Telfer Processing Plant Upgrade – The Implementation of Additional Cleaning Capacity and the Regrinding of Copper and Pyrite Concentrates

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ABSTRACT

The Telfer concentrator, located in the Great Sandy Desert of Western Australia, consists of a dual train gold/copper operation processing ore from one underground and, currently, two open pit mines with differing mineralogy. The flotation circuit of each train was designed to operate in several modes depending on the feed mineralogy. The majority of ore mined at Telfer is processed in a sequential mode where copper minerals are first floated into a saleable copper concentrate followed by the flotation of an auriferous pyrite concentrate which is treated in an on-site hydrometallurgical plant (carbon-in-leach (CIL)). Gold is recovered as a gravity product within the primary grinding circuit, to the copper concentrate, and to a lesser extent, the CIL circuit.

Since Telfer was re-opened, with a new concentrator, in 2004, the processing plant has struggled with poor copper concentrate grades, partially due to the excessive entrainment of non-sulfide gangue minerals in the copper flotation circuit and, more recently, due to composite copper particles produced when processing ore from a supplementary satellite pit that has not previously been processed through the new Telfer concentrator. Gold recoveries in the CIL circuit have also been below industry standard.

This paper presents the implementation of recent changes made to the circuit to address these performance issues. The reconfiguration of the circuit has involved the installation of the following major equipment items: two ISAMills™ in ultra-fine grinding applications (one in the copper circuit and one in the pyrite circuit), two Jameson Cells to improve fine gangue rejection and a bank of 5 × Outotec TC30s to recovery copper and gold from the reground pyrite stream. The equipment was purchased direct from vendors and an engineering firm contracted to design and install the multi-vendor reconfiguration upgrade.

INTRODUCTION

Telfer is a gold/copper operation located in the Pilbara region of Western Australia. Open pit mining (Main Dome) recommenced in 2003, followed by an underground mine (Telfer Deeps) in mid-2006. Copper deportment in the ore varies significantly from mainly chalcocite in the open pit ore to predominately chalcopyrite in the underground ore. In both ore sources, gold is present as free gold and granularly locked in copper sulfides and pyrite.

The ore processing plant consists of two parallel trains, Train 1 and Train 2, which are currently treating a total of 21 Mt/a. This includes approximately 6 Mt from the underground mine. Train 1 receives a blend of the underground and open pit ores, while Train 2 treats open pit ore alone. Details of the mine geological and ore mineralogical information, the initial process plant design criteria and operating strategies as well as a summary of the commissioning phase, can be found in previous publications by Goulsbra *et al* (2003) and Benson *et al* (2007).

Ore is processed through both trains in a variety of configurations. The predominant configuration is sequential flotation, where copper bearing minerals are recovered to a saleable copper concentrate, followed by re-activation and flotation of the pyrite, which is leached with cyanide to recover gold. Much of the free gold that is not recovered in the gravity stage during grinding is recovered to the copper concentrate.

More recently, Telfer has been processing ores from a secondary deposit, namely West Dome. Whereas, the Main Dome, Telfer's primary ore source, is generally well liberated following grinding to a nominal target P_{80} of 120 µm, the mineralogy of the West Dome ore differs significantly. In

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particular, the West Dome ore has a significantly higher sulfur content and the copper minerals tend to present as rimming around or veining through pyrite.

Zheng *et al* (2010) reported an initial change made to the Telfer processing plant to alleviate overloading of the Train 1 copper cleaner circuit and also presented the foundations of the reconfiguration that has taken place at the Telfer plant. This paper outlines three significant changes made to the processing plant over the last 12 months. These changes have been implemented in order to improve the metallurgical performance of the Telfer plant. These changes are summarised in Table 1.

TABLE 1

Telfer reconfiguration strategies to address different factors affecting plant performance.

Factor/opportunity	Process plant reconfiguration
High proportion of liberated, non-sulfide (non-value) gangue content in the copper concentrate stream preventing recovery of additional auriferous pyrite and gold containing composite particles	Cleaner scalper flotation – Two (E3432/8) Jameson cells in a cleaner-scalper configuration in front of the pre-existing two stage cleaning circuit
Poor copper concentrate grade when processing high proportions of supplementary, West Dome, ore – due to lower liberation of copper sulfides as compared to the primary ore source, Main Dome.	Copper regrind – A copper regrind mill and preclassification circuit for the regrinding of copper rougher concentrate (ISAMill M3000 – 1.1 MW)
Below industry standard recovery and high incremental operating cost of gold recovery from pyrite leach (carbon-in-leach) circuit.	Pyrite Regrind and Recleaning – A pyrite regrind mill and recleaner flotation cells to liberate and recover gold and copper from Pyrite concentrate prior to cyanidation. (ISAMill M 5000 – 1.5 MW plus 5 × Outotec 30m^3 tank cells with high shear stators).

Figure 1 and Figure 2 show the Telfer flow sheet pre- and post- the reconfigurations discussed in this article.

