CYANIDE MANAGEMENT BY SART

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ABSTRACT

Telfer Gold Mine treats both gold/copper oxide and sulfide ores in a remote location in the Great Sandy Desert, Western Australia. Currently, the oxide gold ore is treated in a conventional CIL circuit by blending the low and high grade copper ores to minimize cyanide consumption and allow smooth operation. The sulfide ore is treated through a flotation circuit to produce pyrite and copper concentrates. The pyrite concentrate is treated in the CIL. Copper concentrate is stockpiled and sold to a smelter for further processing. In recent times, as the depth of the pit has increased the copper head grade has also increased, to the point where the ore was becoming uneconomical to treat. In addition, it was desirable to reduce the amount of cyanide reporting to the tails dam both from an environmental and economical viewpoint.

Newcrest Mining Limited engaged GRD Minproc Limited to evaluate a process to reduce the amount of cyanide entering the tail dam with consideration given to copper recovery. From this investigation, the Sulfidization, Acidification, Recycle and Thickening (SART) process was selected. A detailed testwork program for SART was undertaken with the objective to design and construct a SART plant at Telfer. This paper outlines how the SART process was chosen and summarises the testwork that led to the design of the SART plant. It also touches on some of the important issues for designing this type of process.

INTRODUCTION

The Telfer Gold Mine (Telfer) is owned and operated by Newcrest Mining Limited (Newcrest) in the remote Sandy Desert at the top end of Western Australia. Telfer was first discovered for its potential as a copper deposit. As exploration continued gold was also discovered in sufficient quantities to justify developing the site as a gold mine instead. In 1977 the gold recovery plant was built using the Merrill Crowe process which was converted to a conventional CIL circuit in 1986.

The majority of copper associated with the oxide gold ores exists as chalcocite, which is readily cyanide soluble. At the beginning of the project the cyanide soluble copper (CNSolCu) grades were very low and the impact on the cyanide consumption was minimal.

From late 1998 the CNSolCu levels began to steadily increase and pockets of high grade CNSolCu ores were discovered. These ores had a significant impact on the cyanide consumption and were stockpiled so they could be blended with lower grade CNSolCu ores to feed the plant.

Newcrest recognized that the low CNSolCu ores were depleting and from their experience with the high grade CNSolCu ores, knew they would not be economical to treat using the existing process. The plant would also be facing possible environmental problems at the tailings dam due to the increasing cyanide level in CIL tailings.

Newcrest contacted Minproc and requested them to review and comment on alternatives to reduce the impact of CNSolCu on the Telfer process. In this review, consideration was given to the use of existing equipment and occupational health and safety issues relating to cyanide regeneration.

After the evaluation of many processes, the SART route was selected as both copper and cyanide can be recovered and the operating and capital costs comparatively low. After conducting bench scale testwork, a pilot plant trial and feasibility study, the SART process was considered to be effective and economical. Thus, the SART plant was designed and successfully commissioned.

ORE PROCESSING AT TELFER

Telfer utilizes three different process routes to treat their ore and recover the gold. Undergound sulfide ores are crushed, milled and the sulfides concentrated in a flotation plant. Differential flotation is employed to separate the copper concentrate from the pyrite gold concentrate. Recovered copper concentrate is dewatered and the concentrate sold to a smelter for copper and gold credits. The pyrite concentrate is intensely cyanide leached and reports to the CIL circuit with the oxide ores to recover the gold.

Oxide ores are treated via two process routes. Lower gold grade oxide ores are processed through the heap leach operation and the higher gold grade ores are treated through the leach/CIL circuit. this circuit comprises crushing, milling, cyanide leach, CIL followed by cold elution, hot elution and electrowinning.

This discussion focuses on the leach/CIL circuit, where measures were in place to limit the impact of copper in the control of cyanide in the leach circuit:

- Blending of the high grade copper ores with the low grade copper ores to smooth the copper grade reporting to the plant.
- Cold elution of the loaded activated carbon to remove copper from the circuit.

These measures were acceptable initially when the CNSolCu grade to the CIL was <100 ppm in April 1998. However, the CNSolCu grade steadily increased and by mid 1998 some excursion to as high as 700 ppm CNColCu were experienced in the feed to the CIL. These excursions also resulted in increased cyanide levels reporting to the tailings dam.

