Optimising the Telfer Pyrite Regrind Circuit – Effect of Dissolved Oxygen Demand

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ABSTRACT

The Telfer processing plant commissioned its pyrite regrind and flotation circuit in August 2012. The circuit was designed to regrind pyrite concentrate to a p80 of <30 µm then float a gold and copper rich concentrate before tails from the flotation circuit fed the carbon-in-leach (CIL) circuit downstream. Expected benefits were: improved CIL performance that would result from the finer grind and a reduction in cyanide soluble copper to the CIL circuit, as well as a small increase in overall flotation circuit recovery. While the benefits of a finer grind were soon realised, recovery in the post-regrind flotation circuit (named the 'pyrite recleaner circuit') was consistently and significantly lower than that expected based on laboratory test work. Selectivity in the pyrite recleaner circuit was virtually nil and copper reporting to the CIL circuit did not change as a result of the pyrite recleaner circuit operation.

A pulp chemistry survey of the plant and comparison with the lab showed that the dissolved oxygen (DO) demand in the plant was much higher than that in the lab. Lab flotation tests conducted using nitrogen gas instead of air resulted in recoveries similar to those from the plant. It was identified that the freshly ground pyrite surfaces exiting the regrind mill were consuming oxygen in the slurry and there was insufficient oxygen available for collector adsorption and pyrite depression to occur. Test work, using a pilot regrind mill, showed that a reduction in grind size resulted in an increase in DO demand.

A range of oxidising agents were tested in the laboratory and using a pilot flotation rig set-up in the plant. Oxygen was found to be the most reliable and effective agent and options for increasing oxygen delivery to the plant were explored. Scale-up from the lab oxygen requirement to the plant is difficult and efforts to implement a permanent solution for meeting the DO demand in the plant are ongoing.

INTRODUCTION

The current Telfer processing plant was commissioned in 2004 and comprises two near-identical milling and flotation circuits, named 'Train 1' and 'Train 2'. The plant treats ~22 Mt/a and is fed ore from two open pit mines, named Main Dome and West Dome, and an underground mine. Gold is recovered via gravity separation, copper flotation and carbon-in-leach (CIL). A portion of the primary cyclone underflow stream feeds Falcon gravity units and Knelson gravity concentrators are fed by flash flotation rougher concentrate. They are located in the grinding building. Primary cyclone overflow reports to the copper roughers, which is the first stage of the sequential flotation process. Concentrate from the copper roughers is upgraded to produce a gold bearing copper concentrate. Tails from the copper roughers are fed to the second stage of the sequential float, the pyrite roughers. Concentrate from the two pyrite rougher trains is combined and upgraded in the pyrite cleaning circuit. Historically, pyrite cleaner concentrate was deslimed and then directed to the CIL circuit. In 2012, a pyrite regrind and flotation circuit was installed ahead of the CIL circuit as described by Seaman *et al* (2012). Figure 1 shows the Telfer processing plant flow sheet in 2016.

Pyrite concentrate is now treated through the M5000 IsaMill™, at 30–90 t/h, with the option to feed the M3000 IsaMill™ when throughput is below 30 t/h. When pyrite concentrate production is greater than 90 t/h, both the M5000 and M3000 are utilised in parallel and the M3000 product reports to the M5000 discharge hopper. If pyrite production is greater than ~120 t/h the additional material bypasses the

