



DEVELOPMENT OF A GLYCINE-CYANIDE LEACH PROCESS FOR GOLD-COPPER CONCENTRATE

By

¹Brigitte Seaman, ²Tim Newton, ³Elsayed Oraby

¹Newcrest Mining Limited, Australia

²Mining and Process Solutions, Australia

³Curtin University, Australia

Presenter and Corresponding Author

Brigitte Seaman

Brigitte.Seaman@newcrest.com.au

ABSTRACT

The GlyCat™ process offers a simple and effective method to reduce cyanide consumption caused by the presence of copper in gold ores and concentrates. Reusable glycine is added to the leach to enable a 5-to-10-fold reduction in cyanide usage for the same copper feed concentration in order to yield similar gold extractions. Copper is recovered by either sulphide precipitation or resin ion exchange. Gold is recovered by conventional carbon adsorption or alternatively using gold-selective resins.

The process is being developed for potential implementation at Telfer Gold Mine to facilitate a change in circuit design that would then allow for increased concentrations of soluble copper. This paper examines why GlyCat™ is preferred over alternative processes and describes the process development activities conducted over the past 2 – 3 years.

An extensive program of batch testwork has defined the optimum leaching chemistry and proved the effectiveness of downstream processes. Continuous piloting campaigns have shown that the process is robust and controllable, while verifying the reagent consumptions and gold recovery under steady-state conditions. Bench-scale testwork, process modelling, and engineering studies have narrowed down the circuit configurations to a preferred flowsheet, involving single-stage leaching and conventional downstream recovery.

Glycine consumption is anticipated to be less than 3 kg/t concentrate, while the resulting saving in cyanide is at least 30 kg/t if the same concentrate were treated using cyanidation leaching alone.

Keywords: Gold Recovery, Copper Recovery, GlyCat™, Process Development, Pilot Plant

BACKGROUND

Telfer gold mine is located in the Great Sandy Desert in the East Pilbara region of Western Australia. The mining operation comprises mining from one of two open pit mines, Main Dome and West Dome, and an underground sub-level cave concurrently. Mined ore is crushed and ground to a floatable size. Flash flotation and gravity gold recovery are employed in the grinding circuit remove any coarse-liberated copper and gold particles early in the process. Ground ore is directed to a differential flotation circuit where pyrite is depressed, and copper is concentrated to produce a copper concentrate for sale to smelters. Pyrite is then re-activated and concentrated to produce a pyrite concentrate that is then re-ground and fed to a cyanidation leaching process. Products include gold doré and copper concentrate.

In all flotation processes, a trade-off exists between mineral concentrate grade and recovery. The severity of this trade-off is very dependent on the nature of the ore body (i.e. mineral types and textures with respect to both gangue and value minerals and the relative concentrations of each), the adopted grind size and the applied chemistry.

In order to maximize gold recovery, it is proposed that the concentrate grade constraint be eliminated, and that the flotation process be re-purposed for pre-concentration of valuable minerals into a single stream that is then fed to an on-site cyanide-based hydrometallurgical process.

Extensive flotation testing both at laboratory and pilot scale has shown that in making this change to the flotation circuit operating philosophy, gold recovery may be maximized into a bulk sulphide concentrate and that a substantial component of the non-sulphide gangue is rejected. The copper concentration in the leach feed will, however, be increased to approximately ten times the upper limit that is typically imposed on Telfer cyanidation leach feeds for the purposes of managing cyanide consumption. A need therefore existed for use of a chemistry that could best manage copper in this environment and allow for more economically viable dosages of cyanide to be applied for gold extraction. Following on various patents by Eksteen and Oraby from Curtin University, and through years of Newcrest involvement in AMIRA P420 (Gold Processing Technology), cyanide-catalysed glycine (GlyCat™) was identified as one chemistry that may facilitate this change in operating philosophy. This process relies on operation on a glycine leach running under cyanide starvation conditions where no free cyanide is present.

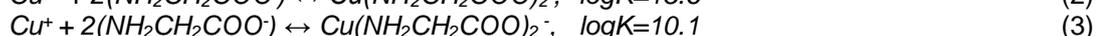
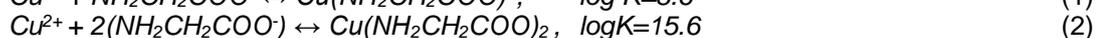
GLYCINE LEACH TECHNOLOGY

The presence of soluble copper with gold has detrimental effects on both gold recovery and cyanide consumption. At least 2.3 kg of cyanide is required to bind with each kg of copper leached⁽¹⁶⁾. Multiple studies have confirmed that the presence of copper with gold can lead to negative effects on the extraction of gold by cyanidation^(8, 10, 6). In the presence of highly reactive copper, low gold recovery was found along with high cyanide consumption⁽⁶⁾. When copper is mineralised as sulfides, further cyanide consumption is caused by the formation of thiocyanate, ferrocyanide and cyanate.

