Is the Python Right for Me? Python Amenity Test Work

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ABSTRACT

Gekko Systems Pty Ltd have developed the Python Underground Processing Plant for the concentration of gold and sulfide ores. The Python plant has an established flow sheet including fine crushing, screening, gravity separation and flotation which aims to concentrate the valuable minerals (gold/sulfides). The aim of the plant is to achieve high valuable recovery into a mass yield of 10 - 30 per cent to reduce the amount of material that is needed to be taken to downstream processing.

This paper examines the test work protocol for testing an ore to assess its suitability for the Python flow sheet. This paper will discuss the test methods employed to determine crushing requirements, continuous gravity recovery and flotation performance and how the results relate to Python design for the comminution, gravity and flotation circuits. Results from past test work will be discussed.

INTRODUCTION

Processing of gold-bearing ores has traditionally been undertaken in fixed processing plant located on surface. Run of mine ore is transported to the processing plant from the mining areas underground. Typically gold processing plants have involved a number of unit operations to recover the gold which varied depending on the complexity of the orebody. Over the life of the deposit the distance that ore needs to be transported increases particularly as depth increases. Ore transportation costs increase proportionally. In addition to the increased distance that ore needs to be transported, the grade of the ore may drop, increasing costs further as more ore needs to be transported and processed to maintain gold production. The ability to process the ore as closely as possible to where it is mined has the potential to significantly reduce mining costs by reducing the amount of material needing to be transported to the fixed processing plant. This also holds true for deposits located remotely from the fixed processing plant on surface.

The operating cost benefits of underground ore processing has been noted by a number of authors; Bamber et al (2005), Hughes and Cormack (2008) and Dominy et al (2009). These financial savings are estimated to range between six per cent and 25 per cent depending on the ability of the valuable mineral to be concentrated. A number of operational benefits have also been identified, Bamber et al (2005), including increases in mine-life, a decrease in cut-off grade, application of less selective mining methods and reduced surface footprint.

In 2004, Gekko Systems Pty Ltd (‘Gekko’) was awarded a grant to develop and produce a modular processing plant that could process gold ores underground, (Hughes and Grigg, 2009). The result of this research grant was the Python Underground Processing plant. The Python flow sheet utilises crushing, screening, coarse gravity concentration and flotation to concentrate the gold and sulfide minerals into between 10 - 30 per cent of the original mass. Typically valuable recoveries of over 90 per cent are targeted in plant design.

Hughes and Cormack (2008) estimated that 25 - 40 per cent of all samples tested have ore that may be suitable for treatment via the Python processing plant. Gekko have developed a testing regime to assess an ore’s suitability for Python processing and provide metallurgical data for final design. This paper details the test work required to determine an ore’s suitability to the Python processing route and discusses how the data generated in this testing relates to final Python design.

THE PYTHON FLOW SHEET

The Python relies on the use of coarse and fine crushing, wet screening, continuous gravity concentration, flash or conventional flotation and water recycling to concentrate greater than 90 per cent of the gold into a high mass pull concentrate of ten to 30 per cent of the mass. The higher mass pull level is used where very high recoveries are required or where only up to 60 per cent of the tailings can be returned as backfill due to the swell factor of the tailings compared to the original rock.

The Python process flow is shown in Figure 1.

To concentrate the ore as soon as possible ideally means locating the primary recovery device in a re-circulating crushing circuit to capture coarse liberated minerals as soon as they are liberated. This concept is realised in the Python by using a vertical shaft impactor (VSI). The VSI uses rock on rock crushing to liberate minerals at the grain boundaries. Figure 2 shows pyrite crystals liberated from Lihir Gold’s Ballarat Goldfields ore.

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High mass pull gravity recovery in an InLine Pressure Jig (IPJ) has been used for over ten years in many applications including gold, base metal sulfides, tin and diamonds (Gray and Hughes, 2008). The IPJ combines a circular bed with a moveable sieve action. The screen is pulsed vertically by a hydraulically driven shaft of which the length and speed of the stroke are fully adjustable. Inside the IPJ hydrophobic issues associated with conventional jigging are eliminated as the IPJ is kept hydrostatically full. The slurry within the IPJ also acts as a pseudo dense medium above the jigging bed assisting with the separation.