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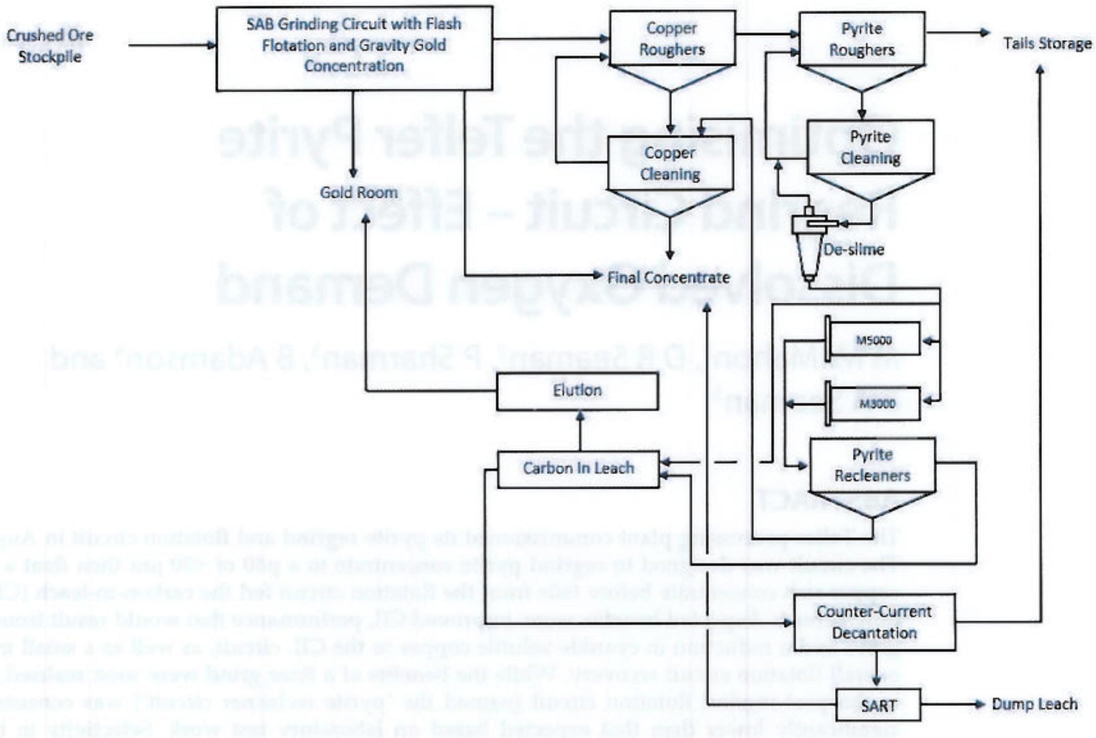

FIG 1 – Simplified Telfer processing plant flow sheet.

regrind stage and is fed directly to CIL. Pyrite regrind product is pumped from the M5000 discharge hopper to the feed box for a single stage flotation circuit consisting of five OK-30 tank cells. The post-regrind flotation circuit is named the pyrite recleaner circuit.

Lime and cyanide are added to the M5000 discharge hopper, to depress pyrite, and RTD11 A (collector) and DSF004 (frother) are added to the pyrite recleaner feed box. An Aachen Reactor has been installed on the discharge of a pump that recirculates slurry from the M5000 discharge hopper. Compressed air is fed to the Aachen Reactor to oxidise the reground pyrite concentrate. The Aachen Reactor was installed as a result of the test work discussed in this paper.

Burns *et al* (2013) concluded that regrinding CIL feed to a p80 of 25 µm would increase CIL gold recovery but the corresponding increase in cyanide consumption, required to recover the liberated gold as well as liberated cyanide soluble copper, would offset the benefit of improved gold recovery. The purpose of the installed pyrite recleaner circuit is to recover the liberated copper minerals prior to CIL. Test work indicated that gold and copper recoveries of 50–75 per cent would be achievable (Seaman *et al,* 2012) in the pyrite recleaner circuit. In the six months following commissioning of the pyrite regrind circuit, overall recovery of gold from pyrite concentrate was in line with that expected from the development study (Burns *et al,* 2014); however, copper and gold recovery in the pyrite recleaner stage is closer to 30 per cent. There is therefore opportunity to increase gold and copper recovery in the pyrite recleaner circuit, with the expected result being a decrease in cyanide consumption and cost in CIL. This paper discusses the investigation into the difference between actual pyrite recleaner gold and copper recoveries and those expected based on laboratory test work.

The pyrite concentrate feeding the regrind circuit at Telfer contains approximately 40 per cent sulfur, 0.2 per cent copper and 4 g/t gold. Mineralogically, this equates to approximately 60 per cent pyrite, five per cent copper sulfides and 35 per cent non-sulfide gangue. The majority of the gold in the regrind discharge is deported between fine liberated free grains of native gold (~50 per cent) and small non-refractory inclusions in the pyrite grains.

