Cleaner circuit optimisation at Cadia operations

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ABSTRACT

The Cadia Hill concentrator at Newcrest's Cadia Operations has undergone several modifications and upgrades to treat an increased throughput rate of harder ore from the Cadia East block cave mine.

Subsequent to the commissioning of the expanded circuit, the flotation cleaner block has undergone a systematic optimisation programme tackling all facets of circuit operation. This included debottlenecking circuit constraints and installation of Jameson cell technology to enhance copper and gold recovery while rejecting fluorine and gangue from the concentrate.

This paper outlines the improvements over the course of the project and results obtained from the implemented actions.

INTRODUCTION

The Ore Treatment department at Cadia mine operate two separate concentrators. Concentrator 1 (formerly the Cadia Hill Concentrator) and Concentrator 2 (formerly known as the Ridgeway Concentrator). The combined design throughput rate is 26 Mtpa, however debottlenecking completed since construction will see the throughput increase to 30Mtpa by June 2018. A simplified flowsheet of the Cadia concentrators is shown in Figure 1.

Ore is crushed underground and conveyed to the surface stockpile where it is fed to the two concentrators.

Concentrator 1 consists of a secondary crushed HPGR fed 40' SAG mill, which feeds three parallel ball mill lines. The nominal target grind size is a P_{80} of 150µm. Two 10MW ball mills feed what is known as the T1T2 flotation circuit while the 3rd ball mill (16MW) feeds a separate flotation circuit (T3) that will be discussed later. Each grinding line has gravity gold recovery and flash flotation on the cyclone underflow.

The Concentrator 2 32' SAG mill (7MW) is fed from a newly constructed tertiary crushing circuit, with a ball mill (7MW) and secondary / tertiary grinding Vertimills. The primary grind size in this plant is lower than that achieved in Concentrator 1, typically around a P_{80} of 120µm. The gravity effort in Concentrator 2 is higher than Concentrator 1, with a higher proportion of the cyclone underflow sent to gravity concentration and the flash flotation units.

The flotation concentrates from each plant are thickened separately before being combined in thickened concentrate stock tanks. Positive displacement pumps transfer this slurry via buried pipeline to the Cadia Dewatering Facility located in the town of Blayney. The concentrate is dewatered to 9 per cent moisture and railed to Port Kembla for storage and shipping.

Gravity concentrates are upgraded in the goldroom through tabling and smelted to produce doré for further refining.