In 1998 a mine schedule was produced for the Telfer ore body. This schedule predicted the oxide ore throughput and the CNSolCu feed grade to the CIL for the next three years (see Table 1).

Table 1 Telfer Treatment Schedule
CIL Feed Rate and Cyanide Soluble Copper Grades

YEAR	CIL FEED t/h	CIL FEED CNSolCu GRADE g/t
98/99	235	128
99/00	239	146
00/01	202	1418

It was already recognized that as the pit progressed the CnSolCu copper grades were increasing. However, the CNSolCu grade predicted for the third year was 10 fold higher than current levels. it would not be possible to treat this high grade CNSolCu ore economically using the current techniques and this would drastically reduce the life of the mine. In addition, if these ores were to be treated then environmental problems may result in the tailings dam.

PROCESS ALTERNATIVES AND SELECTION

Newcrest engaged Minproc to investigate process routes that would allow the high grade CNSolCu ores to be treated. Minproc evaluated the possible process routes and placed them in three broad categories:

- Opportunities - Technologies that have been evaluated on a bench scale.
- Established technologies - Technologies that have been implemented and are proven.
- Piloted technologies - Technologies that have been evaluated on a pilot scale.

These processes were evaluated using the following criteria:

- operating cost
- capital cost
- simplicity
- suitability for use
- safety
- level of risk

Those grouped under opportunities included membrane technologies and solvent extraction. These were rejected on the basis of high level of risk and potentially high operating and capital costs.

Established technologies included:

- Acidification and copper cyanide precipitation: Discounted due to high acid consumption and problems with the sale of copper cyanide precipitate.
- Sceresini process: Newcrest conducted laboratory evaluations and rejected this option due to high copper grades in the ore.
- Cyanide recovery process (CRP): The poly metallic product was considered difficult to market.
- Ammonia cyanide process: Cyanide regeneration and copper were not recoverable and ammonia was too expensive.
- Acidication, Volatilization and recovery (AVR): High reagent, operating and capital costs, problems with gypsum scale and increased occupational health issues were considered principal disadvantages.
- Cyanide destruction: Cyanide regeneration and copper recovery were not involved and operating costs were high.

Piloted technologies included:

- Augment®: Newcrest evaluated and rejected this option
- Ion exchange resins: resin operating and capital costs were too high
- Ion flotation: this was piloted Telfer in 1992 and retested in 1999 and in both instances was not successful.
- SART

This evaluation resulted in the process selection of the Sulfidization, Acidification, Recycle and Thickening (SART) process. This was particularly advantageous as the Telfer operation had four CCD thickeners (ex Merrill-Crowe plant) that could be used for washing the cyanide from the CIL tailings. It also has the heap leach operation to cope with a positive water balance, cyanide and copper are both recovered and the copper sulfide produced from the SART plant could be sold with the copper sulfide concentrate produced from the flotation plant.

SART PROCESS

SGS had evaluated the SART process, at pilot scale, for Teck Corporation for the Lobo-Marte project. Both copper and cyanide are recovered in the SART process. The copper-cyanide complexes are washed from the CIL tails slurry in a de-watering process. At telfer the existing CCD thickeners were employed for this duty. The solution containing the cyanide and copper from the de-watering process (CCD overflow at Telfer) is then fed to the SART plant where the copper cyanide complexes are converted to a copper sulfide precipitate and free cyanide as HCN by the addition of sulfuric acid and sodium hydrogen sulfide (NaSH).

The Acidification and Sulfidization reaction is presented below:

$$2\ Na_3Cu(CN)_4 + 3.5\ H_2So_4 + NaSH \rightarrow Cu_2S_{(s)} + 3.5\ Na_2SO_4 + HCN_{(aq)} \quad (1)$$

The resulting slurry, containing copper as copper sulfide precipitate and cyanide as HCN in solution, is fed to the SART thickener where they are separated. The thickened solids containing the copper sulfide can either be treated further to

produce copper metal or as in the case of Telfer, combined with the copper concentrate from the sulfide flotation plant. The thickener overflow containing the cyanide discharges to the neutralization tank where hydrated lime is added to convert the HCN in solution to $Ca(CN)_2$.