INVESTIGATION

Routine batch flotation tests were conducted to measure the difference between plant and laboratory flotation recoveries and identify opportunities for improvement. The batch flotation procedure is as follows: sample was collected from the pump discharge of the M5000 discharge hopper, raw water was added to achieve a target density of 20 per cent and the slurry mixture was added to a 5L Essa flotation machine. Lime was added, to target a pH of 11 and the mixture was conditioned for one minute. RTD 11A and DSF004 were added at 50 g/t and 10 g/t respectively. After one minute conditioning, air was turned on at a rate of ~7 L/min and a bulk concentrate was collected over a five minute period, with concentrate scraped every ten seconds. Air addition was increased throughout the test to maintain a consistent rate of froth recovery. Concentrate and tails from the test were pressure filtered, oven dried and sent to the Telfer assay laboratory to assay for gold, copper, sulfur and iron.

The plant consistently underperformed when compared with laboratory flotation tests. Of particular note was the low selectivity in the plant, with metal recovery being directly proportional to mass recovery at a ratio of 1:1.

While conducting the daily tests, a number of initiatives were implemented in the plant in an attempt to improve recovery. The diameter of the froth crowders was increased, a control loop was introduced to maintain a consistent mass pull from the cells and an alternative frother was trialled. There was an improvement in circuit stability with the installation of the new froth crowders and mass pull control loop but the selectivity between copper minerals and liberated gold against pyrite did not increase as a result.

To better understand the poor plant performance, electrochemical measurements were taken throughout the batch flotation test and in each of the pyrite recleaner flotation cells. Results showed a clear difference in dissolved oxygen concentration in the plant measurements when compared to those from the laboratory. Dissolved oxygen concentration in the plant was below 2 ppm, indicating the plant was essentially oxygen starved. The observed plant selectivity was simulated in the laboratory when the batch flotation test was performed using nitrogen gas instead of air.

At this point, a workshop was arranged and attended by Newcrest personnel and external specialists in the field of electrochemistry of flotation. Knowledge transfer and brainstorming sessions helped to improve the Telfer metallurgy team's understanding of the importance of dissolved oxygen (DO) in flotation circuits and the concept of DO demand was introduced. DO demand refers to the rate at which oxygen is consumed by the slurry and is an indication of the rate of oxidation of a pulp (Grano, 2010).

Effect of dissolved oxygen demand on Au and Cu recovery

Fresh pyrite surfaces exiting the IsaMill™ oxidise rapidly, consuming oxygen in the system. Dissolved oxygen is required for the adsorption of thiol collectors onto valuable minerals, and also to depress pyrite from floating by the formation of a hydroxide layer. It is expected that until the demand for oxygen resulting from pyrite oxidation is satisfied, there will be insufficient oxygen in the system for collector attachment and selective flotation. The oxidation (and resulting depression) of pyrite will also assist with selectivity in the pyrite recleaner circuit, and will help to improve recovery of gold and copper. This is supported by Owusu *et al* (2014), who showed that the volume of air added prior to flotation of a reground pulp, containing a blend of chalcopyrite and pyrite, affected mineral recovery. Owusu *et al* (2014) found that an increase in the volume of air added resulted in an increase in chalcopyrite recovery (up to a maximum value, after which it decreased) and a decrease in pyrite recovery. To understand the rate of oxygen consumption in the IsaMill™ discharge pulp, DO demand tests were conducted on a number of M5000 discharge samples.

The method used to estimate DO demand utilised a TPS 90-FLMV unit and is adapted from Grano (2010). The procedure was altered for measurements in the field following advice from Dr Christopher Greet. The field procedure used is as follows: the DO probe was held 'bulb' up until the oxygen reading was greater than 5 ppm, the slurry sample was collected and the recorder started (recording measurements every two seconds for one minute). A couple of readings were taken while the DO probe was in air and then the probe was submerged in the sample and stirred gently until the recording period was finished. An exponential equation was fit to the first few data points (the initial rate of oxygen consumption) to determine the kla (rate constant) from the below equation (Owusu *et al*, 2014).

$$DO = DO_0 e^{-(kla \times t)}$$

Using this method, the plant DO demand was found to range from 10 ppm/min to 30 ppm/min. The DO demand appeared to increase with increasing amounts of West Dome material in the feed blend. This is expected based on the higher quantities of pyrite in West Dome compared to Main Dome material. This is supported by Owusu *et al* (2014), who showed that as the portion of pyrite in a pyrite-chalcopyrite mix increased, the DO demand of the mix also increased. Owusu *et al* (2013) concluded that the amount of oxygen required for optimum selectivity and recovery of chalcopyrite from pyrite will vary as the ratio of each mineral in the mix changes.

