PYTHON UNDERGROUND PROCESSING PLANT CRITICAL DESIGN

S Gray[1]

ABSTRACT

The use of continuous gravity recovery in combination with a controlled breakage fine crushing and screening system followed by flash flotation has been incorporated into the Python processing plant. This provides miners with a flexible, robust, low cost, low energy pre-concentration process for the recovery of gold and/or heavy minerals. The Python plant incorporates fine crushing utilizing either High Pressure Grinding Rolls or Vertical Shaft Impactors in combination with the InLine Pressure Jig and Flash Flotation to continuously liberate and recover the valuable minerals. The use of these technologies has enabled a narrow, transportable pre-concentration plant to be produced which can easily be installed and operated in underground drifts and tunnels.

Keywords: underground processing, continuous gravity recovery, coarse recovery, gravity-flotation, low energy

INTRODUCTION

Gekko Systems (Gekko) have developed a gravity/flotation pre-concentration flowsheet over the last 10 years primarily for the purposes of an alternative process route to CIL/CIP processing of gold ores. Previous work has covered the benefits of this flowsheet including reduced power and water consumption as well as reduced reliance on cyanide (Gray, 2007). In the development of the flowsheet it has been seen that significant tradeoffs can be made leading to a highly efficient integrated circuit.

Over the last 20 years the circulating load in the comminution/classification circuit has been seen as a target for mineral recovery. Centrifugal gravity concentrators and flash flotation cells are examples of units designed to operate in the circulating load and recover valuable mineral prior to over-grinding. The Gekko Gravity Float Intensive Leach (GFIL) flowsheet pushes this concept to the point where the post comminution downstream process is the scavenger and the recovery in the circulating load becomes the primary focus. Driving the recovery to the front of the process means integrating it into the comminution circuit where the mineral is recovered at close to its liberation size!

The GFIL flowsheet has developed over a number of years and across many minesites where the value of recovering sulfides from the milling circuit has been identified and developed. This started with Gekko's first trials at Stawell Gold Mines and progressed through to coarse impactor style liberation at Bendigo Mining's pilot plant and finally reached the embodiment of the full flowsheet in the Ballarat Gold Fields (now Lihir) mine. Integration of the continuous coarse gravity recovery circuit into the comminution system is the key to the success of the GFIL concept.

This flowsheet was then taken and developed into the Python flowsheet and the Python underground processing concept was developed (Hughes, 2008).

PYTHON DESCRIPTION

The Python is a modular, transportable processing plant for use on surface or in underground drifts with little to no additional excavation (Hughes, 2008). The plant is designed to finely crush and recover minerals by continuous gravity and flotation concentration from the ore.

---

[1] Technical Director, Gekko Systems Pty Ltd, 321 Learmonth Road, Ballarat Vic 3350, Australia. Email: sandyg@gekkos.com