$2\ HCN_{(aq)} + Ca(OH)_2 \rightarrow Ca(CN)_2 + 2\ H_2O$ (2)

BATCH TESTWORK

Bench scale testwork was carried out in parallel at SGS in Canada and AMMTEC Ltd (AMMTEC) in Australia. This was to allow AMMTEC to gain experience in the SARTY process so the pilot plant trail could be conducted in Australia.

The aim of the batch testwork was to:

- establish consumptions of sulfuric acid, NaSH and lime
- determine the cyanide recovery efficiency
- investigate alternatives to sulfuric acid

Over 32 batch tests were performed by Lakefield and AMMTEC on samples with grades of approximately 100, 1000, 1500 and 2000 ppm copper. The effects of pH and NaSH addition on cyanide and copper recovery were also examined.

A summary of the findings of this testwork is presented below:

- Synthetic samples were generated from copper chloride for the original batch testwork. Reagent consumptions and copper and cyanide recoveries for these samples were very different from the solution obtained from leaching the Telfer ore.
- A pH of 5 was found to be sufficient to remove over 95% of the copper from solution and recover over 94% of the cyanide
- NaSH additions at 100% stoichiometric copper were sufficient to remove over 95% of the copper from solution when sulfuric acid was used to acidify the solution.
- NaSH addition was difficult to control as the concentration was difficult to measure.
- Acid consumption was 1.7-2.4 kg of 100% sulfuric acid/kg WAD cyanide to achieve a pH of 4-5.
- Lime consumption was only determined at pH 3 and ranged from 0.5-1.3 kg/kg WAD CN,
- The use H_2SO_3 as an alternative to sulfuric acid was not successful as over 5 times more copper remained in solution compared to the tests using sulfuric acid to modify the pH. It was thought that the H_2SO_3 reacted with the NaSH to form a complex with the copper preventing it from precipitating out from the solution. Using H_2SO_3 for pH adjustment was therefore not recommended.

Using the reagent consumptions from the batch testwork, and taking copper and cyanide credits into account preliminary operating costs were obtained for the SART plant. These preliminary figures demonstrated the SART process would be economical for Telfer and allowed the project to advance to pilot plant testwork.

PILOT PLANT TESTWORK AND PLANT DESIGN

The pilot plant testwork was performed at AMMTEC with assistance from Lakefield. The main objective of the pilot plant trial was to provide information for the engineering and design of a full scale SART plant. Minproc and Newcrest directed the pilot plant, focusing on the following operational parameters:

- determining the maximum operating pH for effective copper sulfide precipitation;
- degree of agitation at the copper sulfide precipitation stage;
- residence time for precipitation;
- thickening of the copper sulfide concentrate;
- gypsum formation in the neutralization stage and thickening;
- neutralization of the hydrogen cyanide solution, and
- reagent consumption.

Approximately a 1500 kr sample of ore was received by AMMTEC from the Telfer operation. The sample was crushed to <3mm and milled to a P_{80} of 120 µm in Telfer process water. The sample was then leached in >0.1% cyanide for 28 hours at 36 % solids and left to settle overnight. After settling overnight the solids had not settled sufficiently for the solution to be suitable for use in the pilot plant. The slurry was further diluted and allowed to resettle. After 24 hours of settling 1170 litres of solution was available for the trail with a copper grade of 980 ppm. The base metal grades in this solution were below 10 ppm. A schematic of the pilot plant is shown in Figure 1 with the same components as the full-scale plant.

Operating pH for acidification and sulfidisation

Four pH levels were examined in two separate trials. Copper and free CN levels in the neutralized effluent were monitored and the reagent usage noted to assess the tests.

The effect of pH is clearly illustrated in Figure 2.