The synergy between coarse gravity recovery with an IPJ and fines recovery using flotation has been reported previously in a number of sources Longley (2004), Gray and Hughes (2007) and McLean et al (2007). The actual data from a milling circuit operating a flash flotation cell in combination with an IPJ in the cyclone underflow stream shows the IPJ recovering gold down to 106 μm and the flotation cell recovering the gold in the finer fractions (see Figure 3).

It is the above two principles that have enabled the development of a high recovery, low energy consuming flow sheet that can be engineered into a narrow, portable processing plant. It should be noted that though the focus of the Python design was gold-bearing ores the flow sheet is adaptable to other minerals that are amenable to gravity separation and/ or flotation concentration.

It should be noted that though the Python flow sheet outline contains gravity and flotation stages the plant has a modular design which enables different skids/modules to be added or removed as the testing requirements dictate. For example on particular ores sufficient valuable recovery may be achieved by gravity only thus the flotation skid would be removed. Alternatively if the testing showed that a slow floating fraction existed, it may be necessary to double residence time and an additional flotation skid could be added.
PYTHON AMENABILITY TEST WORK

In order to determine if an ore will be amenable to the Python processing methodology, a detailed test work program is required covering:

- mineralogy,
- impact crushing work index,
- Vertical shaft impactor amenability,
- gravity recovery versus crush size – yield versus recovery,
- flotation recovery versus crush size – yield versus recovery.

Sample requirements

The typical sample weight required for Python amenability testing is between 30 and 200 kg. A number of factors control the size difference for a particular project. The grade and nature of the gold deportment will affect the sample size required. It is recommended that proper sampling protocols be undertaken to ensure representivity of the sample from an orebody point of view and also to ensure that sufficient sample is used to accurately characterise the gold. Some general considerations to be borne in mind when collecting a sample from gold projects for coarse gravity test work are outlined in Laplante and Spiller (2002) and Dominy, Xie and Platten (2008).

With a minimum sample of 30 kg (assuming appropriate mineralogy) the VSI, gravity and flotation test work can be conducted to give an indication as to whether or not this treatment route has potential. A positive result will justify further orebody sampling and comprehensive test work following this project route.

Mineralogy

The ideal starting point for a Python Amenability test program (or any metallurgical test program in fact), is to determine the gold occurrences via detailed mineralogy. Of importance to the Python are the gold occurrences – free, locked in sulfides, locked in other – and the liberated particle size of the gold, if it is free, and the gold-bearing minerals if not.

Both gold and gold-bearing mineral particle sizes are critical as the following QEM-SCAN image indicates (Figure 4).

The gold in this case was approximately 5 μm whereas the gold-bearing pyrite was almost 400 μm. Pyrite has an sg of 5.2 making it easily recoverable in the InLine Pressure Jig at its natural grain size (Gray and Hughes, 2008) and as such a high continuous gravity gold recovery was achieved.

Crushing amenability

The Bond (impact) crushing index test is carried out on a minimum of 20 selected rock samples between 50 mm and 75 mm in diameter. The result is used to calculate the net power requirements for crushers and the required open side setting for a jaw crusher to obtain a given crushing size. This is very important in the case of the Python as there is a fine balance between creating a small jaw crusher product size for further processing versus a reduction in crushing capacity at small closed side settings.

The capacity of each Python model needs to be carefully considered pending the hardness of the ore based on this crushing test.

Vertical shaft impactor amenability

This test is conducted to determine the amenability of processing the sample through a VSI crusher. It involves reducing the sample to -11.2 mm in a lab scale jaw crusher, screening the material at the desired product size (eg 1.18 mm, 850 μm, 600 μm, 425 μm) and passing the sample through the laboratory scale VSI. The product from a single pass through the VSI is sized to determine the production rate of the required product size (see Figure 5).

The curve for Sample 1 showed a high amenability for VSI crushing with over 40 per cent of -600 μm product produced in a single pass. Sample 2 on the other hand barely produced 20 per cent passing 1 mm in a single pass and would not be amenable to this type of crushing due to excessive recirculating loads.

The lab scale VSI used in these tests has been calibrated against actual VSIs operating in Australia and South Africa in fine gold ore crushing applications.

The production rate of product size is used in combination with a LIMN mass balance to determine the ore’s amenability.
to VSI crushing. The VSI amenability and crushing work index are used to determine the capacity of each Python unit based on the capacity of the major items of equipment. This is demonstrated in Figure 6 which shows how the Python 500 model’s throughput increases as the VSI amenability of the ore increases. In the case shown the overall capacity is limited to 80 t/h due to the jaw crusher capacity.