To understand the impact of reducing oxygen demand on metal recovery at Telfer, flotation tests with additional aeration time were conducted. In these tests, oxygen or air was added for the specified time and then flotation was conducted using nitrogen gas.

Figure 2 shows there was increased selectivity for all aeration tests when compared with the baseline test, which consisted of flotation using nitrogen gas without pre-aeration.

When metal recovery is plotted against the number of moles of oxygen delivered from the aeration tests with air and from aeration tests with oxygen, the recoveries are aligned. That is, based on the laboratory test work, the source of oxygen (when comparing air and pure oxygen) does not affect recovery; only the amount of oxygen supplied affects recovery.

To understand the rate at which oxygen demand is reduced, and the impact of DO demand on selectivity, laboratory

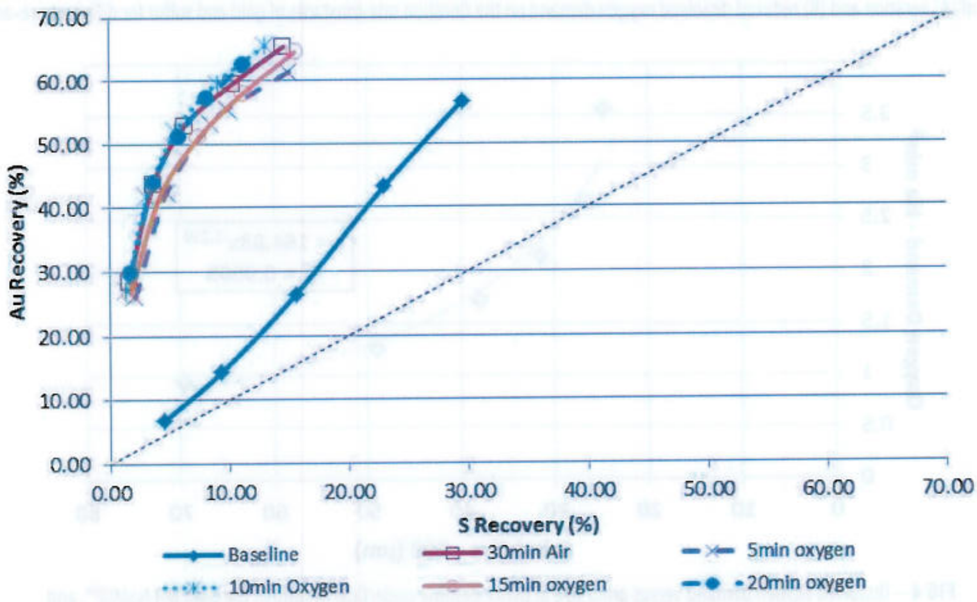

FIG 2 – Gold and sulfur recoveries from laboratory aeration tests comparing air and oxygen; Au/S selectivity.

flotation tests were conducted after varying degrees of aeration. The tests were conducted on discharge of an M4 pilot IsaMill™, which was being fed pyrite concentrate from Train 2 at the time. Figure 3 shows the recovery by aeration time and DO demand. In the laboratory tests, aeration with air for one minute was sufficient to improve selectivity and recovery in the flotation step.

Other factors affecting the DO demand and resulting selectivity were also investigated. Of importance, it was found that DO demand increased as the product grind size was decreased due to a resulting increase in the surface area of sulfide minerals liberated. Figure 4 was generated using a pilot IsaMill™ (M4) fed with unground slurry in the plant and the DO demand was measured after five minutes of aeration in a laboratory cell.

DEVELOPMENT AND IMPLEMENTATION OF A FULL SCALE SOLUTION

A series of laboratory and pilot investigations were carried out to identify practical methods of reducing the DO demand of the full scale circuit. A pilot flotation rig was operated on a bleed stream from the actual mill discharge. An investigation of using different liquid oxidants as well as gaseous oxygen and air sparging were compared. It was found in both laboratory and pilot test work that aeration of the slurry with either oxygen or air was the most reliable method of reducing DO demand and obtaining a significant improvement in selectivity.