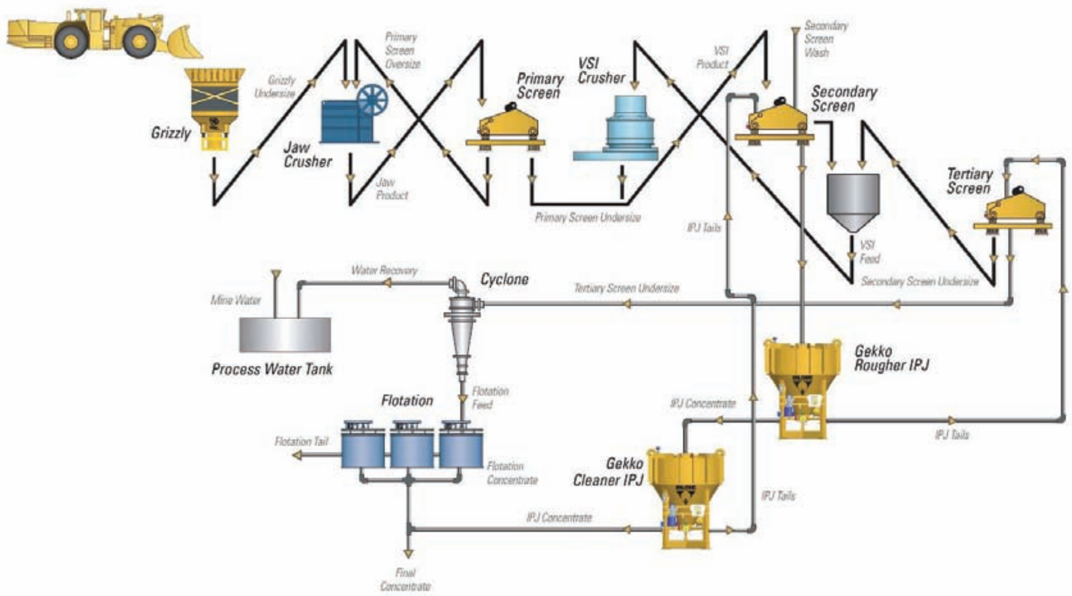

FIG 1 - Python processing plant process flow diagram

Processing of the ore includes the following activities (see Figure 1):

- Primary crushing and screening
- Secondary (Fine) crushing and gravity concentration
- Water recovery
- Flotation

The concentrate produced (between 5 to 30% of the feed mass) can be transported to the surface or to other processing facilities. This concentrate lends itself to intensive treatment which may enable higher recoveries than that achieved by whole of ore processing (Gray, 2007).

The key concepts in the design of Python underground processing plant are described below.

COMMINUTION

To achieve a low profile / low power consumption process route for the Python many issues were taken into account. Perhaps the most significant is the utilisation of a 2 stage crushing system to achieve a final crush size of P_{80} <400 µm with a power consumption of less than 6 kWh/t. The maximum feed size to the unit is in the order of 300 mm.

Critical in this system is the removal of multiple breakage events prior to mineral separation. The downstream recovery, in this case continuous gravity recovery (CGR), needs to see the heavy particles as they are liberated and so a key to the system is the single pass, plug flow, concept where rock sees a single controlled breakage (liberation) followed by a mineral recovery step (Powell, 2009). “Controlled breakage” means particles can not preferentially return to a size reduction process without first passing a recovery stage. Also the level of breakage can be controlled so that it is staged to allow for progressive recovery of liberated mineral as it occurs. “Plug flow” comminution means that ore flows through the process in a single stream without re-cycle or short circuiting.

In comparison, a ball mill incorporates many repeated breakage events without the opportunity to recover minerals between events. This results in finer grinding of the heavy minerals (sulfides, gold etc). Heavy particles tend to be caught in the mill for longer with no means of controlling the breakage and liberation. A mill is not a plug flow system.

Conventional classification systems incorporate hydrocyclones which preferentially produce finer sized heavy particles than gangue in the hydrocyclone overflow as demonstrated in Figure 2. This is because the mechanism of hydrocyclone separation relies on particle density as well as size. Given that mill / hydrocyclone combination represents the bulk of all mineral processing comminution circuits, it is understandable that the downstream processes have been developed around this system. Or was the milling front end developed around the downstream process?

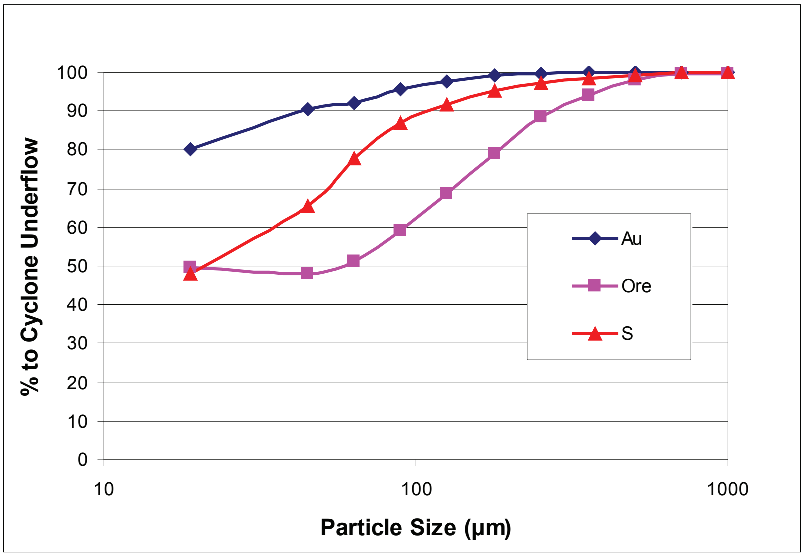

FIG 2 - Partition curve for a hydrocyclone showing the finer size distribution for both gold and sulfide than for the gangue. This is caused by a combination of the effect of the mill and the hydrocyclone.