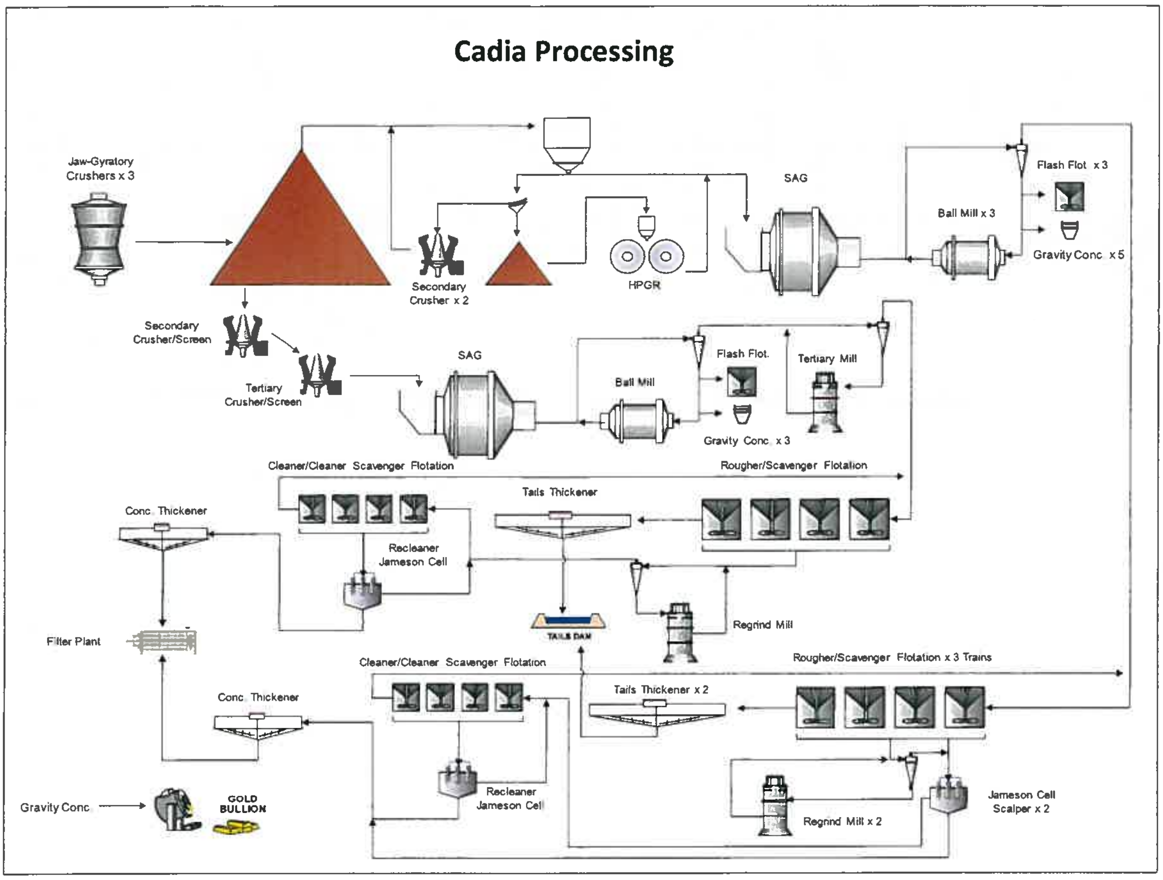

Figure 1 – Cadia processing facility.

Geology

Mineralisation at Cadia East can be divided into two broad overlapping zones; an upper, copper-rich, disseminated zone and, a deeper gold-rich sheeted vein zone proximal to the interpreted monzonite. The upper, copper-rich portion of the deposit is stratigraphically controlled within the upper volcaniclastic unit. Sulphide mineralisation is predominantly chalcopyrite, with lesser quantities of bornite and pyrite. Gold grade increases with depth as disseminated chalcopyrite levels decrease and disseminated and vein bornite levels increase. The deeper gold-rich zone is centred on a core of steeply dipping sheeted quartz-calcite-bornite-chalcopyrite veins. The highest gold grades are associated with bornite-rich veins. Molybdenite forms a mineralised blanket above and to the east of the higher grade gold envelope. Cadia East gold ore is primarily in the form of native gold and electrum, in a ratio of ~3.5:1.

MINERAL DEPORTMENT: PRE-CLEANER OPTIMISATION

In order to understand the impact of treating Cadia East ore through the modified Cadia Hill processing circuit (Concentrator 1) and pre-empt potential flotation bottlenecks two separate targeted mineralogy studies were conducted by AMTEL in 2012 and 2013 to determine the form of the gold and copper losses in the flotation final tail. The first study was initiated after suffering particularly high gold and copper losses in the middle part of 2012 while the plant was treating predominantly low grade Cadia Hill stockpiles. A three month composite of final tail samples was sent for copper and gold deportment analysis. A second study commenced following the commissioning of the HPGR circuit, part of the progressive upgrade associated with the Cadia East mine project (Engelhardt et al, 2011) with the samples derived from a full plant flotation survey conducted in November 2013 on pure Cadia East block cave ore.

Gold deportment

Gold from the Cadia ore deposits exist primarily as native gold with some electrum. The fine texture of the gold grains suggests recovery is sensitive to grind size and liberation in the flotation circuit (refer to Figure 2). Following the mineralogical study in 2012, it was evident that poor liberation did not entirely explain the recovery losses of gold in the final tailings. The data showed at the time that 37 per cent of the gold losses to final tail were in the form of fully liberated gold grains, with 28 per cent below 10μm and generally considered not readily floatable. Similarly a large portion of the gold tail analysed from the 2013 survey was in the form of fully liberated gold particles.