At the time of writing, the first modification (installation of Jameson cells as cleaner scalpers) had already been implemented and commissioned, with construction of the second two items well advanced and commissioning expected to take place within months of authoring this paper. Figure 3 shows a 3D model of the major equipment layout for the reconfiguration project. The equipment was kept to one area for ease of maintenance and also to minimise cost and disturbance to the running operation during construction and commissioning. The regrind mills share a common platform with a 10 t gantry crane overhead for ease of maintenance.

The major equipment was purchased directly from vendors by Newcrest Mining to reduce the time frame of the installation, and to allow a staged process of capital commitment during the project development phase. Process design and major equipment sizing was carried out by Newcrest Mining personnel (authors of this paper), and a third party engineering firm (GR Engineering Services Limited) was contracted under a lump sum EPC to complete the installation of the equipment. Xstrata Technology supplied a vendor package containing the pyrite regrind mill (the copper mill was purchased from a third party as a second-hand unused mill), the mill platform to support both mills, feed and discharge hoppers, media handling systems and all associated instrumentation and steel work. ISAMillTM technology was chosen for the regrind duty due to their proven energu efficiency and the inert grinding environment which prevents passivation of the sulphide surfaces (Pease *et al*, 2006). Several of the improvements outlined by Rule and de Waal (2011) were incorporated into the ISAMill configuration). Outotec supplied the flotation cells (5 × OT30s) used in the pyrite regrind circuit which have been fitted with Outotec's float force mechanism (Coleman and Rinne, 2011) as well as high shear stators (Bilney, MacKinnon and Kok, 2006) to optimise the hydrodynamic conditions for fine particle flotation.

The on-site construction period will total approximately 12 months by completion of all three stages, with initial equipment orders placed approximately six months prior to

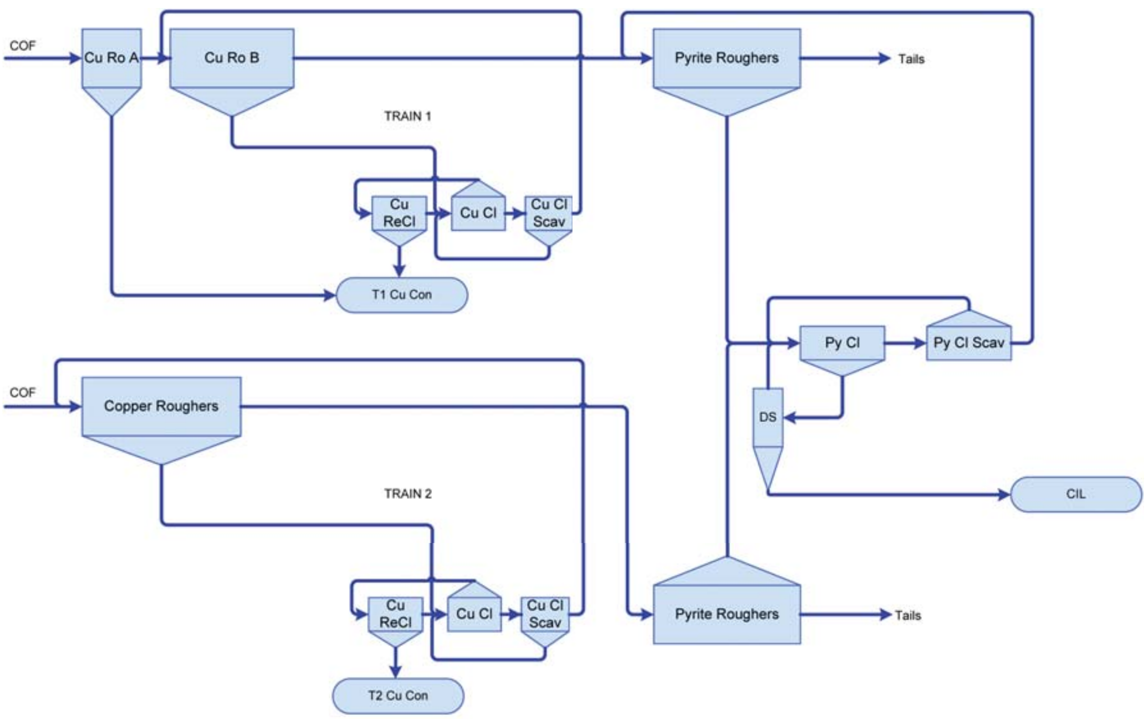

FIG 1 - Telfer flow sheet prereconfiguration outlined in this paper (note: grinding circuit containing gravity recovery and flash flotation not shown).