The old gold processing plants (stamp mills) were not as efficient as today's processing plants but had some very interesting attributes that should be considered when developing new processes. In the case of stamp batteries they were single stage fine crushing systems with downstream processing designed for the relatively coarse particle output. The typical product size from a stamp battery was controlled by the screen size but was in the order of 100% passing 500 µm which is similar to the target size of the Gekko Python crushing/screening system.

Depending on ore type, issues associated with these systems were many and varied, however many of the tailings have been treated from these old systems and surprisingly few have had to be re-ground to achieve high cyanide recoveries. This would indicate that liberation was relatively high in many of these old plants at the fine crush sizes we are discussing.

Supporting this supposition, Gekko have completed hundreds of test work programs utilising fine crushing (P_{80} 500 µm) at the front end followed by gravity separation and flotation to come to an understanding on liberation in this area. As expected the liberation and hence recovery ranges from excellent through to poor (see Figure 3). The figure shows the results from the testwork programs sorted from lowest to highest recovery. The "Sites" on the x-axis are individual samples from a variety of ore bodies and mine site locations.

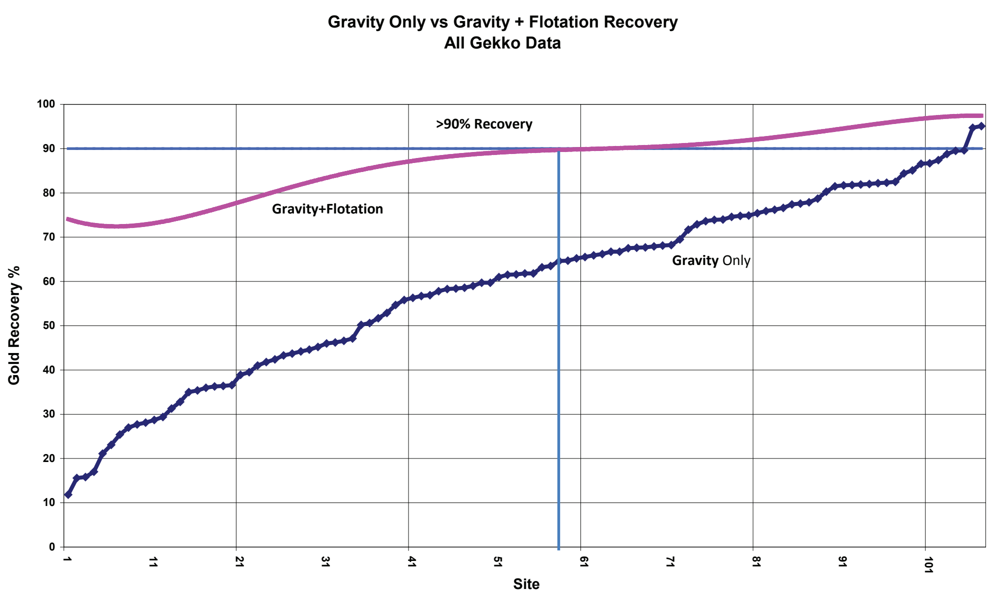

FIG 3 - Combined continuous gravity and flotation recovery test results

Gekko's focus is on deposits that respond well to this technique whilst at the same time it is looking to develop equipment to further enhance the recovery at coarse crush sizes and bring more deposits into the acceptable recovery range of this technology. Currently the test work program employed emulates the tools available, with fine crushing being carried out in the lab in either a lab scale High Pressure Grinding Rolls (HPGR) or Vertical Shaft Impactor (VSI). At present these two technologies appear to be the only proven units capable of economically and reliably reducing coarse (12 mm) feed to the fine sizes (400 μm) required for test work. At this stage, three key parameters are explored; size reduction per pass, liberation and recovery.

Size reduction per pass

Size reduction per pass test work enables us to look at the ore's response to fine crushing technologies to ensure circulating loads will not be too high. A minimum size reduction in the order of 20 – 30% target size fines production per pass indicates the ore is amenable to this method of crushing. Lower fines production rates result in higher capital and operating cost for the crusher, screens, conveyors and pumps due to higher recirculating loads.