Various methods were applied to estimate the full scale oxygen requirement based on the laboratory tests, and a series of plant trials were undertaken. The regrind circuit was originally installed with spargers in the discharge tank and had been operated on compressed air since installation.

Pure oxygen gas was selected for the plant trial instead of compressed air due to the estimated air requirements from previous test work. Oxygen was supplied in liquid form and was stored in a 12 000 m³ International Standards Organisation (ISO). The oxygen passed through a vaporiser prior to delivery to the plant via pipework that was installed for the trial. Two locations were ultimately selected for oxygen delivery to the plant:

1. inject oxygen through the hyperspargers, which were installed on the M5000 discharge hopper
2. inject oxygen into an Aachen Reactor that would be fed by a recirculating stream of slurry from the IsaMill™ discharge container hopper.

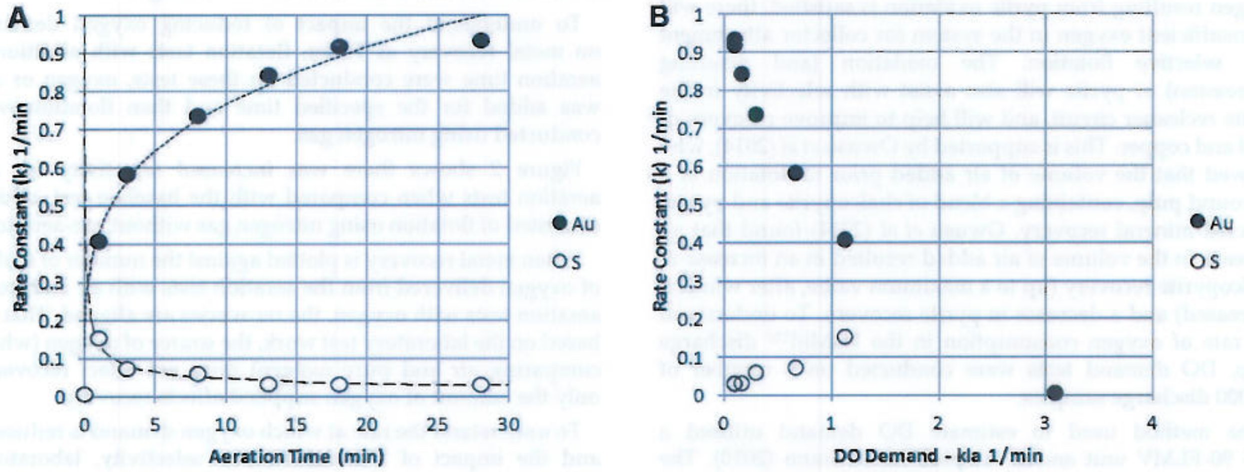

FIG 3 – Impact of (A) aeration and (B) reduced dissolved oxygen demand on the flotation rate constants of gold and sulfur for different pre-aeration times.

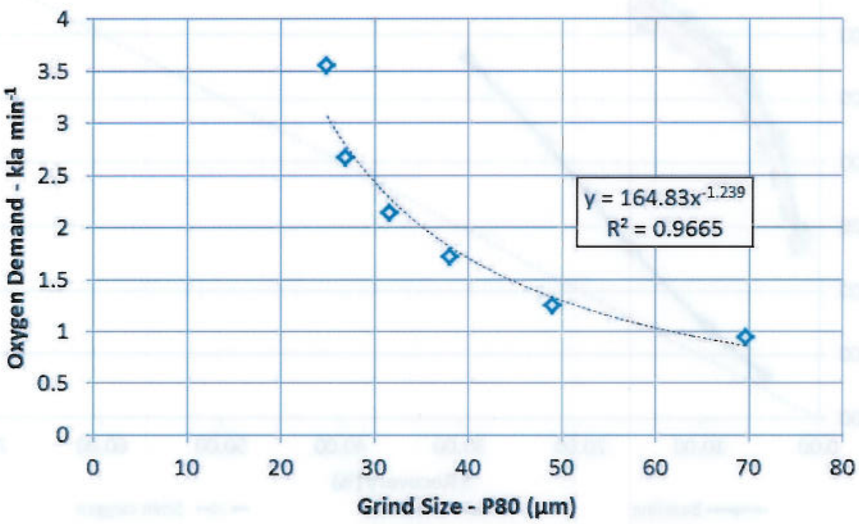

FIG 4 – Dissolved oxygen demand versus grind size of pyrite deslime underflow ground in the pilot M4 IsaMill™, and dissolved oxygen measured after five minutes aeration at 10 L/min in the laboratory flotation cell.