It is recommended that a Bond Abrasion Index test is also carried out on samples from the ore as abrasive wear plays a major role in VSI tip wear and thus operating cost and application viability. The test is conducted on 1.6 kg of -19 + 12.5 mm material. Further details on the test procedure can be found elsewhere (Bond, 1963).

Continuous gravity recovery

A laboratory size Holman-Wilfl ey shaking table is used for the tabling test to simulate the continuous gravity recovery (CGR) achievable in an IPJ. A thin film of water is applied to the shaking surface and several concentrate ports are available to separate the products. The tails are then taken and reduced in size using a VSI and re-processed over the table. The tails of the second stage can then be reduced in size again for a third pass over the table if required. The concentrates from each pass are then re-tabled to produce a number of concentrate products which are weighed and assayed. A yield-recovery curve is determined for that sample (see Figure 7).

This test can be repeated at various final crush sizes to determine the optimal liberation size for the ore. Recovery versus crush size was very significant in the case of the Ballarat Goldfields processing plant (Gray and Hughes, 2007) where initial tests were carried out at a fine grind size, 106 µm, then progressively coarser and the tabling test showed significant increase in recovery as the grind was coarsened (see Figure 8). This affect is believed to be the result of over-grinding naturally coarse sulfides (up to 5 mm) resulting in fines that aren’t gravity recoverable. In practice, Ballarat Goldfields’ IPJ gravity circuit achieved sulfide recoveries that were double what was achieved in the laboratory. This was due to the presentation of the sulfides to the IPJ at up to 5 mm rather than the 1 mm top size used in the test work (Gray and Hughes, 2007).

Data exists from a number of IPJ applications validating that the yield-recovery curve obtained by the continuous gravity recovery test is a realistic estimate of in plant IPJ performance. This is illustrated in Figure 9 which shows laboratory data from the continuous gravity recovery test against actual plant operating data. A number of other examples of this for gold/sulfide systems have been published; Gray et al (2004), Gray et al (2006) and Gray and Hughes (2008).

Flotation recovery

Flash flotation testing is used due to the Python operating at crush sizes that are too coarse for conventional float cells. The procedure used is as recommended by Outotec (Coleman, 2009) with the modification of extended float times to simulate longer residence time in the Python flotation cells compared with conventional milling circuit applications.
The procedure involves screening the gravity tail at 600 μm to remove coarse particles that won’t float but will damage the laboratory float cell, adding the float reagents in quick succession to simulate short conditioning times and collection of flotation concentrates over four 30 second periods (Coleman, 2009) followed by an extended collection over five minutes.

A subsample of tailings from the continuous gravity recovery test Tail is taken and float testing is generally performed in a 4 L Denver flotation cell. Sighter tests may be conducted to identify the optimum reagent dosage conditions. The test is very aggressive in terms of float residence time and reagent conditioning but is required to enable the design of the smallest float circuit practicable.

The original Python 200 (20 t/h) and Python 500 (50 t/h) designs built for Central Rand Gold (CRG) in South Africa utilised Outotec flash flotation cells for the flotation component of the plant (Hughes and Grigg, 2008; Dominy, 2009). The primary reason for moving toward flash flotation cells in the initial Python design was to minimise the chance of the cell sanding when being fed with a reasonably coarse feed. A particle size exists where recovery efficiency falls off (Trahar, 1981), regardless of whether the cell is flash or conventional. In the specific example of a coarse gold/sulfide project at Bendigo Mining, McLean et al (2007) noted that, particle sizes, greater than 150 μm were not targeted due to poor flotation characteristics. A design modification to the Python has been identified where fine screening can be used in front of conventional flotation cells in the situation where the laboratory work indicates that additional residence time may be beneficial. Size by grade analysis of the flotation feed (continuous gravity recovery test tail) is undertaken to select an appropriate screen aperture to minimise any gold/ valuables losses.

The flotation and gravity results are combined to produce a gravity plus flotation yield-recovery curve at the test crush size (see Figure 10). The data contained in this curve is then interpreted to determine the required mass yield from each stage to give the desired recovery.

**TRENDS IN TEST WORK UNDERTAKEN**

Laboratory testing of a wide variety of ores using high mass pull gravity recovery in the InLine Pressure Jig has shown nearly 20 per cent of samples tested could achieve gold recoveries at around 90 per cent in a gravity only circuit (Figure 11).