In the test, the ore is passed through the crusher and sized before and after to give a size distribution (see Figure 4). It can be seen that between 30% and 40% fines were generated passing 1 mm in the 2 tests and that the HPGR produced the greater single pass reduction as expected. This of course can be manipulated by adjusting the pressure on the HPGR rolls and the velocity of the VSI rotor.

The HPGR will achieve a greater fines production per pass on any given ore type. However the VSI has other advantages not the least of which is the ability to handle far higher moisture content in the feed as well as being lower capital cost. The liberation of the two systems appears to be very similar with post crushing gravity recovery the same for both units. Generally one system or the other will be chosen on specific criteria related to the client and the ore.

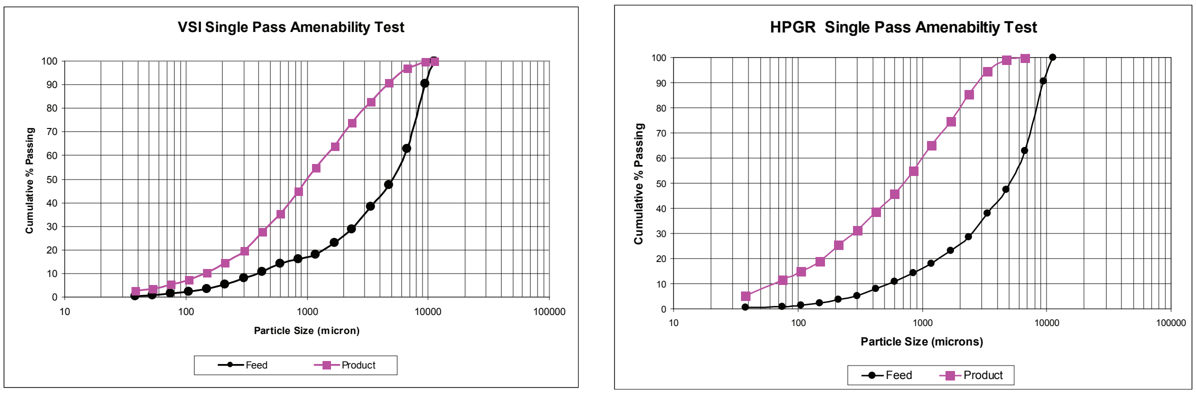

FIG 4 - Single pass crushing results for a VSI and HPGR respectively.

Liberation

The key to gravity recovery is coarse liberation with particles being broken from the rock at its naturally occurring crystal size. In the case of sulfide ores, typically the sulfide crystals make up the inconsistency in the rock and breakage occurs along the grain boundaries. In this breakage and recovery system it is common to see complete sulfide crystals liberated and recovered to the concentrate (Gray,2007). When assessing this type of recovery system it is good practice to have scanning electron microscope (SEM) work carried out on whole sections to measure the particle sizes of the mineral as it occurs in the original rock as this will give early indication as to whether coarse liberation is possible . Figure 5 is a QEMSCAN image from a gold/sulfide ore. Whilst the gold was very fine at <20 μm, it was associated with large pyrite particles which could be liberated and hence the gold could be recovered at 500 μm together with the sulfides.

For ore with coarse sulfides, simple optical mineralogy (Figure 6) can be used to gauge liberation size and indicate the opportunity to recover the sulfides at their liberation size.

Another feature of mineralogy is that highly mineralised ore with coarse mineral particles tend to break relatively easily whilst finely distributed sulfides in a tight matrix will respond poorly.