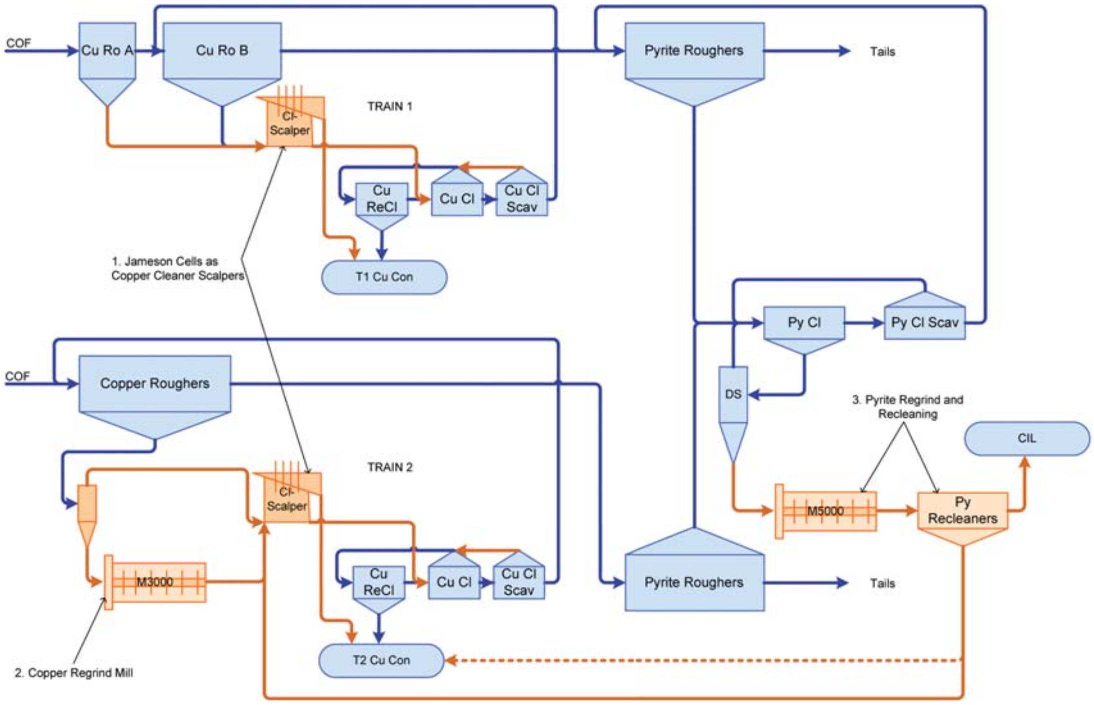

FIG 2 - Telfer flow sheet post-reconfiguration outlined in this paper, process changes shown in orange (note: grinding circuit containing gravity recovery and flash flotation not shown).

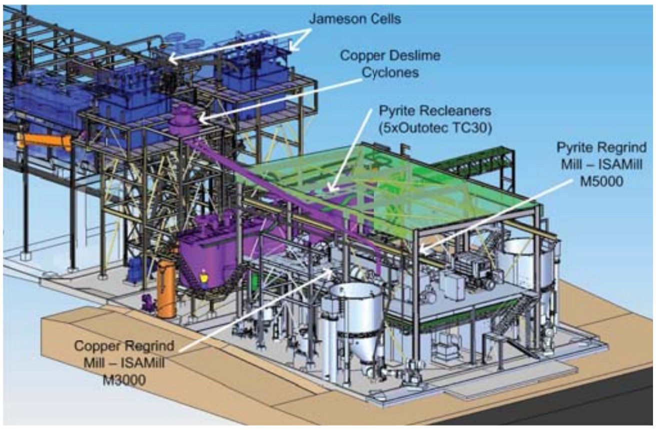

FIG 3 - Model of Telfer reconfiguration equipment layout.

construction commencement. The final capital approval for the entire reconfiguration project was granted in July 2011, and commissioning of all equipment is due to be completed by mid-August 2012.

Cleaner scalper flotation

Based on a review of historical copper concentrate data, Seaman, Manton and Griffin (2011) showed that a large portion of liberated, non-sulfide non-floating gangue material was being recovered to the copper concentrate via entrainment.

Zheng, Crawford and Manton (2009) presented details on how a reconfiguration of Train 1 was completed in 2009 to assist the rejection of some of this gangue and to debottleneck the cleaning circuit. While this modification was successful, further improvements were identified and implemented as described by Seaman, Manton and Griffin (2011).

The new Jameson cells installed in a cleaner scalper duty were commissioned in November 2011. Each Jameson cell was installed to allow gravity discharge of tailings and concentrate to the existing plant, which meant the cells were installed on a steel structure 15 m off the ground, with the recirculation pumps located on ground level for ease of maintenance. The additional cost of elevating the cells was offset by lower operating and maintenance costs than if tailings and concentrate pumps and hoppers had been required. The cells have eight downcomers each, and are each driven by a 75 kW Warman 10/8 pump with a recirculating slurry flow rate of approximately 700 m^3/h. The fresh feed rate to each Jameson cell is in the order of 175 - 350 m^3/h (or approximately 20 to 60 t/h solids). The washwater system was designed to achieve a flow rate of up to 100 m^3/h per cell.

Jameson cells described by Evans, Atkinson and Jameson (1995) are highly efficient flotation machines that require a smaller footprint than conventional mechanical flotation cells and enable the efficient use of froth washing to improve gangue rejection. A schematic figure of the latest Jameson cell technology was presented by Young *et al* (2006).

Figure 4 shows a photograph of the installation. This stage of the Telfer Reconfiguration Project was initiated in

FIG 4 - Photograph showing the installation of the Jameson (cleaner-scalpler) flotation cells at Telfer.