Cyanide dissolves copper and forms different copper-cyanide species such as $\text{Cu}(\text{CN})_2^-$, $\text{Cu}(\text{CN})_3^{2-}$, $\text{Cu}(\text{CN})_4^{3-}$. Various research studies have attempted to treat gold-copper ores by a cyanide-ammonia process or cyanidation with cyanide recycling^(7, 9, 2, 5, 1).

Over the past five years the use of amino acids and particularly glycine in the gold industry has been developed and patented^(11, 12, 13, 14). Oraby and Eksteen have found that a mixture of glycine and cyanide significantly improves the recovery of gold from gold disc⁽¹⁴⁾ and different gold-copper ores and concentrates⁽¹⁵⁾. It was reported that the major roles of glycine in leaching gold-copper ores and concentrates can be one or more of the following:

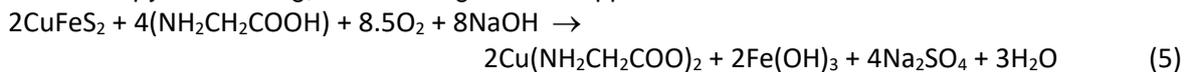
(i) glycine complexes with copper ions as shown in Equations (1), (2) and (3);



For chalcocite leaching the reaction follows the following stoichiometry:



For chalcopyrite leaching, the following reaction applies:

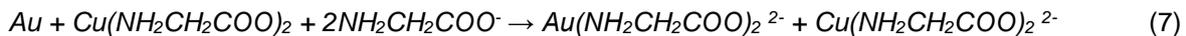


Sulfur oxidation is here shown for complete oxidation to form sulfate, although lower levels of oxidation is possible.

(ii) glycine acts as an additional lixiviant for gold dissolution as shown in Equation 6 (Eksteen and Oraby, 2015).



(iii) glycine presents an additional oxidant, via stabilisation of the cupric ion:



Research studies have shown that activated carbon can efficiently adsorb gold from GlyCat™ solutions^(17, 18). Furthermore, the the recovery of cupric recovery by sulphide precipitation has been demonstrated by Deng et al.⁽³⁾. The results showed that almost all the cupric copper can be precipitated from solution and gold can be adsorbed on activated carbon in a subsequent step.

PROCESS SELECTION

A programme of ore characterisation was originally initiated for Telfer West Dome ore in 2009. As part of this testwork, gold is cyanidation leached at a P80 of 106 microns in a bottle roll for a period of 48 hours to determine the level of “refractoriness” of the gold within the ore. In most cases very high levels of gold extraction via cyanidation leaching were achieved (on average 95%) and this sparked interest in the potential application of cyanidation leaching either as a whole of ore process or as a bulk sulphide concentrate leach process for maximising gold recovery from this ore body. A concept engineering study was completed in June 2012 to assess the following processing options:

- A whole of ore leach with SART for cyanide recovery,
- A whole of ore leach with cyanide destruction,
- A bulk sulphide leach with SART for cyanide recovery,
- A bulk sulphide leach with cyanide destruction.

The bulk sulphide leach was favoured over the whole of ore leach options, despite their higher recoveries owing to the substantially higher capital requirement for a whole of ore option and difficulty in managing the water balance, particularly for the SART option. Both whole of ore leach and bulk sulphide leach options suffered from high operating costs related to the higher cyanide demand resulting from the cyanide soluble copper species in West Dome ore. SART is an option for cyanide recovery. AVR would, however also be required to concentrate the recovered cyanide to a level that could be re-usable within the process. Whilst the concept is considered to be viable from a high-level forecasting perspective, uncertainty in forecasting both the total copper concentration and the level of cyanide soluble copper on a day-to-day and hour-to-hour basis meant that the concept was not pursued further in this format.

Options for removing the uncertainty in cyanide demand as a result of the varying copper concentration in feed include,

- The application of a single stage GlyCat™ process whereby copper is essentially managed through the application of glycine to the process and thus allowing for cyanide consumption to be managed to more feasible levels.
- Application of a two stage leach whereby copper is extracted in the first stage, the copper enriched PLS is recovered via either solid-liquid separation or counter-current washing and the residue is then neutralised for conventional cyanidation, carbon-in-leach gold extraction.