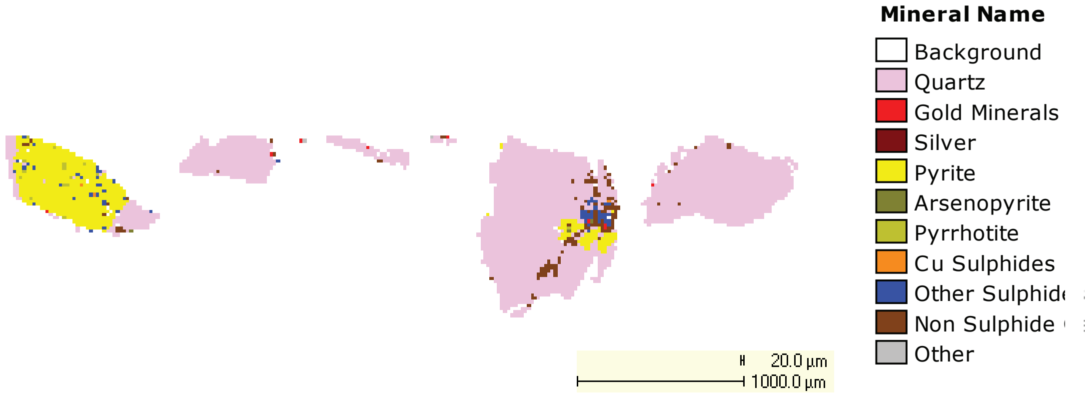

FIG 5 - QEMSCAN image of a gold/sulfide ore. The gold is typically less than 20 µm but is associated with large pyrite particles.

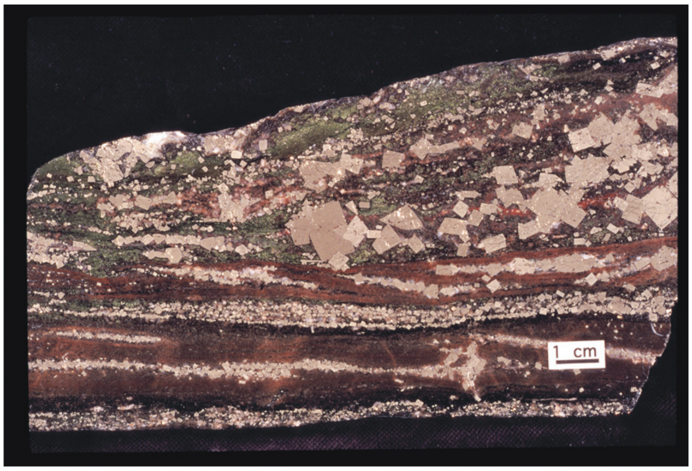

FIG 6 - This photograph shows the distribution of sulfide particles in a piece of ore. When comminution is carried out on this ore it can be seen how important it is to recover these particles at their liberation size.

Recovery

Once liberation has been achieved it is important that these particles should then be immediately removed from the system before further size reduction occurs. The most efficient recovery for coarse liberated mineral is gravity separation. In more recent times gravity has been an add-on to conventional leach and flotation systems and it has been recognised that these systems suffer where coarse liberated mineral reaches the downstream process by short circuiting and is lost to tails as the process is not capable of handling these coarse outliers. In the Python system the priority is switched around, deliberately focussing on the coarse particles. Therefore gravity recovery at the front of the process is critical to the efficiency of the system.

At this stage it is important to define coarse and fine. In the case of crushing, comminution and screening, "fine" can be defined as anything below 2mm. In the area of separation a "coarse" separation would occur between 4 mm and 100 µm. A "fine" mineral separation would occur below 100µm and down to 20 µm with anything below this being "ultrafine".

The continuous gravity combined with flotation system has a high efficiency below 4 mm with an overlap at the boundaries of the two methods. In the lab, a small shaking table is used to simulate the InLine Pressure Jig (IPJ) and target the coarser fractions above 100 µm, while flotation is used to recover the particles below 100 µm. Both systems are capable of recoveries below and above these sizes as is shown in Figure 7 and so a good overlap is achieved ensuring no size range is disadvantaged.

Figure 7 shows the decline in gravity recovery with finer sizes. It can be seen that flotation takes over where gravity recovery starts to reduce. It is apparent from the above chart that flotation efficiency reduces above 212 µm.