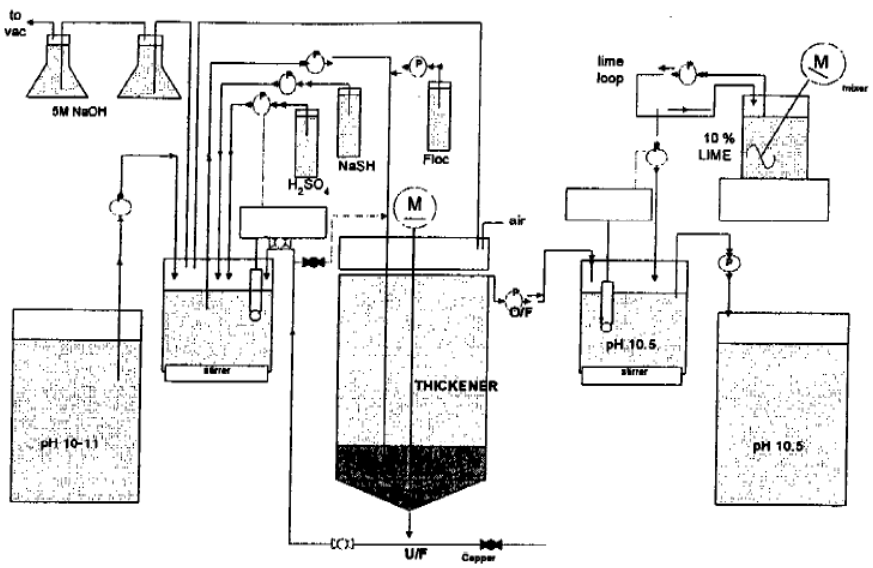

Figure 1 Pilot SART flowsheet (Supplied by Lakefield)

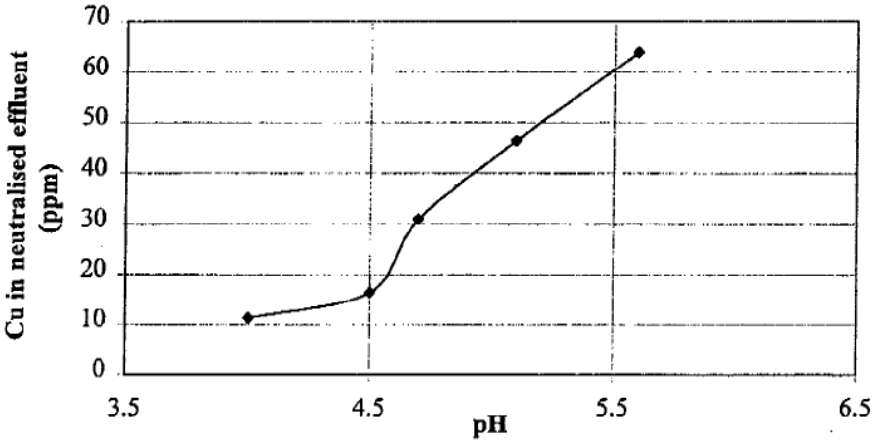

Figure 2 pH versus Copper Removal

Table 2 Effect of the NaSH addition to the SART process

FEED COPPER GRADE mg/l	NaSH ADDITION % STOICH.	NEUTRALIZED EFFLUENT	
		COPPER RECOVERY %	CYANIDE CONC ppm
1011	93	91.8	1750
1011	99	93.3	1780
1011	112	92.8	1770

Table 2 Effect of the NaSH addition to the SART process

FEED COPPER GRADE mg/l	RETENTION TIME (MINUTES)	NEUTRALIZED EFFLUENT	
		COPPER RECOVERY %	FREE CN RECOVERY %
1011	28	96.4	95.5
1011	15	97	93.2
1011	10	94.4	93

Residual copper values increase markedly with pH above 4.5. Residual cyanide levels were similar for all pH trials, raning from 1700 to 2000 ppm, and the effect of pH was not as apparent, possibly as the high cyanide concentrations masked the effect.

Reagent consumption

At the operating pH of 5 the acid and lime consumptions are reduced by 0.3 and 1.2 kg/kg Cu, respectively compared with the reagents consumption at pH 4. Whilst the acid savings are small, the lime savings are significant and both can contribute to lowering the operating costs. At the optimum pH opf 4.5 for copper recovery the lime consumption was 3.5 kg/kg Cu, 1.07 kg/kg Cu higher than at pH 5. the operating pH range for the plant was considered to be between 4.5 and 5. For the remainder of the testwork pH 5 was used.