Oxygen injection through hyperspargers

Four hyperspargers had been installed on the M5000 discharge hopper and one on the feed line to the discharge hopper as discussed by Seaman *et al* (2012). The hypersparger nozzles were increased from 7.5 mm to 9 mm to allow delivery of ~280 Nm^3/h of gas through each hypersparger. During the plant trial, oxygen was delivered to two hyperspargers, both on the discharge hopper, and compressed air was delivered to the remaining three hyperspargers.

Three plant surveys were conducted with oxygen addition to the hyperspargers; however, no additional surveys were conducted due to failures that occurred to the stainless steel oxygen supply hoses.

Oxygen injection through Aachen Reactor

An Aachen Reactor was relocated from the CIL circuit to the regrind circuit. It was installed on the discharge line of a temporary skid mounted diesel pump. This installation allowed a recirculating stream of M5000 discharge to be oxygenated through the Aachen Reactor. Figure 5 illustrates the installation and Figure 6 shows photos of the installation at Telfer.

Results

Throughput during plant surveys ranged from 35–45 t/h and the plant feed was predominantly direct feed from the Main Dome open pit mine, direct feed from the underground mine and there were some periods of stockpiled ore treatment. No West Dome ore was available during the trial period. As West Dome material is higher in pyrite content than other feed sources, and based on the work by Owusu *et al* (2013), it is expected that the DO demand will increase when West Dome is included in the feed blend.

Following the success of oxygen injection through the Aachen Reactor, plant trials were also conducted with compressed air addition through the Aachen Reactor for comparison. Oxygen demand in the first pyrite recleaner cell was reduced from ~4 ppm/min to ~2 ppm/min when compressed air was added to the Aachen Reactor. No improvement in DO demand was evident with the addition of oxygen to the Aachen Reactor compared to the addition of air. The initial DO demand of 4 ppm/min is low compared to daily DO demand tests that were conducted during the early stages of the investigation. This could be a result of the Main Dome material in the feed blend during the trial.

The baseline surveys were generally in the line with plant operating data. Recoveries from two of the three surveys that involved oxygen injection through the hyperspargers were similar to those from baseline data. With consideration given to the copper recovery during the oxygen hypersparger trial, it was concluded that this configuration did not provide significant improvement in downstream pyrite recleaner flotation performance.

A regression on the data from the Aachen Reactor trial showed no statistical difference in gold or copper recovery when oxygen or compressed air was used. Figure 7 gold recovery regression comparison for aeration via the Aachen Reactor and the baseline shows the regression comparison for gold recovery. Both the regressions are significant with

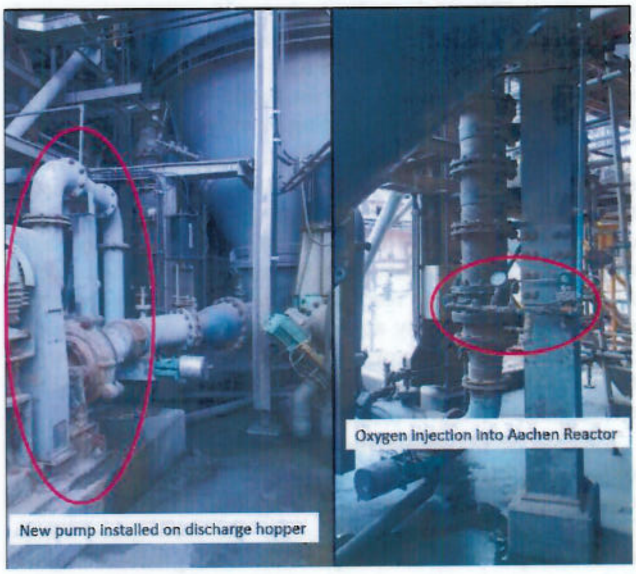

FIG 6 – Photos of Aachen Reactor installation at Telfer.