In a conventional process plant it is imperative to ensure coarse liberated particles do not report to the flotation circuit. Actual plant efficiency will be affected by the capability of the operators and so overlap in this area helps to ensure maximum recovery is achieved. In some cases actual plant

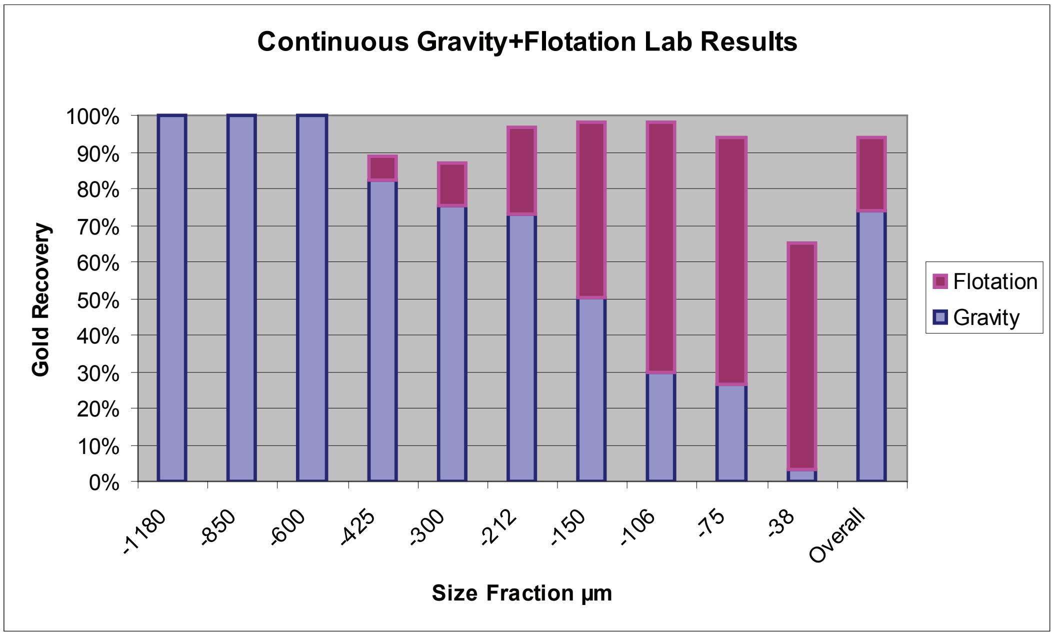

FIG 7 - Lab continuous gravity and flotation recovery by size.

results are better than lab results due to the higher gravity recovery at particle sizes coarser than the laboratory can test. Both the Ballarat and Bendigo plants achieve higher gravity sulfide recovery than predicted from the test work due to their coarse (4 mm) sulfides.

The test work typically allows for gravity recovery to remove the coarse mineral ahead of the flotation stage. The coarse slurry is then fed to flotation for recovery of the fines that were not recovered in the gravity stage. The flotation circuit is not required to recover coarse mineral as it has already been removed from the system. To remove the requirement for fine screening the coarse slurry is sent directly to the flash flotation unit. Flash flotation equipment is used because it is capable of physically handling the coarse feed. Flotation residence times are typically less than six minutes in the flash flotation cells but as the majority of the gold and sulfides have been recovered in the IPJ, testwork has indicated typical laboratory residence times of less than two minutes can be used to achieve high combined recovery.

A combined recovery is achieved which varies greatly by ore type in the ratio of gravity:flotation recovery as previously shown in Figure 3. At this stage the ratio is not important only the overall recovery and the mass required to be recovered (Yield %) to ensure the optimised recovery. As mass yield is increased recovery increases but conversely the grade of mineral in the concentrate reduces (see Figure 8). The yield is basically driven by the characteristics of the ore not the process. The mineral abundance and liberation in any given ore type will drive the yield.

The coarser the particles the more efficient the gravity recovery becomes. The more efficient the gravity processing is the more weight of mineral is recovered at the front end and the less mineral that needs to be recovered by flotation. This allows for lower reagent additions and reduced residence times in flotation resulting in capital and operating cost savings.

Continuous gravity recovery is applicable in all systems where sulfides are associated with the valuable mineral to be recovered. This is necessary as the physical mass required to be produced by the gravity concentrator is not possible with a batch or semi-batch device. Typical mass yields in a continuous gravity circuit range from 1% - 20% compared to batch devices recovering only 0.05%. The shaking table in the lab has a variable yield and is used to define the mass yield required in any system to maximise recovery.