A single trial, at pH 5, was conducted with the feed solution synthetically saturated with calcium and sulfate. The lime consumption for this test was 3.46 kg/kg Cu, whilst the trails at pH 5 without a saturated feed solution had an average lime consumption of 2.60 kg/kg Cu. For the full scale the SART overflow solution from the SART thickener would be saturated and therefore the higher lime consumption of 3.46 kg/kg Cu was anticipated.

The effect of varying NaSH addition stoichiometrically to copper was evaluated and the results presented in Table 2.

These test results indicate the copper recovery was not greatly affected by varying the NaSH additions. The cyanide recovery didn't appear to be affected either. During the test trials NaSH concentrations were difficult to establish. The NaSH may have been overdosed, explaining the lack of response of the copper recovery to NaSH addition.

To avoid forming thiocyanate in the plant NaSH addition at 95% of stoichiometry was considered appropriate in the full-scale plant.

Resident time

Nucleation reactor batch residence time (BRT) of 28, 15 and 10 minutes were tested at a pH of 5 with the following copper and cyanide recoveries shown in Table 3.

At the BRT of 28 and 15 minutes the copper recoveries were similar. At 10 minutes BRT the copper recovery dropped significantly from 97 to 94.4%. In comparison to the other trials, the copper recovery only dropped below 95% when the pH was either too high at 5.6 or the NaSH dose rate was too low at less than 90% stoichiometric.

Neutralized effluent free cyanide concentrations were similar indicating that cyanide recovery is not affected by residence time.

Due to the drop in copper recovery, fifteen minutes batch residence time was chosen for the SART plant to maximise the copper recovery. A single reactor was selected for the full-scale plant as per the pilot plant.

Nucleation reactor agitation

During the pilot plant campaign the acid and NaSH were dosed directly into the nucleation tank with the feed solution and therefore mixing efficiency was considered an important issue. To affect good mixing different agitation methods were trialed. The change in agitation method did not affect the pilot plant as the copper recoveries were greater then 94% irrespective of how the solution was agitated. Since chemical precipitates do not require a lot of energy to form, and high energy agitation may break up those that have formed, a standard aerofoil agitator would be used for suspension in the full scale nucleation tank.

To prevent localised pockets of reagents, it was decided that the NaSH and acid would be added via in-line mixers prior to the nucleation reactor on the full-scale plant.

Copper Sulfide Thickening/Clarification

It was important, at Telfer, to ensure that the SART copper sulfide thickener underflow density was at least greater than 10% solids as this slurry would be pumped to the existing flotation copper concentrate thickener. Too low a density from the SART thickener underflow to the flotation thickener would exceed its capacity as the copper sulfide concentrate from the flotation plant would also report to this thickener. Also at the lower density more free cyanide would report to the flotation thickener where it would:

- react with the copper sulfide and re-dissolve the precipitate as well as the flotation concentrate,
- enter the flotation circuit via the overflow from the [process water tank and suppress sulfide flotation completely; and
- be lost to the tails dam via the flotation tails and as SCN.

Supaflow and Consep both performed thickener testwork on a batch of copper sulfide precipitate that was produced from the solution generated for the pilot plant. Both vendors indicated that the maximum underflow density that could be achieved was between 2 and 4% w/w solids. These underflow densities were determined from Supaflo's dynamic rid and overnight settling tests performed by Consep and were lower than desired. However, both Supaflo and Consep commented that not enough precipitate was available to form a proper bed in the thickener/ measuring cylinder, which may be a contributing factor to the low underflow densities obtained.

Supaflo tested rise rates of 1.1, 2.4, 4.1 and 8.8 m/h in their dynamic rig. At the highest rise rate of 8.8 m/h a clarity of <20ppm was initially obtained but unfortunately the test was cut short due to lack of feed material. Visually the bed of solids was very fluidised and the clarity of the rising liquor within the thickener was deteriorating. Supaflo felt that had the test been run for a longer period, the clarity of the overflow would have been eventually deteriorated. Therefore they selected 4 m/h upflow velocity for design; corresponding to a 13.5 meter raked clarifier. At this upflow velocity Supaflo considered a flocculation addition of 2 g/m^3 of solution would be adequate.