Both options are in development and both have advantages and disadvantages, however it is the intention of this paper to present on the development of the application of a single stage GlyCat™ process. Which, if scalable provides a potentially more cost effective solution to the “copper-problem”.

BATCH TESTWORK

An extensive program of bench scale metallurgical testing was undertaken through 2017 and 2018. This work found that high gold extraction could be obtained with low cyanide consumption by addition of glycine to the leach. The elevated copper levels of West Dome could thus be treated by modifying the leach circuit to incorporate glycine addition, filtration and washing of the leach tail, and downstream recovery of copper and gold by sulphide precipitation and carbon adsorption respectively.

Samples

Concentrate samples for the leaching testwork were produced via a series of large scale (25L) batch flotation testing for the bottle role testwork and via a flotation pilot plant at ALS AMMTEC for the leaching pilot plant. A low sulphur concentrate was sourced from the Telfer plant as additional development material to be used while the tailored concentrates were being generated in the laboratory. Table 1 presents the elemental analysis for the concentrates used in the development of the leaching process.

Table 1: Sample elemental analysis

Element	ALS Bench Scale Concentrate	Telfer Plant Low Sulphur Concentrate	Pilot Plant High Sulphur Concentrate
Au (g/t)	14.9	15.6	11.2 - 10.6
Cu			
Total (%)	2.1	3.2	2.0 - 1.8
Cyanide soluble (%)	0.8	1.1	1.0 - 1.2
Acid soluble (%)	0.3	0.6	0.3
S (%)	45.3	10	35.2 - 37.3

Experimental

All experiments were carried out using solutions prepared from analytical grade reagents and raw water from site.

All the experimental were performed under controlled dissolved oxygen (DO) leach mode. DO control was utilised to ensure sufficient oxygen is present during the cyanidation and glycine-cyanide leaching systems. Leaching experiments were conducted for 48 hours at 35°C temperature in 1.25 litre leach vessels with slurry agitated at a speed of 500 rpm using overhead stirrers. In each experiment, 400 g of sample was mixed with 600 mL of raw water before reagents were added to the slurry. In the cyanidation tests, the pH of the solution was maintained by the addition of lime, however, in the glycine-cyanide system, sodium hydroxide was initially added to adjust pH and lime was used to reach and maintain the targeted pH (Dual pH modifiers). The DO level of the leach solution was measured and controlled at a target value over 48 hours using a Syland DO meter, mass flow controller, multifunction data acquisition module (DAQ) and a laptop operating with the LabVIEW program. The DO level was controlled to an accuracy of ± 3 %. Figure 1 shows the setup of these controlled DO leach tests. Figure 2 shows a photograph of the DO control system in the lab and during the leaching.

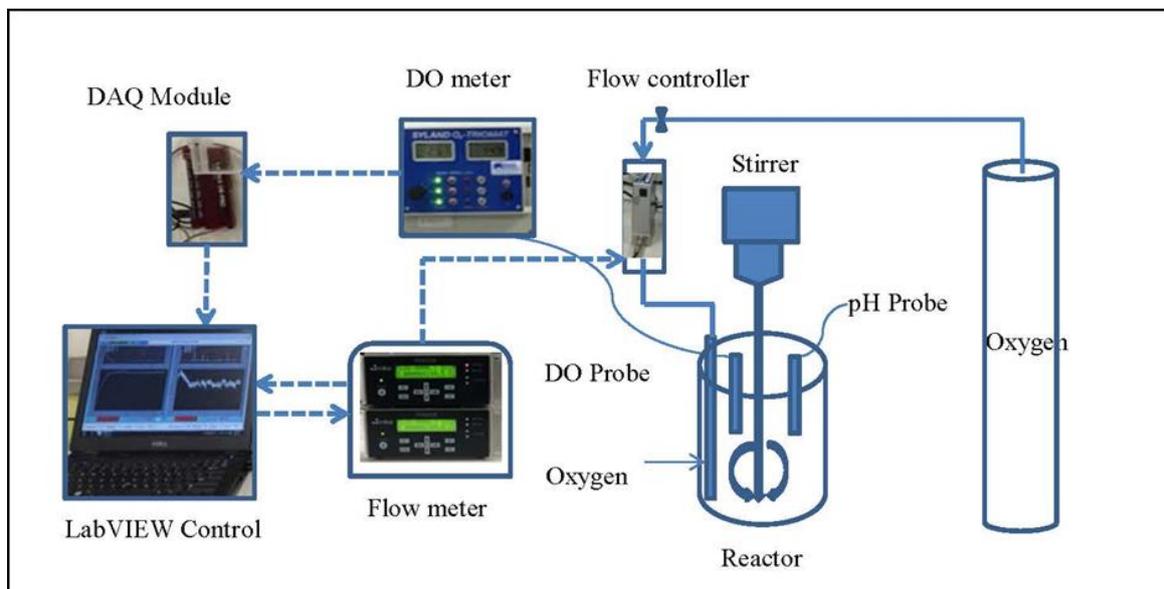


Figure 1 - Schematic presentation of experimental set-up.