October 2010, major equipment order was placed in May 2011, and the cells were commissioned in November 2011.

Performance of cleaner-scalper flotation circuit

The benefit of the Jameson cell installation was derived from rejection of non-sulfide gangue allowing the recovery of slower floating valuable minerals (be they composites or liberated fines) and also the potential to replace liberated non-sulfide gangue with auriferous pyrite. Dilute batch flotation tests were conducted as part of the project development phase and the resulting selectivity curves used in a flotation model to predict the ultimate performance of the plant (Seaman, Manton and Griffin, 2011). It was assumed that a copper recovery of at least 50 per cent could be achieved across the Jameson cells.

Figure 5 shows the selectivity derived in the batch flotation tests compared with actual plant operating points generated from spot samples collected for four months following the Jameson cell commissioning.

It can be seen in Figure 5 that the actual operation of the Jameson cells matched the predicted test data reasonably well on Train 1, and with potentially poorer performance on Train 2 for the majority of the time. In addition, the stage recovery achieved by the cells, in most cases, well exceeds the expected 50 per cent metal recovery.

It is also clear from the operating data that at higher metal recoveries (over 80 per cent), the Jameson cells lose their selectivity. Thus, it is the ongoing focus of the Telfer operation to monitor and control this stage recovery below 80 per cent metal recovery.

Prior to installation of the Jameson cells, the copper recleaners were heavily loaded, and froth often built-up to a point where it would overflow the cells as shown in Figure 6. This phenomena has ceased since the Jameson cells have been commissioned as there is now much less floatable material reporting to the mechanical cells.

The Jameson cells themselves have proved to be fairly simple to operate, with little operator intervention required in terms changing operating conditions. Downcomer blockages are an ongoing problem with the cells, caused by scale in upstream pumps and tanks.

Assay by size

An assay-by- size survey and mass balance was conducted on the Train 2 cleaning circuit to investigate the performance of this circuit by size.

FIG 6 - Photograph of overloaded Train 2 reCleaners prior to Jameson cell installation.

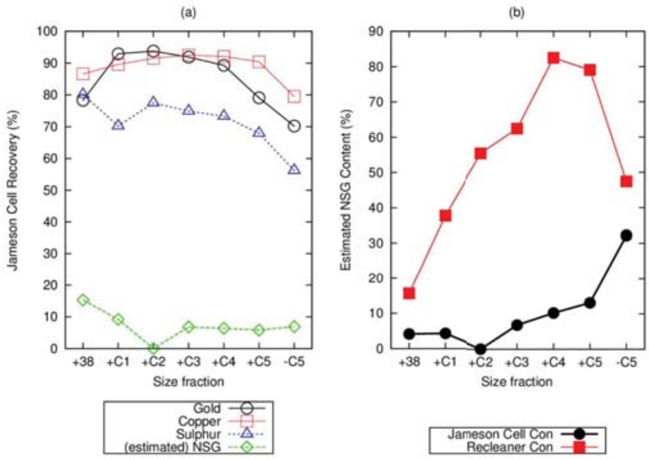

FIG 7 - Size by recovery across the Jameson cell and estimated non-sulfide gangue (NSG) content per size fraction of the Jameson cell concentrate and conventional Recleaner concentrate streams as a function of screen/cyclosize fraction (NSG, estimated from assay data).

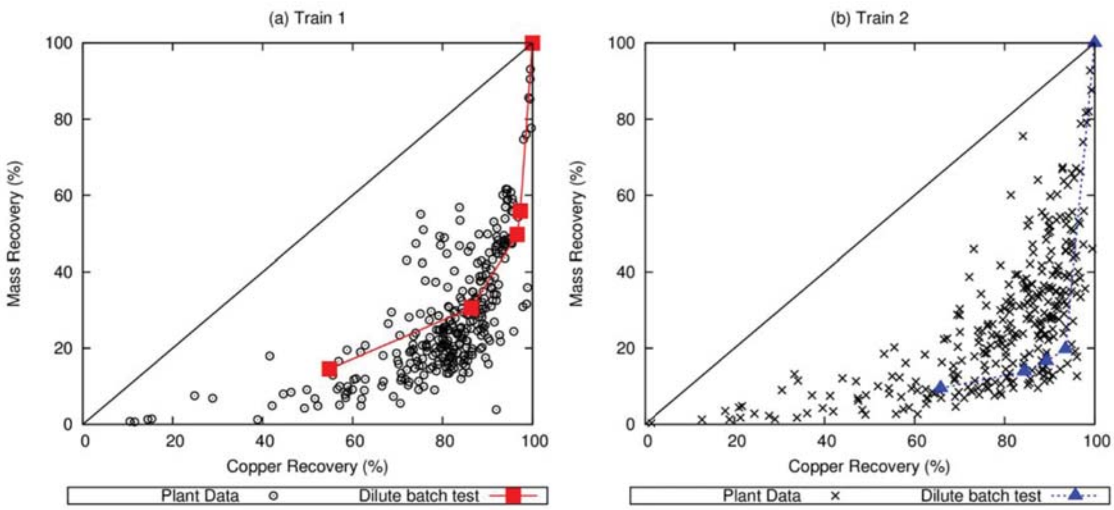

FIG 5 - Mass versus copper selectivity for (A) Train 1 and (B) Train 2. Comparison of spot data (Nov 2011 - March 2012) with dilute batch flotation tests conducted as part of the project development phase.