Consep performed a settling test and using the Talmage and Fitch method calculated a solids settling rate of 16.29 m/h. Consep selected a 10 m/h rise rate for design to add a degree of safety and recommended a 9 meter diameter clarifier with a pinned bed to assist in achieving a good over clarity.

During the pilot plant trial copper sulfide thickener underflow densities of 20.6% solids were obtained after 5 days residence and 13.6% solids after 2 days residence in the thickener. From this it was concluded that the copper sulfide precipitate would consolidate provided it had sufficient sold to compress it. By operating a high bed level in the full scale plant thickener, an underflow density of 20% may achievable. The thickening device would therefore be designed to withstand an underflow density of 20% solids.

Provision would also be made in the full-scale plant re-circulate the copper sulfide from the SART thickener underflow back to the nucleation tank. This increases the thickener feed density so that flocculation is more effective.

Gypsum formation and Neutralization

Feed to the SART plant contains calcium due to the lime addition from the cyanidation process. When sulfuric acid is added, sulfate ions are introduced to the solution. Prior to acidification, the feed is not saturated with calcium sulfate due to the addition of the wash water. Once the sulfuric acid is added there is a sufficient concentration of sulfate ions for the solution to be saturated. Despite this there was very little evidence of gypsum formation in the nucleation tank of the pilot plant although some gypsum crystals could be seen in the copper sulfide precipitate.

During a pilot plant trial calcium and sulfate were added to saturate the feed solution prior to acidification. A significant increase in the amount of gypsum crystals was observed on the copper sulfide precipitate compared to the unsaturated solution. Scale formation on the sides of the nucleation and thickener tanks was not observed.

After the introduction of lime to neutralize the thickener overflow solution to a pH of 10 and recover the cyanide, gypsum precipitates were readily observed in solution. Gypsum crystals were also observed to rapidly grow on the sides of the neutralization tank used in the pilot plant trials. Crystal growth was expected to occur in the full scale plant, therefore a standby neutralization tank was provided to be interchanged with the duty tank. This would allow scale build up to be removed without shutting the plant down. The standby and neutralization tanks were given the same

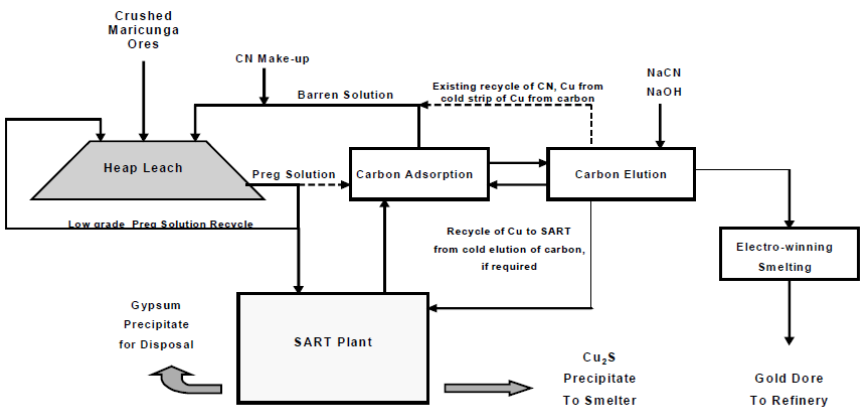

Figure 5 Maricunga Flowsheet with SART

volume as the nucleation tank so they could also be used as standby nucleation tank if needed.

Gypsum Thickening/ Clarification

Supalfo and Consep performed thickener testwork on the neutralization effluent that was generated from the pilot plant. Supaflo indicated that an underflow density of 19% solids could be achieved, whilst Consep were unable to establish an underflow density. A 19% solids density was considered adequate for the duty. At 20% solids, the addition of the gypsum thickener U/F to the tails hopper would increase the WAD CN levels in the tailings dam feed from 56 ppm to 61 ppm. It was anticipated that the gypsum thickener U/F density would be greater than 20%, and at 30% solids the combined gypsum thickener U/F and CIL tailing would have a WAD CN level of 58 ppm. Although these WAD CN levels in the tailings were acceptable, the gypsum thickener U/F would be disposed in the last stage CCD thickener to recover the majority of this cyanide.