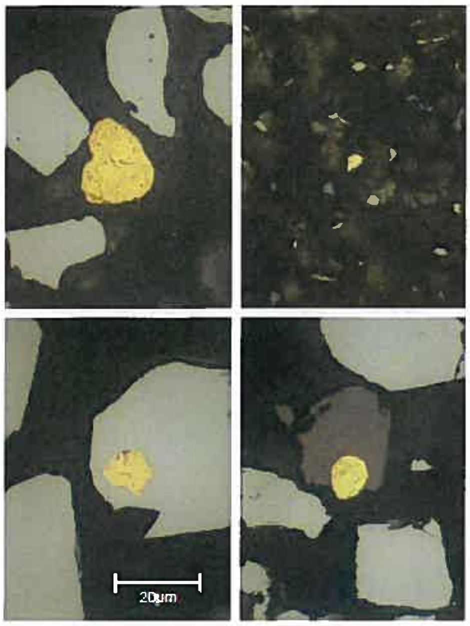

Figure 2 – Typical gold grain size in final tail stream.

A summary of the final tail gold deportment from both studies is presented in Figure 3. This indicated an opportunity to recover not only the fully liberated gold minerals but also the gold associated with the fully liberated sulphides. For both studies the final tail P_{80} was approximately 150µm which is the nominal primary grind size for Concentrator 1 from the Cadia East feasibility study. Most of the fine grains produced in the circuit were a result of regrinding, which at the time of the study treated rougher and scavenger concentrate only.

A cleaner block tail sample was also taken from the 2013 survey to determine the contribution of this stream on the overall final tail losses. Figure 4 summarises the deportment of gold in this stream and clearly illustrates the majority of the cleaner losses are fully liberated particles, the majority of which are less than 7µm. Due to the progressive upgrade of the Cadia circuit in line with the ramp up of metal units supplied from the Cadia East mine, only the rougher capacity had been expanded up to the 2013 survey. This was in the form of a bank of five 300m^3 tank cells, in open circuit with the new 16MW ball mill. The rougher concentrate from this circuit was combined with the concentrates from the existing roughing lines in a new 900kW regrind mill. As a consequence, the cleaner block tailing stream was recirculated to the head of the original rougher trains (T1 and T2) only. The new Train 3 (T3) was operated in open circuit. When comparing the normalised gold deportment for the separate tails streams (refer to Figure 5) the effect of the recirculation of cleaner block tailings on the final tails is evident with a larger proportion of fully liberated gold losses in T1/T2 compared to T3.

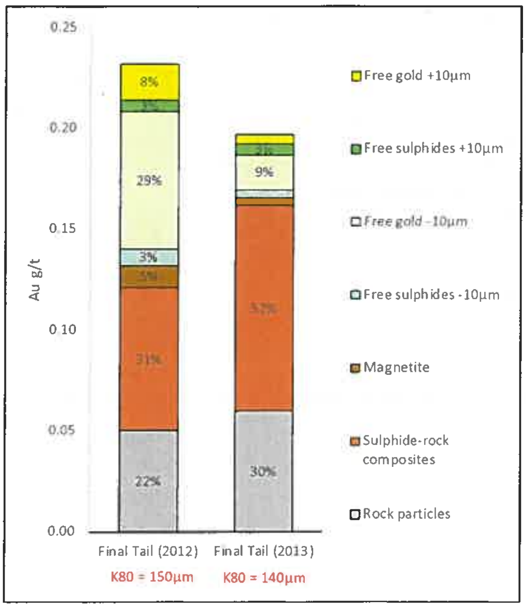

Figure 3 – Gold deportment in final tail.

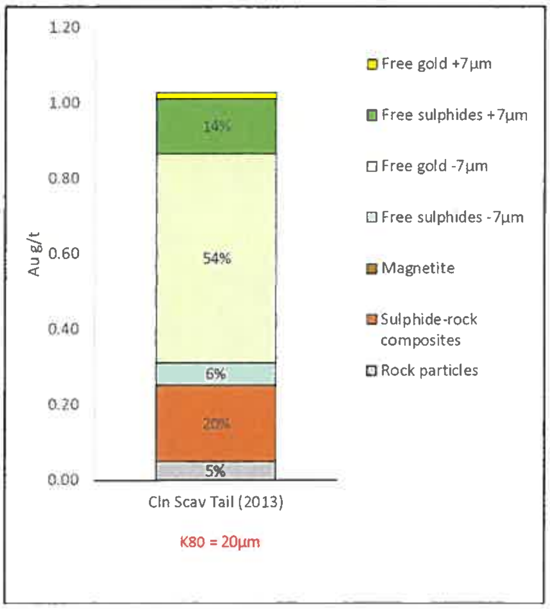

Figure 4 – Gold deportment in cleaner scavenger tails stream.