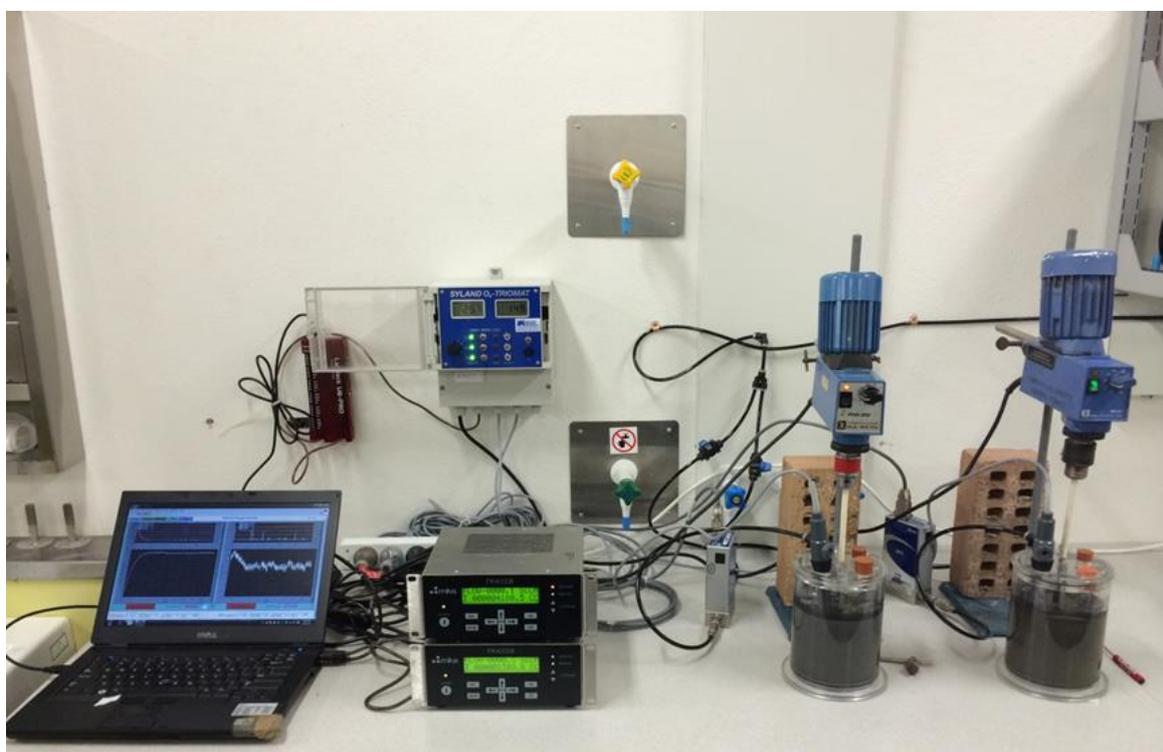


Figure 2 - Photograph of experimental set-up.

Results and Discussions

A preliminary cyanide leaching experiment was conducted to evaluate the leaching of gold by the conventional cyanidation processes. The cyanidation test was carried out at 40% solids and test conditions included 8 ppm O_2 , room temperature and rolling agitation at 500 rpm. Not surprisingly the cyanide consumption was very high, reaching up to 56.2 kg/t. Adding glycine enabled similar gold extraction with markedly lower cyanide consumption.

Table 2 shows the gold extraction and reagent consumption during the leaching tests. The table also shows the resulting shift in copper behaviour. In the cyanide system, copper is entirely present as cuprous, whereas cupric glycinate becomes dominant when glycine is added. Copper extraction is greatly suppressed by the lack of free cyanide in solution, but would increase with increasing glycine concentration and higher dissolved oxygen and E_h .

Table 2: Metal recovery and reagent consumption during the leaching of the concentrate.

