the IPJ/ILR circuit is producing an average of between 2,500 oz. and 3,000 oz. of gold per month, and excluding the common cost to all processes of crushing and milling, stripping and electrowinning, the average cost per oz. of extracting gold through this process is only US$2.00 to US$2.50 per oz. By contrast, sending pulverised, classified feed to the chemical circuit is costly. With monthly production from the chemical circuit varying between 1,200 oz. and 1,500 oz., the average cost per oz. (excluding crushing, milling, resin stripping and electrowinning) is estimated to be about US$200 per oz., most of which consists of chemicals and reagents.

FUTURE PLANS

The success of the jigs/leach reactor circuit at Penjom has prompted the company to continue with cyclone underflow circuit optimisation, adding another jig to the underflow, and enlarging the size of the InLine Leach Reactor. Testwork and plant experience has shown that recovery can be improved further by increasing the residence time in the reactor, at the same time increasing the tonnage of cleaned material for leaching. A fourth jig is also expected to ease the individual jig throughput, and thereby increase the overall efficiency of the jigs, which have been operated at almost twice their design throughput for much of the past year.

From sulphur analysis of the cyclone underflow stream, significantly more sulphides are available for extraction from the recirculating load. The limit for the IPJ/ILR concept has therefore yet to be reached. Water management becomes a key issue as more gravity equipment is added to the milling circuit. However, if recoveries are improved by diverting more gold to the most efficient process in the plant, then a solution can be found to the water problem. It is possible that more jigs and an even larger reactor will be required in the near future.