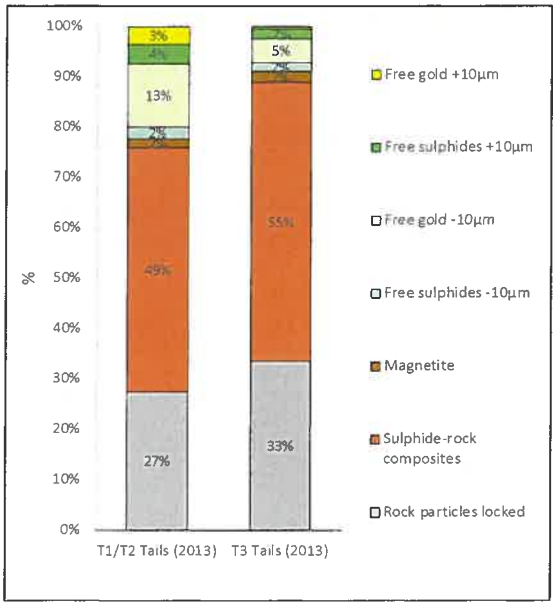

Figure 5 – Normalised gold deportment in Train 1/2 and Train 3 tails streams.

Copper deportment

Copper from the Cadia ore deposits is primarily found as chalcopyrite with some bornite and minor covellite/chalcocite. Pyrite is the only other major sulphide, with minor molybdenite. The texture of the copper minerals is coarser than the gold minerals (refer to Figure 6) and hence the target primary grind size is a balance between the two valuable constituents. Similarly to gold, the analysis of the 2012 final tails composite showed significant losses of fully liberated copper minerals. A large proportion (54 per cent) was 5µm or finer with a total of 77 per cent of the losses attributed to fully liberated copper sulphides.

A summary of the copper deportment for the 2012 and 2013 study is shown in Figure 7. Analysis of the 2013 survey tailings indicated a similar opportunity to recover the fully liberated copper sulphides, particularly chalcopyrite, albeit to a much lesser extent than in the 2012 study. Complementing the gold data, examination of the cleaner scavenger tails stream from the 2013 survey suggests the major source of the liberated copper losses originates from the cleaning circuit (refer to Figure 8). The normalised comparison between T1/T2 and T3 confirms this (refer to Figure 9).

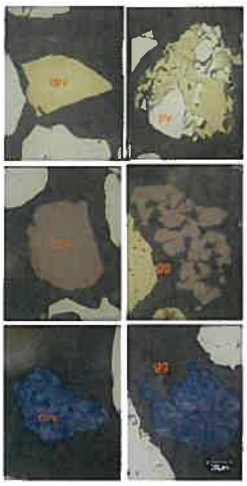

Figure 6 – Typical copper mineral grain size in final tail stream. Cpy = chalcopyrite, py = pyrite, bnt = bornite, cov = covellite, gg = non sulphide gangue.

The combination of copper and gold mineralogy highlighted a significant opportunity in the cleaning circuit of Concentrator 1 to improve overall recovery.

Fluorine deportment

It was identified early in the Cadia East feasibility that levels of fluorine, disseminated throughout the ore body, may be significant enough to result in smelter penalties being applied to the flotation concentrate upon sale. It was therefore important in the 2013 mineralogy study to identify the form of fluorine in the flotation feed and the mechanism by which fluorine is recovered to the final copper concentrate. Figure 10 summarises the fluorine deportment for the 2013 survey flotation feed and flotation concentrate. Close to 65 per cent of the fluorine present in the flotation feed was found as free fluorite over half of which was in the slimes fraction (<9µm). Initial process data while treating Cadia East showed that fluorine concentrate grades were similar to feed grades. Given the hydrophilic nature of the fluorine minerals and that a significant proportion of these grains contained within the slimes fraction and liberated, entrainment was identified as the principal recovery mechanism. As such, an opportunity existed to reduce the entrained fluorine through the application of froth washing.