	Unit	Cyanidation	GlyCat™
Gold Recovery	%	91.9	90.3
Cu recovery	%	43.1	13.0
Cu concentration	mg/L	3728	1108
Cu(I)	mg/L	3728	342
Cu(II)	mg/L	0.0	766
Cyanide consumption	kg/t	56.2	8.0
Lime consumption	kg/t	1.2	2.9
Glycine consumption	kg/t	-	5.8

The series of GlyCat™ tests that were carried out using the controlled DO and overhead stirring set-up were used to determine the following key findings summarised below:

Glycine addition: Lowering the glycine addition was considered to reduce operating cost, ideally to the point where recycle of barren liquor was no longer considered worthwhile. Tests show that this could be a possibility if the feed metal concentrations are fixed with a high level of confidence; i.e. semi-fixed feed copper and cyanide soluble copper concentrations or systems to be able to forecast and adapt to changes in feed copper and cyanide soluble copper well in advance of being introduced to the leaching stage. This is therefore not considered an option at this point of process development where maximising gold recovery is paramount. This will be revisited if the process is developed to the point of implementation and demonstrated to be sufficiently stable prior to this type of optimisation.

Cyanide addition: The lowest cyanide addition was achieved by gradually staging cyanide addition over the course of the leach. Gold recovery began to be affected once cyanide addition was dropped below 8 kg/t in the batch tests.

Dissolved oxygen: As with any gold leaching, maintaining sufficient dissolved oxygen was essential. 8 ppm DO was found to be adequate. This was achieved with an oxygen:air mixture of 1:5 in the first tank, 1:10 in the second, and air only in the remaining tanks.

pH adjustment: A dual-alkali approach worked best, using a combination of caustic and lime. A lime-only system was tested but showed slower leach kinetics.

Particle size: Fine grinding to 100% passing 15 micron gave faster gold leaching, but also dramatically increased reagent consumption, particularly lime. Considering the risk to downstream solid-liquid separation, this option was not taken any further.

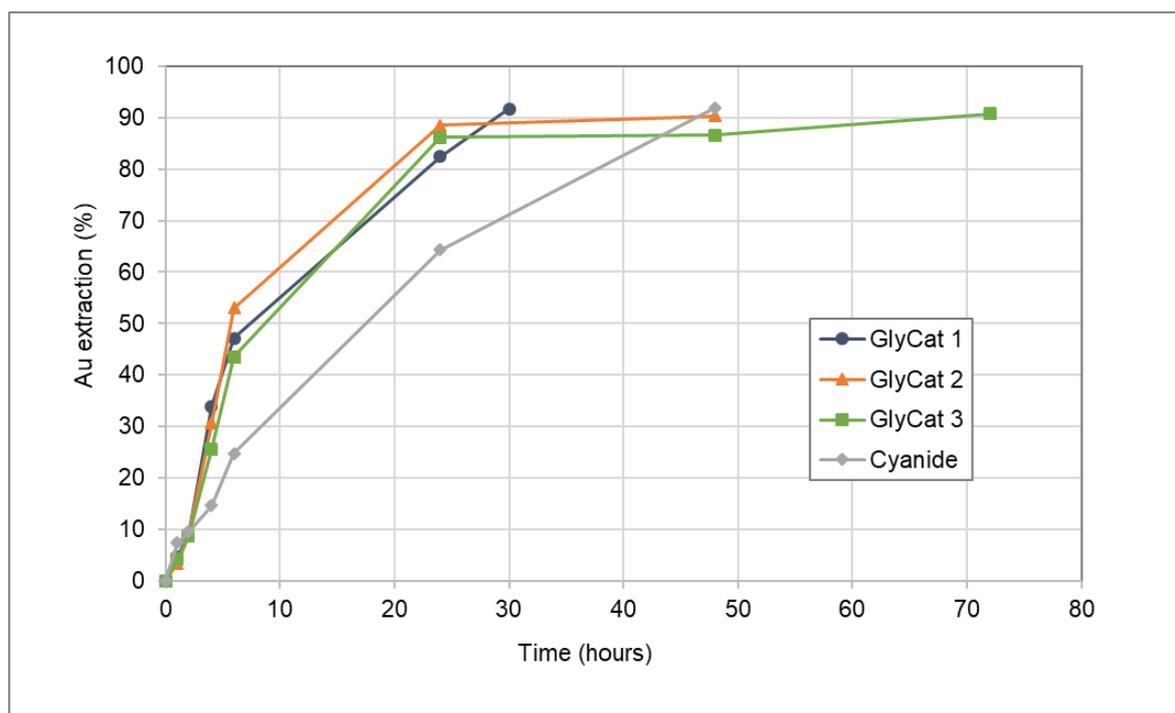


Figure 3 - Leach curves – Cyanidation Vs GlyCat (3 repeat tests).