Figure 7 shows the recovery by size fraction of different elements across the Jameson cell as well as the gangue content by size fraction of the Jameson cell (cleaner-scalper) and (conventional) recleaner concentrate.

It can be seen that the valuable (gold and copper) recoveries across the Jameson cell are particularly good across all size fractions, with some drop off on the coarse and fine ends. The NSG content by size demonstrates that the Jameson cells are rejecting NSG far better than the mechanical recleaner cells due to the addition of wash-water in these cells. Trials of wash-water addition to the mechanical recleaner cells have demonstrated that further NSG rejection is possible. The permanent extension of wash water addition to these cells is expected to be completed within months of authoring this paper.

Cleaner block survey summary

Metallurgical surveys were conducted in the two month period leading up to the Jameson cell commissioning. The data collected was mass balanced and cleaner performance data for the surveys conducted are shown below in Table 2.

It can be seen that, prior to Jameson cell installation, the cleaner block performance is variable and averages below 90 per cent for both trains – copper and gold. The lower iron and sulfur recoveries are a result of deliberate pyrite rejection in the cleaning circuit.

Table 3 shows a summary of cleaner block recoveries determined post installation of the Jameson cells. Note that in the case of Train 1, the Ro Con A stream is now included in the cleaner block, where previously it by-passed the cleaner block.

Comparing the pre- and post- Jameson cell cleaner block performance, it is clear that the overall cleaner block performance has significantly improved, with gold and copper cleaner recoveries in excess of 95 per cent.

This improved cleaner block performance was also observed in the cleaner scavenger tail grades which have significantly reduced on both trains as shown in Table 4.

Two months of operating data before and after installation was analysed to determine the circuit recovery improvement resulting from the installation of the cells. After taking into account known factors that affected recovery during this time

TABLE 2

Pre-Jameson cell cleaner circuit survey results for T1 (Train 1) and T2 (Train 2)[a].

	Cleaner recovery				
	Mass	**Cu**	**Au**	**Fe**	**S**
	11.3	76.2	86.8	27.2	31.3
	31.9	90.3	89.0	50.7	46.7
	21.7	89.4	88.9	62.3	69.4
	24.1	93.2	94.6	57.6	74.1
Average T1	22.2	87.3	89.8	49.4	55.4
	26.7	50.0	80.1	51.5	61.6
	29.5	88.1	94.2	74.8	85.2
Average T2	28.1	69.0	87.2	63.1	73.4

a. Cleaner circuit block represented by copper rougher concentrate as feed, copper recleaner concentrate and copper cleaner scavenger tail as products.

TABLE 3

Post-Jameson cell cleaner circuit survey results.

	Cleaner recovery				
	Mass	**Cu**	**Au**	**Fe**	**S**
	89.5	99.5	99.6	98.2	95.4
	43.6	92.4	93.4	45.7	47.3
	25.1	95.2	95.3	55.0	57.3
	11.0	87.4		27.1	37.9
	26.7	95.3		47.2	55.7
	33.2	97.5		56.5	65.6
	20.8	95.3		37.5	48.0
	57.5	99.4		84.0	91.5
	64.0	99.6		84.2	93.0
Average T1	52.7	95.7	96.1	66.3	66.7
	68.6	94.3	97.2	82.6	90.0
	25.5	97.4	98.0	67.9	83.8
Average T2	47.0	95.8	97.6	75.3	86.9

TABLE 4

Copper and gold grades in Cl-Scav Tails before and after Jameson cell installation (two month daily composite average before and after circuit commissioning).

	% Cu in Cl scav tail		Au (g/t) in Cl scav tail	
	Train 1	Train 2	Train 1	Train 2
Before	0.46	0.46	2.00	2.79
After	0.39	0.31	1.78	1.38
Significance (%)	84	100	75	100

(feed grade, ore mineralogy, plant throughput, concentrate grade, etc), it was found that the cleaner scalper installation had a payback of between two and seven months.

Improving copper concentrate grade

Within the last 12 months Telfer has started supplementing its primary Main Dome ore source with West Dome ore while development work is being carried out in the Main Dome pit. Historical test work and plant trials have demonstrated that copper concentrate produced from West Dome ore typically does not achieve a suitable grade for sale. This is owing to a number of factors which include but are not limited to:

- higher pyrite content in West Dome ore
- copper mineralogy of West Dome is primarily as secondary copper sulfides (chalcocite, bornite etc) of smaller grain sizes than Main Dome copper sulfide minerals
- on average, the copper sulfide minerals are less liberated than in the Main Dome ore.

Limiting the quantity of West Dome ore in blend has overcome some of these limiting factors, however there have been, and will be in the future, times when the quantity of West Dome ore in feed exceeds the tolerable amount in blend.