Supaflo tested rise rates of 2, 4.2 and 6 m/h in their dynamic rig. Two tests were conducted at the rise rate of 2 m/h; one with recirculation of thickener underflow and one without. Without recirculation the overflow clarity was 85 ppm and with recirculation the clarity reduced < 5 ppm, therefore recirculation of the thickener underflow to thickener feed was recommended. At the rise rate of 6 m/h the overflow clarity rose to 10 ppm from <5 ppm at a rise rate of 4.2 m/h. At 10 ppm the overflow clarity was considered good and therefore Supaflo chose 6 m/h rise rate for design and recommended an 11 meter thickener/clarifier for the duty. At this rise rate flocculant addition of 1 g/m^3 of solution was considered adequate.

Using the Talmage and Fitch method, Consep established a gypsum settling rate of 13.03 m/h and selected a design rise rate of 10 m/h for design and recommended a 9 meter diameter pinned bed clarifier.

The Supaflo thickener was significantly cheaper than the Consep clarifier and was selected.

Provision for recycling thickener underflow to the neutralization tank via the in-line mixer was recommended to help form larger nuclei and increase the thickener feed density to assist in settling and consolidation in the thickener.

OTHER CONSIDERATIONS

Safety and control

The new SART plant was classified as a hazardous area as it would be treating cyanide contaminated water in a low pH environment. Therefore the plant was located away from the main plant and was designed to operate without continual operator attention.

To affect this philosophy the plant was heavily automated an in particular attention was paid to automatic NaSH addition. NaSH addition was important, at too low a dosage copper would be recirculated back to the process and would consume additional reagents. Over dosing of NaSH causes three problems:

- excess S ion reacting with cyanide form thiocyanate, which contributes to cyanide losses.
- highly toxic hydrogen sulfide gas can readily form.
- NaSH is wasted.

To assist with NaSH metering, on-line copper analysis was considered. An UV instrument was selected to detect copper cyanide complexes. This method of analysis can also detect other metal cyanide complexes, such as iron cyanides but they were not expected to be present in high concentrations and their interference would be minimal, particularly as the copper cyanide complex concentrations would be so high.

Also the instrument could only detect $Cu(CN)_3$ and $Cu(CN)_4$, and would rely on all the copper to be present in these forms. Since excessive cyanide would be added in the CIL to ensure good gold recovery this would not be an issue.

Water balance

As CCD thickener would be employed to recover the cyanide and copper from the CIL tailings a positive water balance would be generated due to wash water addition. This wash water would manifest as discharge from the SART plant; containing the recovered cyanide. At Telfer the excess water would be disposed off in the dump leach circuit where both the water and cyanide could be used.

Whilst Telfer are able to cope with the excess water through a dump leach operation, techniques can be applied so that positive water balance is not created e.g. the use of belt filters to recover the cyanide copper from the CIL tailings. Whilst employing these techniques increase the application to those operation who do not have dump leach the capital costs may increase.

Operating economics

At Telfer the SART process could be easily justified as the copper feed grade was high and the majority of cyanide was present as WAD CN. At the proposed treatment rate of 250 t/h and a CNSolCU grade of 1000 g/t, 5.4 t/d of copper and 2.5 t/d of cyanide would be recovered and less than 50 ppm WAD CN would report to the tails dam. By operating the SART plant and only considering reagent addition, power and labor cost and copper and cyanide credits the treatment costs were expected to drop by 35%.

The SART plant, comprised three reactors, two thickeners, associated equipment and instrumentation was estimated to cost AUS$4.8 M including designing and building. Refurbishment of the CCD thickeners is excluded from this cost. Including the refurbishment the project had a pay back period of less than a year.

CONCLUSION

Batch and pilot testwork demonstrated that the SART process would be technically suitable for recovering both copper and cyanide from the CIL tails at the Telfer operation and that it would be economical.

In addition, the process would be easily retrofitted to the existing plant by using the existing CCD circuit to wash to recover the copper and cyanide from the CIL tailings. Excess water would be

easily disposed at the heap leach.

Cyanide and copper recovery using a CCD circuit has limited application for other operations because of the positive water balance. To address the water balance issue for sites without a heap leach operation, techniques can be applied to reduce the water required but these increase the capital costs.

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