PILOT CAMPAIGN

A pilot plant was built at Simulus Laboratories in Welshpool, Western Australia to confirm the bench scale findings were reproducible at a larger scale in continuous, closed-circuit operation. Accordingly, the objectives of the piloting exercise were to:

- Demonstrate metallurgical performance at larger scale in a continuous operation
- Show the true reagent consumption over an extended timeframe in a recirculating system
- Show the operability and controllability of the integrated process
- Generate process design data for engineering of the full-scale plant
- Identify any unforeseen problems or design flaws

The Simulus GlyCat™ leaching pilot plant was run in September/October 2018, processing a total of 2,157 kg of concentrate. Feed to the pilot included:

- A low sulphur concentrate sample of 4.75 t that was collected from Telfer processing plant in January 2018.
- A high sulphur concentrate sample of 2.1 t that was generated for purpose via a 10-day flotation pilot plant at ALS Metallurgy in June 2018.
- Blended intermediate sulphur

The pilot plant covered the following process operations:

- Re-pulping the damp pilot plant feed samples with barren solution,
- Single stage GlyCat™ leach,
- Tails filtration and washing,
- Copper (II) removal from PLS via either sulphide precipitation or ion exchange,
- Gold adsorption from the copper barren onto carbon via two carbon columns operated in series, and
- Recycle of barren solution to leach feed repulp.



Figure 4 – Leach circuit.

Two circuits were used for the campaign. The leach circuit is unchanged, but the downstream uses alternative routes for copper removal:

- Circuit A: Copper precipitation by sodium sulphide addition as shown in Figure 5
- Circuit B: Copper extraction by resin ion exchange as shown in Figure 6

Circuit A was switched to circuit B mid-campaign without stopping the leach for the purposes of generating data on both copper recovery options.

In both circuits below, the operations shown in dashed lines were not piloted but would be required in practice.