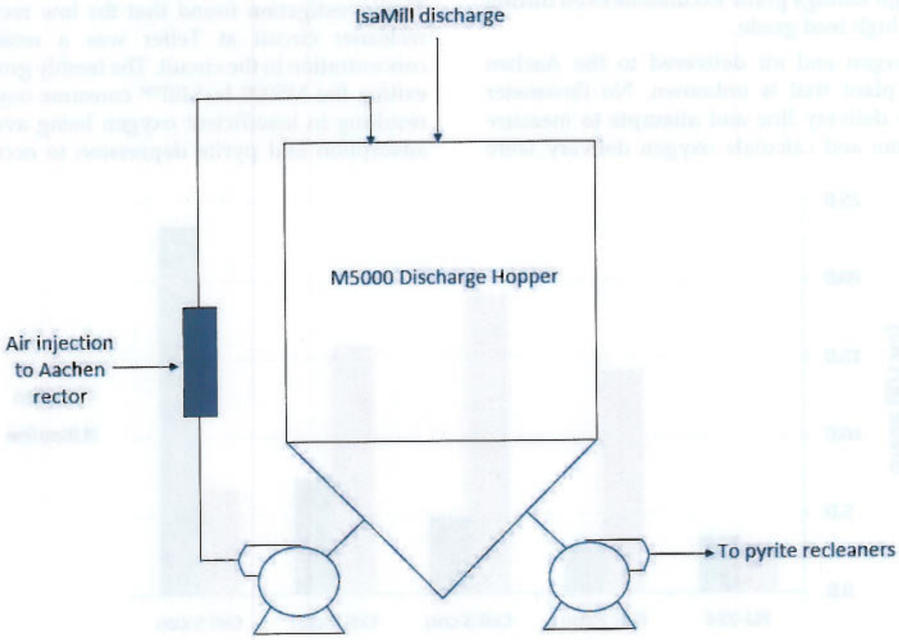

FIG 5 – Schematic of Aachen installation on M5000 IsaMill™ discharge hopper.

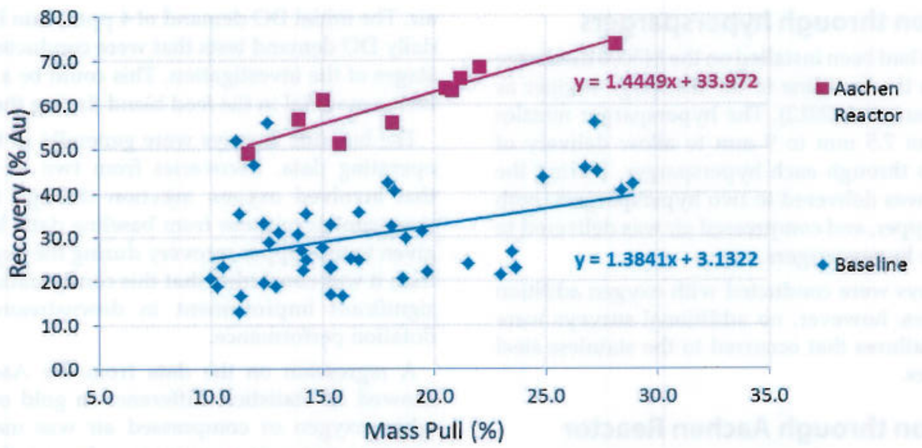

FIG 7 – Gold recovery regression comparison for aeration via the Aachen Reactor and the baseline.

>98 per cent confidence and there is not a statistical difference in gradient. The results indicate that gold recovery increased by 29 per cent when the Aachen Reactor was operating with either air or oxygen during the trial period. Similarly, results indicated that copper recovery increased by 35 per cent when the Aachen Reactor was operating on either air or oxygen.

Figure 8 shows a comparison of concentrate grades from the baseline and Aachen Reactor surveys. The graph indicates that when the Aachen Reactor is operated, higher grade concentrates are produced from the first two flotation cells and then grade decreases from the next two flotation cells – as per typical flotation responses. The baseline tests show the opposite: the selectivity appears to increase down the bank. This suggests flotation conditions are slow to improve during the baseline condition as the dissolved oxygen content of the slurry increases down the flotation bank.