PYTHON COMMINUTION

From the work carried out in hundreds of test work programs at Gekko and utilising current technology, an integrated comminution/recovery system was developed to emulate what had been achieved in the Gekko lab. The system developed is shown in Figure 1 and has the following

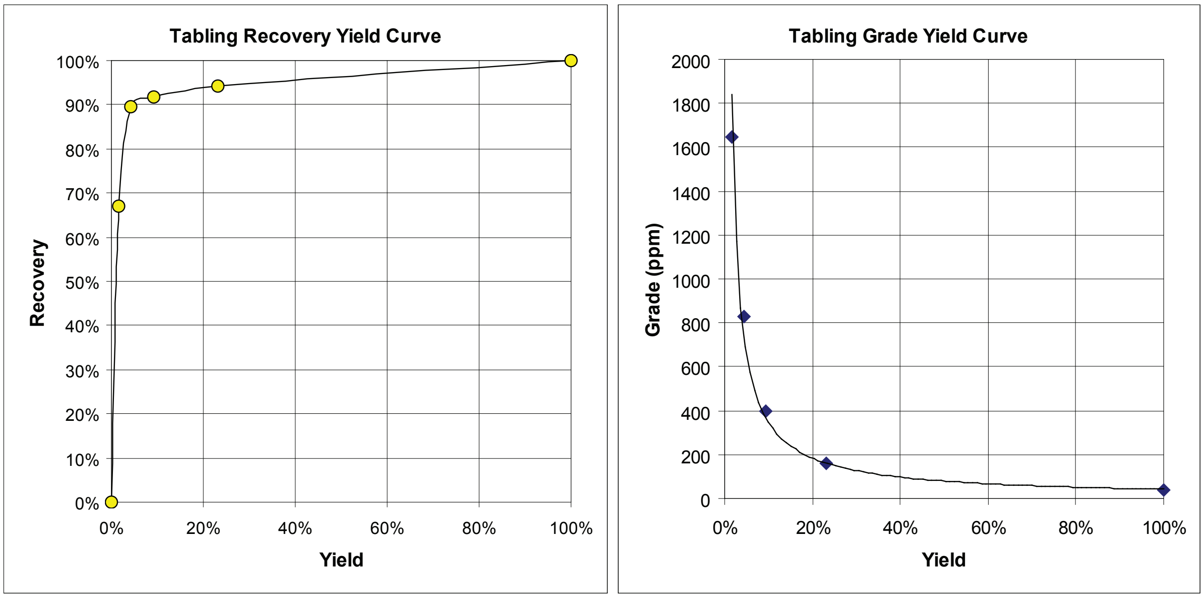

FIG 8 - Examples of Yield-Recovery and Grade-Yield curves.

FIG 9 - Python 200 unit showing primary screen and jaw crusher in closed circuit.

properties; as few components as possible, reliably achieve the desired fine crush of 400 µm, having "plug flow" components, total control of the breakage process.

The choice for the Python front end was a conventional jaw crusher followed by either VSI or HPGR. Both these technologies have the capability of very high size reductions with good fines production. Neither device produces large quantities of ultra fine material which is important.

The jaw crusher is operated closed circuit with a vibrating screen (see Figure 9) to produce a maximum particle size capable of being directly fed to the VSI / HPGR and to stop coarse slabby particles reporting to the fine crushing circuit. Typically the maximum particle size is in the range of 30 – 45 mm. If the jaw crusher is struggling to achieve the desired sizing in a single pass, the circulating load increases and it builds to a choke feed which allows finer product to be produced by the crusher. The higher the allowable feed size to the VSI / HPGR the higher the throughput from the same jaw crusher/screen combination. This is because throughput increases proportionately with closed side setting.

Fines produced from this stage of the circuit are screened out on the secondary screen (3mm) and report directly to the gravity circuit where liberated mineral is recovered. All oversize material from the screen reports to the VSI / HPGR. At this point moisture becomes critical in the HPGR circuit as maximum allowable moisture is ~ 7% thus the screening / dewatering efficiency must be high. In addition the HPGR requires a stable feed rate and feed distribution. The VSI requires none of the above to operate efficiently. Levels of moisture above 10 - 15% in the VSI can cause premature wear but does not have an effect on the size reduction and metallurgical outcome. The oversize from the secondary screen is joined by the oversize material returning from the gravity circuit to feed the VSI / HPGR.

PYTHON RE-CIRCULATING LOADS

There are three main re-circulating loads in the Python circuit. The first is the jaw crusher/ primary screen which protects the feed to the fine crush section and optimises the use of the jaw crusher and has been discussed previously.