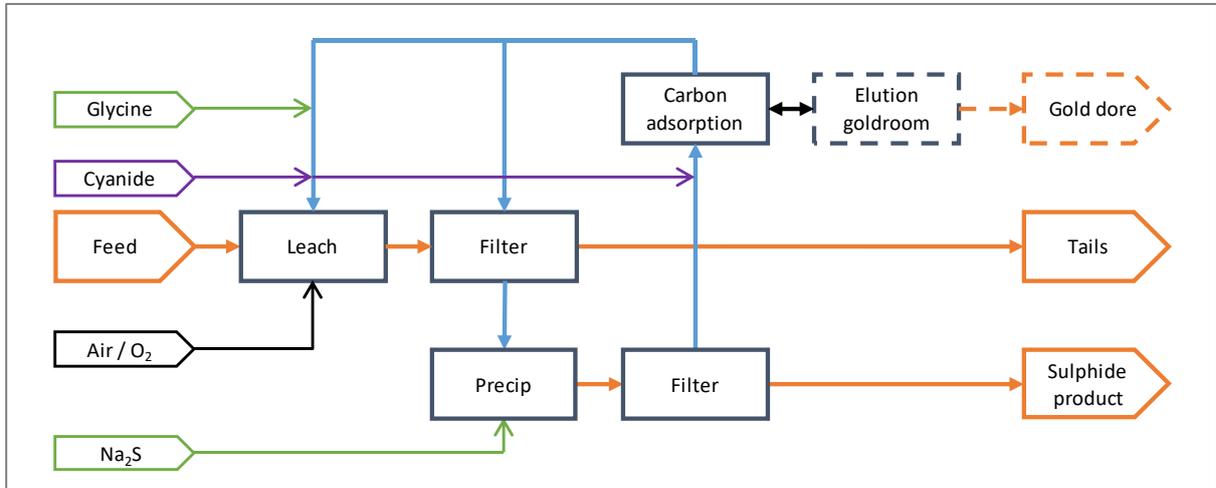


Figure 5 – Circuit with copper sulphide precipitation

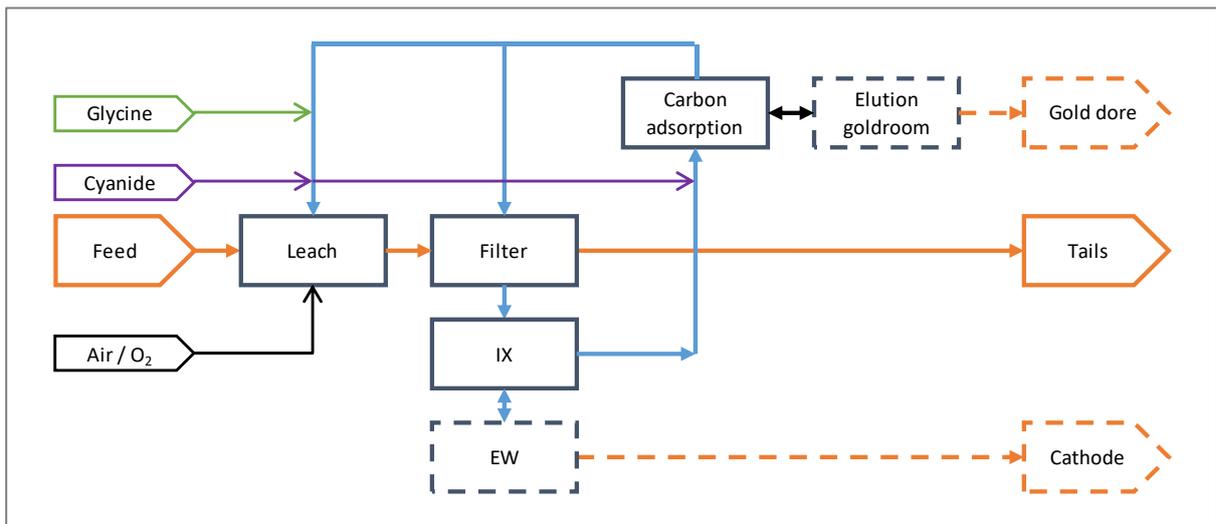


Figure 6 – Circuit with copper ion exchange

Operating conditions for the pilot plant are summarized in Table 3.

Table 3: Pilot plant operating conditions.

Feed rate (dry solids)	kg/h	4.0
Feed rate (slurry)	L/h	7.2
Leach solids content	%	40
Leach pH		10.5
Leach dissolved oxygen (DO)		
Tanks 1 & 2	ppm	8-12
Tanks 3 – 6	ppm	6-10
Leach temperature	°C	35
Filter wash ratio	L/kg solids	0.8
PLS flow	L/h	10.8
Barren flow	L/h	10.8
Precipitation ORP (Ag/AgCl)	mV	-180

The pilot campaign demonstrated that the process can extract gold at a fraction of the cyanide consumption of conventional leaching in a single stage leach with the use of glycine for copper “management”. Specific findings are summarised below:

- Gold extraction kinetics were dependent on the feed blend for the samples tested, with the high sulphur concentrate showing much slower leaching than the low sulphur concentrate.
- Establishing and maintaining the Cu(II)/Cu(total) ratio was an important factor in the extraction of gold from the pilot plant feed. This ratio indicates whether the relative dosages of glycine and cyanide are suitable for the feed, as higher glycine dosages favor cupric production and higher cyanide dosages favor higher cuprous production. For this campaign, leach solutions were stabilized with 20-40% copper as cupric.
- Steady-state extraction and gold and copper recovery was achieved.
- Steady-state levels of ions in solution, however, was not achieved given the low reagent addition rate relative to circuit inventory, i.e. concentration of solutes such as thiocyanate were not observed to plateau in the recycle solution and there it was not possible to conclude where eventual concentrations of such solutes would need to be addressed using methods such as a bleed stream.
- Sulphide precipitation was successful in removing almost all Cu(II) from the PLS, with very low gold losses. Cu(I) passed through to the barren solution.
- The alternative ion exchange process similarly removed Cu(II) from PLS without extracting gold or Cu(I).
- Dosing a fraction of the cyanide ahead of the gold recovery circuit (carbon-in-columns) was effective in minimizing/eliminating copper-cyanide species from being adsorbed onto the carbon in favor of gold.
- Gold adsorption in the carbon column was close to 100%, with barren assays mostly below detection limit when cyanide management of Cu(I) species was effective.

Operating results are presented in Table 4.

Table 4: Pilot plant operating results

Operating period		1	2	3	Overall
Feed concentrate	Units	Low-sulphur	High-sulphur	Blend	
Duration	h	71	247	149	471
Concentrate feed	kg	265.0	987.8	593.2	1,846
Concentrate blend					
High sulphur	%	0	100	40	
Low sulphur	%	100	0	60	
Feed composition					
Gold (calc head)	ppm	6.4	11.9	12.2	
Copper (calc head)	%	1.51	1.82	1.87	
Sulphur	%	8.0	36.2	20.0	
Gold recovery – average	%	74.8	74.1	80.7	
Gold recovery – peak period	%	87.8	-	83.0	
Cyanide consumption	kg/t				5.7
Glycine consumption	kg/t				2.6

A number of plant issues compounded to cause erratic gold recovery with average values lower than expected. In particular, the slower leach kinetics of the high sulphur sample meant that leach residence time was critical. Average residence time was lower than intended, with one tank being taken off-line for part of the trial and some degree of short-circuiting suspected due to the tank downcomer arrangement.