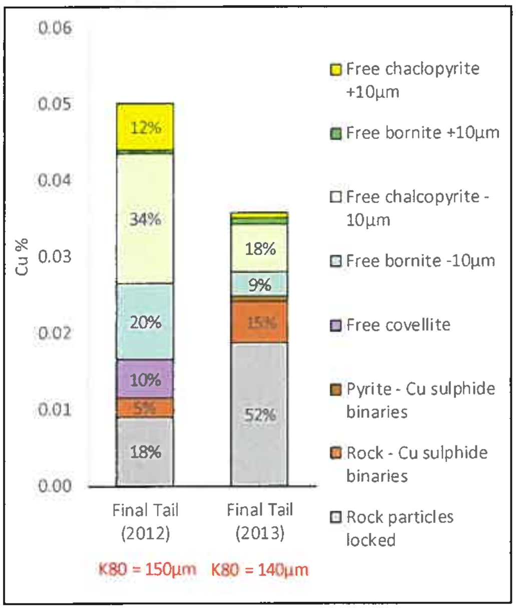

Figure 7 – Copper deportment in final tail.

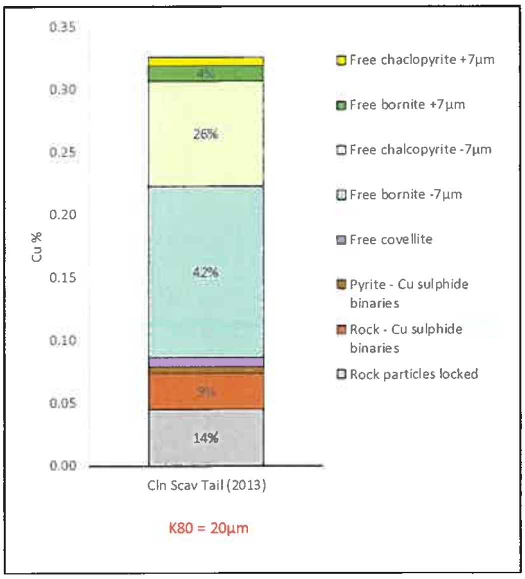

Figure 8 – Copper deportment in cleaner scavenger tail stream.

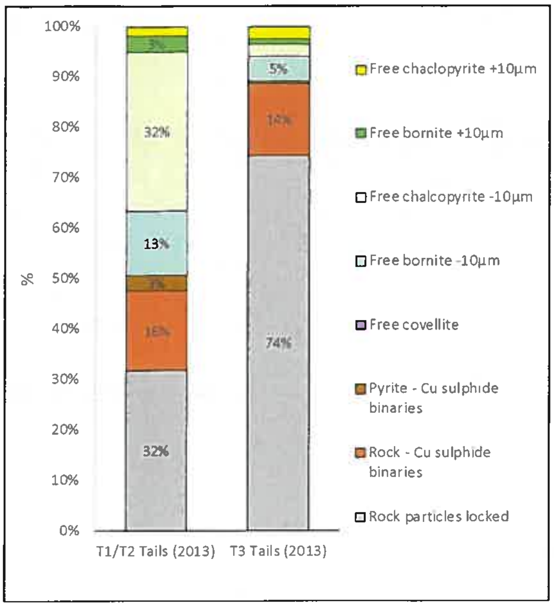

Figure 9 – Normalised copper deportment in Train1/2 and Train 3 tails streams.

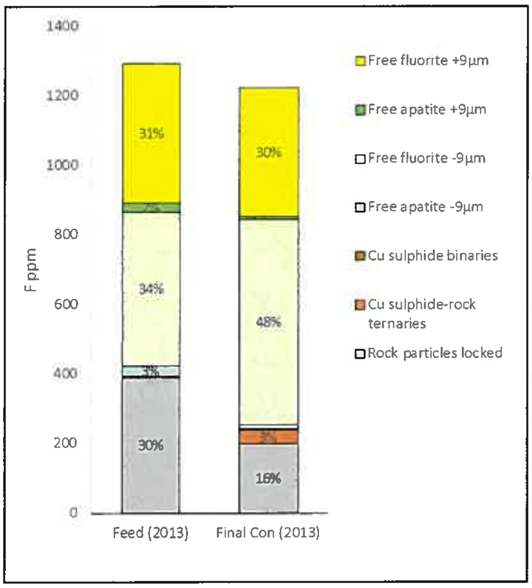

Figure 10 – Fluorine deportment in flotation feed and final concentrate streams.