Floating the gravity test tailings has been carried out on just over 100 samples and indicated an increase to 50 per cent of samples having a recovery greater than 90 per cent with preconcentration using gravity and flotation (see Figure 12).

**OTHER DESIGN AND TEST WORK CONSIDERATIONS**

Though the testing outlined above would be sufficient to define the ore’s suitability to processing by the Python flow sheet, it is recommended that testing also be conducted on the concentrate produced to assess how it will be handled and treated. Further testing should also be conducted to allow selection of options for tailings disposal. These design issues and test work considerations are discussed here as they should be given consideration in the planning phase of the Python test work program.

**Concentrate treatment**

For a brownfield site or satellite deposit where it is planned that the Python concentrate be treated in an existing process plant, sufficient concentrate should be generated from the Python testing procedure so that further laboratory testing can be run to quantify the performance of the concentrate via this route. For a Greenfield application the same should be done however the recommended processing route is to treat the concentrate by intensive cyanidation in an InLine Leach Reactor due to its ability to deal with complex concentrates with a large variation in concentrate size (Longley, 2004).

The amount of material required for Python testing should be back calculated from the amount of material required from the final processing steps for gold winning. In the case of intensive cyanidation leaching for a complex ore (typically containing sulfur and arsenic) the gold will be recovered from solution by electrowinning; however impurities need to be reduced in the solution by a process such as resin absorption. In this case sufficient concentrate is required for up to six sighter intensive leaching tests to identify optimum leach conditions (100 - 300 g each) and a bulk leach at optimum conditions (1000 g each).
conditions (1 - 2 kg) to generate sufficient solution for resin absorption and electrowinning bench tests. From the example given, the Python amenability program needs to generate approximately 4 kg of concentrate, assuming a ten per cent mass yield from the Python flow sheet then at least 40 kg needs to be treated initially.

Concentrate handling

Careful consideration needs to be given to how the concentrate from the Python is to be handled from a material handling and, if necessary, a dewatering perspective.

The transport method for the concentrate to the final processing destination needs to be addressed early in the Python design phase to ensure that sufficient data is generated from the test work. Transport options should be looked at in the context of the mining method used and the distance that the concentrate has to be transported. Methods that may prove suitable for application at one mine may not necessarily be applicable at another operation. Consultation with mining engineers to ensure that the Python is integrated into the mine’s material handling system is critical to the installations’ success.

On the simplest level the concentrate could be pumped to the next stage of treatment, if so it is recommended rheological examination of the material be carried out. For other alternatives from trucking, to hoisting and conveying it is likely that the dewatering characteristics of the concentrate will need to be examined. As for the leaching test work mentioned above, sufficient concentrate has to be produced to enable settling tests and/or filtration tests to be conducted.
on the material to provide this data for further system engineering. Due to the coarse nature of the concentrate settling and filtration rates will likely be relatively fast.

Tailings disposal considerations

One of the major advantages of processing material as close to where it is mined as practical is the reduction in energy used for material transport. In the underground scenario if the waste material can be sent immediately from the Python to be used as backfill this maximises this benefit. Ideally the tailings material from the Python is relatively coarse which leads to excellent drainage and makes it the perfect material for backfill. It is noted by Bamber et al (2005) that it is critical that the supply of backfill from underground processing be included in mine planning as soon as possible to maximise the benefit.

It is likely that along with dewatering and rheological testing on the tailing material that specialist characterisation of the material to be used as mine fill will need to be undertaken. Consulting specialists in this area on their testing sample requirements is essential at the outset of the test work program.

CONCLUSIONS

Gekko’s Python preconcentration plant offers gold mine operators a chance to obtain considerable transportation cost reductions by processing ore closer to the mining site. Based on a combination of fine crushing, gravity concentration and flotation, test work has shown that there is potential to concentrate the gold and/or gold-bearing sulfides into as little as ten per cent of the mass.

The test work flow sheet for a ‘typical’ Python to assess an ore’s amenability and to provide data for engineering design has been described. This test work regime has been developed by Gekko from many years experience with VSI crushing, InLine Pressure Jig applications, flotation and plant design. The testing methods have been outlined in this paper and their correlation with plant design. Other considerations that need to be considered when undertaking a test work program were also highlighted.

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REFERENCES