Furthermore, some carryover of fine carbon from the column was suspected of causing preg-robbing conditions in leach. This could not be proved conclusively, but immediate decreases in recovery were observed on both occasions following the change out of carbon to fresh carbon and recovery was seen to improve when the third batch of fresh carbon where fine carbon was washed out prior to re-loading the carbon column.

There was also evidence of poor wash efficiency in the residue filter. Further work will include assessment of resin-in-pulp to avoid relying too heavily on filtration for gold recovery.

Batch leach tests on the pilot residue showed that the remaining gold was 6% washable and 60% leachable, given a further 24 h batch leach. An overall extraction of around 90% is considered achievable on the blended sample, given sufficient residence time.

Copper extraction was below 10% for the entire duration as was expected from the bench-scale testing.

CIRCUIT CONFIGURATIONS

A number of alternative circuit configurations were considered prior to settling on the pilot design.

The simplest configuration simply introduces glycine to a conventional cyanidation/CIP circuit, with no residue filtration or reagent recycle. This option offers the lowest capital cost. The main drawbacks of this approach are the cupric copper loading on the carbon and the higher glycine cost in the absence of recycle.

The preferred option, a single stage leach with barren recycle that was piloted offers was considered to be a good compromise of capital and operating costs. It was also considered to be the lowest risk option given that higher reagent dosages are viable thus making the performance more insular to changes in the leach feed. The pilot highlighted that further refinement of this option is required in order to maximise gold recovery and protect against losses such as those incurred via PLS entrainment into the filter cake. Further work is in progress evaluating the use of resins for this purpose.

One other alternative approach was considered that involved two-stage leaching, whereby copper is targeted for removal in the first stage followed by a solid-liquid separation step. The copper-rich PLS is directed to a copper recovery circuit and the copper-depleted solids are re-pulped and directed to gold extraction using either convention cyanidation leaching or much lower glycine GlyCat™ leach. This option was not pursued as it adds complexity and capital and potentially operating cost to the process. This option could be revisited if leach concentrates of substantially higher soluble copper are proposed for treatment and added value in the copper recovery warrants the added cost and complexity.

OPERATING COST SAVINGS

It is not the intention of this paper to present a comprehensive economic evaluation. The intention is merely to highlight changes to reagent dosages and the costs incurred as a result of these changes when making the comparison between a typical cyanidation options with the GlyCat™ option piloted.

A high-level comparison of reagent costs is presented below. It is assumed that oxygen and lime consumption are essentially the same for the two alternatives.

Table 5: Key operating cost comparison

	Cyanidation	GlyCat™	Unit price	Cost saving
	kg/t	kg/t	A\$/t	A\$/t con
Cyanide	56	5.7	3,862	194.26
Glycine	-	2.6	2,800	-7.28
Sodium sulphide	-	2.5	597	-1.49
Copper (credit, as CuS)	-	2.0	8,000	16.00
Total				201.49

Other costs for consideration include the additional equipment required in order to implement this option, which in this particular case included:

- Solid-liquid separation equipment ahead of the leaching circuit,
- Additional tankage to achieve a minimum 48-hour residence time,
- Solid-liquid separation (i.e. filtration) if the piloted option were carried forward,
- Carbon-in-columns, again only if the piloted option were carried forward.

The existing SART circuit could be converted to an alkaline copper sulphide precipitation circuit thus presenting some capital savings.

CONCLUSIONS

The piloting experience that was presented in this paper allowed for the following conclusions to be drawn:

- GlyCat™ technology offers an opportunity for the development of a process that could ultimately be implemented at industrial scale.
- Substantially higher copper concentrations (~2% Cu) in cyanidation leach feed may be tolerated with no substantial loss to gold extraction or increase in cyanide dosage if converted to the GlyCat™ process that is being developed.
- More work is required to develop a more robust method for maximizing gold recovery from Telfer ore i.e. resins.
 - Resin testwork at bench scale is on-going and early results show this to be a promising alternative to filtration.
- A longer piloting campaign is required to achieve solution stability and ascertain the effect of the build up of solutes in the recirculating solution.
 - Accordingly, a follow-up piloting campaign is planned for execution at MPS/Curtin in June 2019. This pilot will be operated for 10 weeks and will be used to validate circuit modelling.

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