Figure 8 presents a comparison between the Main Dome copper re-cleaner copper sulfide mineral liberation by free surface for Train 1 and Train 2 across two quarters (Q1 and Q2 – quarter 1 and 2 of FY2010 respectively) with West Dome laboratory re-cleaner copper sulfide mineral liberation. The comparison clearly demonstrates the poorer liberation of West Dome copper sulfides. This is supported by full-scale copper rougher concentrate liberation data included in Table 5. From the mineralogical studies conducted to date, it is known that the copper sulfide minerals most often occur in association with pyrite, either as veins within the pyrite minerals or as rims on the pyrite surface. Figure 9 shows two optical images, typical, of the copper mineral/pyrite association observed within the West Dome material.

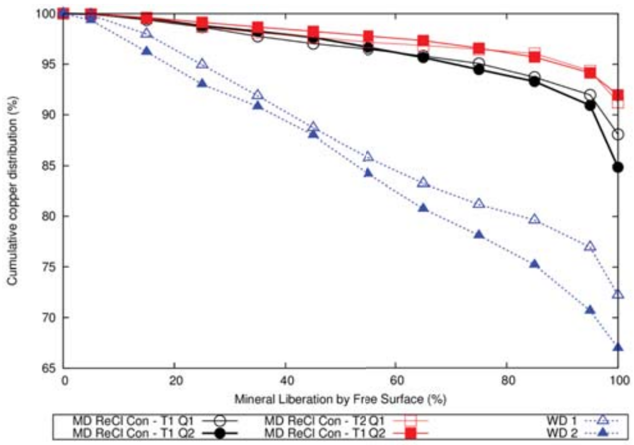

FIG 8 - Comparison of copper mineral liberation by free surface of Main Dome 2010 Q1 and Q2 copper re-cleaner concentrates on Train 2 and Train 2 (T1 and T2) and West Dome laboratory recleaner concentrates (WD 1 and WD 2).

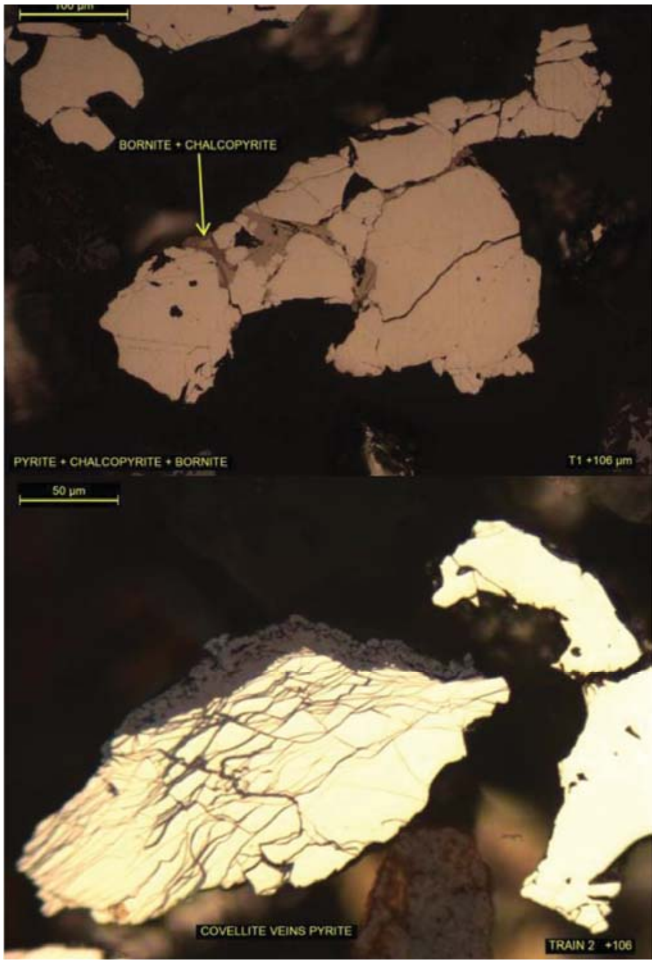

FIG 9 - Examples of copper sulfide inclusions in pyrite host particles.

TABLE 5

Liberation characteristics of West Dome copper rougher concentrate, collected during a plant trial.

Mineral	% liberated (>95%)
Pyrite	96.6
Chalcopyrite	69.8
Other copper sulfides	64.9
Other minerals	97.3

As a result of this liberation issue, it is not surprising that earlier attempts to improve copper concentrate grade via depression, selective collection or chelation (of copper activating ions in solution) have been largely unsuccessful.

Following some promising laboratory tests incorporating a regrind stage between copper roughing and cleaning, a pilot ISAMill™ M20 (see Figure 10) was operated at Telfer during

FIG 10 - Pilot ISAMill M20 used for both copper and pyrite regrind circuit development and scale-up.

a time when West Dome material was being processed. The pilot mill was batch fed with copper rougher concentrate, which was milled in the ISAMill before the ground product was floated in a laboratory flotation machine to investigate whether regrinding the copper rougher concentrate would improve the flotation selectivity between pyrite and the copper minerals. The pilot mill was also used to determine the full scale power requirement by determining signature plots of the copper rougher concentrate – Seaman *et al* (2007) show more detail on the pilot rig and grind determinations carried out at another operation.