Analysis of the pyrite recleaner tails showed that pyrite recleaner tail below 0.1 per cent copper was achieved when oxygen or air were injected through the Aachen Reactor. This tail grade was achieved over the feed grade range of 0.1–0.3 per cent Cu compared to tails grades of up to 0.18 per cent over the same feed range. This indicates that the pyrite recleaner circuit, when aerated sufficiently, will be less susceptible to high tailings grade excursions even during periods of relatively high feed grade.

The volume of oxygen and air delivered to the Aachen Reactor during the plant trial is unknown. No flowmeter was installed on the delivery line and attempts to measure change in ISO volume and calculate oxygen delivery were unsuccessful. Vendor advice indicates the Aachen can receive 14–35 Nm^3/h of gas injection.

Following the plant trials, the Aachen Reactor has been installed on a permanent recirculation pump on the M5000 discharge hopper, and is supplied with compressed air. When treating Main Dome material, the copper grade in pyrite recleaner tail is consistently below the economic cut-off grade for treatment in the CIL circuit. However, it is expected that the DO demand will increase with the increasing amount of West Dome material in the feed blend in the near future.

While the volume of oxygen required to satisfy the DO demand in the pyrite recleaner circuit when treating West Dome material is unknown, it was decided to proceed with connecting an oxygen line from an existing pressure swing adsorption (PSA) plant to the Aachen Reactor. When compared to other options available, this is low cost and can be implemented quickly. A flowmeter will be installed on the oxygen delivery line so the volume of oxygen added to the plant will be known, which will help to improve the understanding of oxygen requirements when treating West Dome pyrite in the regrind circuit.

CONCLUSIONS

The investigation found that the low recovery in the pyrite recleaner circuit at Telfer was a result of low oxygen concentration in the circuit. The freshly ground pyrite surfaces exiting the M5000 IsaMill™ consume oxygen in the system, resulting in insufficient oxygen being available for collector adsorption and pyrite depression to occur. Laboratory and

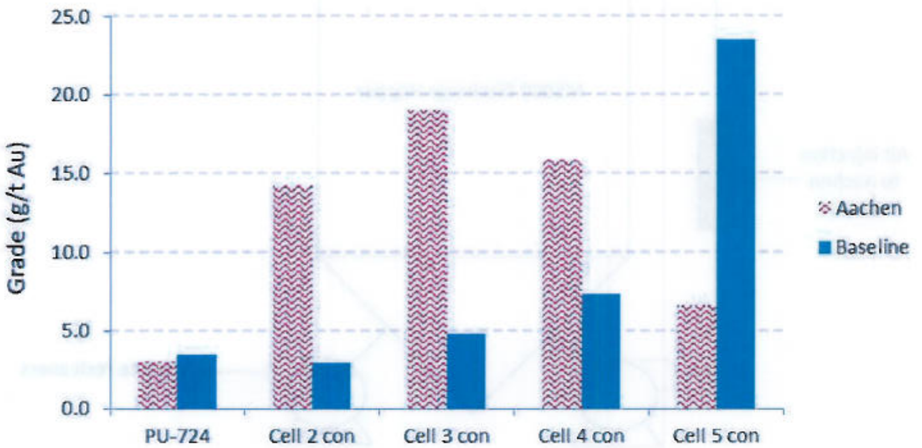

FIG 8 – Comparison of pyrite recleaner concentrate gold grades from baseline and Aachen Reactor surveys.

pilot test work showed that air or oxygen were the most effective methods of reducing the DO demand of the slurry and achieving an improvement in selectivity.

An Aachen Reactor was installed on the discharge of a pump that recirculates slurry from the M5000 discharge hopper. Compressed air is injected into the Aachen Reactor and as a result, when treating Main Dome material, the pyrite recleaner tail grade is consistently below the cut-off limit for economic CIL operation.

The next step is to inject oxygen from the existing PSA plant into the Aachen Reactor, in preparation for treating West Dome pyrite in the near future.

ACKNOWLEDGEMENTS

The authors acknowledge the permission of Newcrest Mining Limited to publish this work. Many people at Telfer gold mine were involved in the laboratory, pilot and plant test work and continue to assist with the final implementation steps. In particular, the authors would like to thank Nee San Yap and Varun Patel, from Gekko Systems for their efforts. A critical step in the project was the workshop held with external specialists. The authors would like to thank Dr Christopher Greet, Dr Max Zanin, Mr Michael Young, Dr Xumeng Chen and Mr John Tang for their assistance throughout the project.

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