The second re-circulating load is around the VSI/HPGR in closed circuit with the secondary screen (see Figure 10). This system controls the top size feed to the gravity circuit. Screening the undersize from the primary screen over the secondary screen allowing fines produced in the mining process and primary crushing circuit to report to gravity concentration before further crushing is carried out. Generally the aperture range of the secondary screen would be between 3 and 5 mm.

The third re-circulating load is around the IPJ and the tertiary screen. The gravity tails report to the tertiary screen ranging in aperture from 500 to 1500 μm. This screen controls the final product size for the comminution circuit. It is this screen which is set depending on actual liberation in the plant. The finer the tertiary screen the higher the re-circulating loads in the crushing circuit.

Operational efficiency and optimisation is carried out around the screen sizes in the various parts of the circuit. Increasing or decreasing screen apertures in any of the three key re-circulating loads will push load upstream or downstream of the change. These re-circulations are a key factor in size reduction, liberation and recovery in this circuit. All elements interact to control the overall circuit performance.

FIG 10 - Python 200 unit showing, from left to right, secondary crusher, secondary and tertiary screens and InLine Pressure Jigs in closed circuits.

CONCLUSIONS

Both mills and hydrocyclones can be the enemy of recovery depending on the downstream process. Over grinding and fine grinding can reduce the ability of the downstream process to achieve high recoveries as well as waste energy that is not required for liberation.

The Python underground processing system reduces 300 mm ore down to 400 μm particles whilst at the same time recovering valuable mineral in a minimum of process steps. This provides a platform to reduce power, water and reagents as well as lowering the number and size of the units from a maintenance perspective.

The two fine crushing technologies - VSI and HPGR - have the capability to achieve very high reduction ratios whilst not producing too many fines. Exceptional performance in the range between 400 and 1000 μm make these technologies stand out amongst the currently available crushing options.

Coarse gravity recovery integrated into the comminution/screening system creates a very powerful tool for recovery for a large number of ores. Having a continuous single pass (plug flow) breakage system combined with the InLine Pressure Jig can provide a very robust gravity recovery system.

Interpretation of a good or poor result will depend on each project's circumstances as some economic models will allow for lower recovery in exchange for lower capital, simplicity and lower operating cost. A major driver in this area is the environment and the requirement for more mines to reduce and limit the use of power and reagents, such as cyanide, on site. The GFIL flowsheet provides a solution to those mines where cyanide use is prohibited or very strictly controlled.

Gold mines with complex ores that may render them prone to low recoveries due to leach passivation or high residence time in weak cyanide solutions (CIL / CIP) could benefit from intensively leaching a concentrate. Recovery of gold to a small mass that can be dealt with in a more intensive process may yield higher overall recoveries.

Most gold mines today are moving to underground mining and the use of the Python technology to pre-concentrate underground ahead of transportation will reduce mining and processing costs.

A significant benefit of coarse recovery is the reduction in both capital and operating cost as well as the ability to reduce the physical size of the system. Total process power consumptions below 10 kWh/t can be achieved with these systems which can be up to 75% lower than conventional CIL type flowsheets.

In conventional circuits the grind is dictated by the downstream process not liberation. Combined gravity / float recovery covers all size ranges from mm down to micron size particles. This system is very flexible as the ratio of coarse to fine is not as significant in the recovery process. It is purely liberation size that dictates the overall recovery.

ACKNOWLEDGEMENTS

The author would like to thank the management team and staff of Gekko Systems Pty Ltd for their data and kind permission to present the information detailed in this paper.

REFERENCES

Gray, S and Hughes, T, 2007. A focus on gravity and flotation concentration and intensive leaching rewrites conventional milling circuit design and improves environmental and cost outcomes, paper presented to *World Gold Conference 2007*, Cairns, 22-24 October 2007.

Hughes, T R and Cormack, G, 2008. Potential benefits of underground processing for the gold sector – conceptual process design and cost benefits, paper presented at *First International Future Mining Conference*, Sydney, 19-21 November 2008.

Powell, M S and Bye, A R, 2009. Beyond mine-to-mill – Circuit design for energy efficient resource utilisation, in *Proceedings Tenth Mill Operators' Conference*, pp 357-364 (The Australian Institute of Mining and Metallurgy: Melbourne).