Figure 11 shows the copper-sulfur selectivity of Train 2 copper rougher concentrate floated in the laboratory before and after regrinding in the pilot ISAMill™.

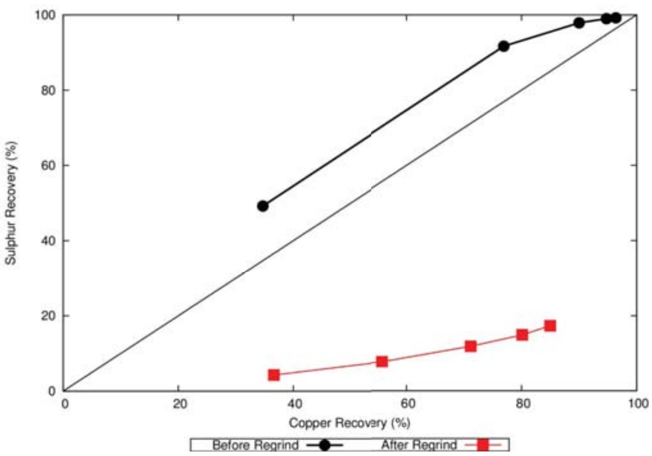

FIG 11 - Copper/sulfur selectivity with and without regrind on Train 2 copper rougher concentrate while processing West Dome ore.

Following regrinding in the pilot mill, the selectivity between copper and sulfur was greatly improved. The ground product had slower flotation kinetics than the unground product, which is likely to be related to the finer particle size of the mill discharge. In this case, the regrind feed and discharge P_{80}s were approximately 40 and 20 µm respectively.

On this basis, a regrind mill is currently being installed to grind the copper rougher concentrate on Train 2 when processing high proportions of West Dome ore at Telfer. The configuration of the ISAMill™ in the circuit is shown in Figure 2. Copper rougher concentrate will be fed to a cyclone cluster, the underflow will be reground in a 1 MW ISAMill™ M3000 operated in an open circuit. Cyclone overrflow will be gravity-fed to the mill discharge hopper and together with the mill discharge will be pumped to the existing cleaning circuit. A large discharge hopper with air-spargers will be installed to allow the oxidation state of the slurry to become suitably oxidised for flotation following the reducing conditions inside the ISAMill™.

Improving gold extraction from pyrite concentrate

Historically, carbon-in-leach (CIL) performance at Telfer has been below industry standard, currently averaging 75.2 per cent gold extraction from gold contained in the pyrite concentrate. Burns *et al* (2012) present a detailed diagnostic analysis of the factors affecting CIL performance at Telfer. They found, after conducting size-by-size analyses, diagnostic leach tests and detailed mineralogical studies, that poor liberation of gold grains in coarse pyrite particles was the primary factor limiting leach performance of Telfer's pyrite concentrate. In addition, the study found that the high levels of cyanide soluble copper (mainly as composite particles with pyrite) entering the CIL circuit was responsible for high reagent consumptions in this circuit.

Burns *et al* (2012) showed that the optimal approach to improving CIL performance (in terms of both improving recovery and reducing operating cost) was to install a regrind mill on the current CIL feed stream, and then remove liberated gold and copper particles by flotation (pyrite recleaning) prior to leaching the flotation tailings stream. In laboratory and pilot testing, the overall gold extraction increased to approximately 90 per cent overall gold recovery together with increased copper recovery and a reduction of approximately 25 per cent in cyanide consumption in the CIL circuit as a result of reducing the cyanide soluble copper concentration in the CIL feed.

The improvement is gained from liberating fine gold grains (~5 - 10 µm) locked in larger pyrite particles. Much of this gold (~50 - 75 per cent) will be recovered by flotation and combined with the copper concentrate for sale, prior to the leaching of the flotation tails. Figure 12 shows some optical micrographs of the typical gold inclusions in pyrite prior to regrinding at Telfer.

This circuit configuration performance and scale-up design criteria were developed using a mixture of pilot-scale and laboratory techniques. A 1.5 kW pilot ISAMill™ M20 (see Figure 10) was used to regrind the CIL feed material to different grind sizes in preparation for bench scale flotation tests and bottle roll leach diagnostics. In addition to preparing the feed for laboratory testing, operation of the pilot mill also allowed for the generation of power requirement curves which were subsequently used to scale-up the power required in the full scale installation.

Figure 13 shows the gold flotation recovery following regrinding to different sizes during the pilot studies (each data series, shows a different day on which the tests were carried out. At target regrind size of 25 µm, the flotation recovery on some of the tests achieved close to the current gold recovery of the CIL circuit (~75 per cent). Operating costs of the regrind circuit are expected to be approximately ten per cent per ounce of the CIL operating costs. If the high gold flotation recoveries can be achieved consistently at full scale, this may provide an option to de-commission the CIL circuit in the future should the leach costs become uneconomical. It is unclear why the recovery of gold reduced greatly when grinding to P_{80}s finer than 20 - 25 µm. The authors speculate that this drop-off could be due to overgrinding of higher sulfide gangue (SG) gold/

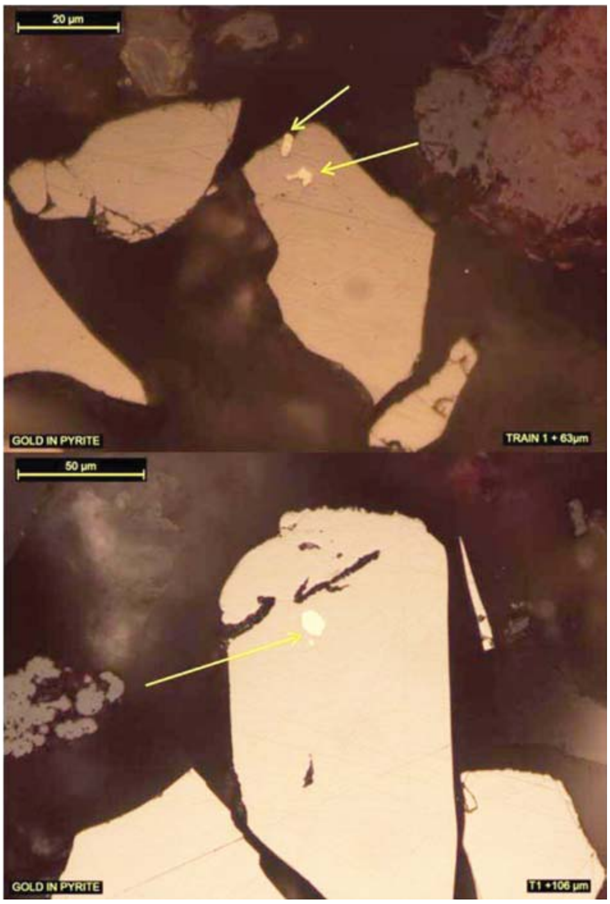

FIG 12 - Example of gold inclusions in larger pyrite particle.

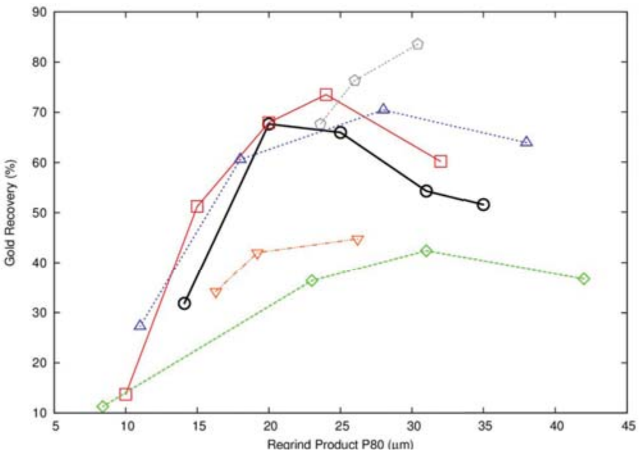

FIG 13 – Flotation gold recovery in the pyrite recleaning stage as a function of regrind size (P_{80}) on different days.

gold composites relative to lower SG barren pyrite as a result of the ISAMill™ internal classification. This will be further investigated once the circuit is operational.

A 1.5 MW ISAMill™ (M5000) is being installed to regrind the pyrite concentrate to a target P_{80} of 25 µm at a maximum design throughput of 90 t/h. The mill will be fed underflow from an existing two-stage deslime hydrocyclone circuit. The mill will discharge into an oversized hopper (approximately five minutes of residence time), where plant air will be sparged into the slurry to assist with increasing the dissolved oxygen level of the slurry to facilitate pyrite depression and enhance gold flotation. The slurry will then be diluted upon transfer to a bank of 5 × 30 m^3 Outotec flotation cells – pyrite recleaners. The flotation cells will be fitted with high shear stators (Bilney *et al*, 2006) and float force mechanisms (Coleman and Rinne, 2011) in an attempt to provide optimal flotation conditions for the fine particles. The circuit will have flexibility to send the pyrite recleaner concentrate to the final copper concentrate tanks or to the copper cleaning circuit if further pyrite rejection is warranted. The pyrite recleaner tail will be sent to the existing leach circuit for further gold extraction, and can also be sent to final tailings to by-pass the CIL circuit.

CONCLUSIONS

The first phase (installation of copper cleaner scalper, Jameson cells) of the latest reconfiguration of the Telfer processing plant has been completed successfully and in accordance with expected improvements. The second and third stages of the reconfiguration are well underway at the time of writing this paper, with commissioning to be completed prior to presentation of this paper at the conference.

The copper regrind mill will improve copper concentrate grade when processing West Dome ores by liberating copper minerals from pyrite/copper (mostly chalcopyrite and chalcocite) binary particles. This modification to the circuit is necessary as Telfer commence processing of West Dome ores.

The pyrite regrind circuit will improve gold extraction from Pyrite while decreasing the operating cost of the existing CIL circuit.

The project construction will be completed within 12 months of initial mobilisation to site and within 14 months of the final capital approval being granted by Newcrest Mining for all stages of the project.

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