CLEANER CIRCUIT BOTTLENECKS

Effect of cleaner scavenger tail recirculation on rougher recovery

Following the initial targeted tailings mineralogical study conducted for Concentrator 1, additional surveys were performed down an isolated roughing train (T1) to specifically quantify the effects of recirculation of the cleaner scavenger tailings (CST) on single train rougher recovery. Two roughing surveys were completed, one with and one without CST recirculation. Feed and products were balanced for gold and copper to determine stage recovery, adjusted for the change in residence time. A summary of the results for the T1 surveys is presented in Table 1. The recovery of both gold and copper was much higher over the T1 rougher without the circulation of CST to the head. An improvement in recovery of over 11 per cent Au and over 4 per cent Cu was realised irrespective of the lower feed grade.

Survey	Head Assay (Combined Feed)		*Cumulative Recovery		Cumulative Con. Assay	
	Au (g/t)	Cu (%)	Au (%)	Cu (%)	Au (g/t)	Cu (%)
With cleaner scavenger circulation	0.35	0.17	62.09	79.24	4.94	2.98
Without cleaner scavenger circulation	0.32	0.14	73.93	83.62	2.70	1.32

***Note:** rougher feed excludes the flash flotation circuit in the primary milling stage

Table 1 – Balanced overall recovery from T1 rougher.

It could be argued that the improved rougher recovery without the recirculated CST was a result of the lower volumetric rougher feed rate and hence increased residence time. Evaluation of the rougher kinetics with and without CST shows the copper and gold recovery was higher for the case without CST after just 6 minutes of equivalent residence time and therefore does not adequately explain the recovery difference of the entire flotation feed. This is illustrated by the cumulative stage recovery of both gold and copper in Figure 11.

Pease et al (2005) described the importance of floating particles in a narrow size distribution. Fine particles require different conditions for flotation, compared to coarse particles, such as increased collector addition and increased residence time. This makes it difficult for the operator to optimise the roughing circuit when fed a bi-modal size distribution of particles. Fines may also be prone to variations in surface chemistry which can reduce mineral hydrophobicity. These particles or slimes can coat the coarser particles in the rougher circuit and consequently reduce hydrophobicity of the coarser particles.

Previous surveys showed that the kinetic response of the Concentrator 1 cleaner circuit was poor (refer to Figure 12). Pilot plant testwork using 4 x 40L conventional flotation cells showed that valuable minerals in the CST would continue to float if given sufficient residence time. This is highlighted by Table 2 which summarises the results of several surveys conducted on a representative CST bleed stream with an equivalent plant residence time of 15 minutes. On average, 54 per cent gold and 53 per cent copper could be recovered from the CST if the cleaner residence time was doubled. As the slow kinetic response is in part a result of the fine size distribution which averages a P_{80} of 20μm, it is reasonable to suggest that this slow floating material is having a detrimental impact on the rougher recovery. Despite the impact of the CST on rougher flotation performance, it was concluded at the time that keeping CST in closed circuit produced a higher overall circuit recovery than open-circuiting the CST.

Sample	Au	Cu
	(ppm)	(%)
Trial 1 CST Feed	1.38	0.52
Trial 1 Concentrate	13.20	5.91
Trial 1 Tail	0.62	0.22
Trial 1 Recovery (%)	**57.91**	**59.92**
Trial 2 CST Feed	1.52	0.51
Trial 2 Concentrate	18.72	8.98
Trial 2 Tail	0.72	0.27
Trial 2 Recovery (%)	**54.95**	**48.52**
Trial 3 CST Feed	1.32	0.52
Trial 3 Concentrate	13.13	6.53
Trial 3 Tail	0.69	0.26
Trial 3 Recovery (%)	**50.12**	**52.07**

Table 2: CST Pilot Plant Results.

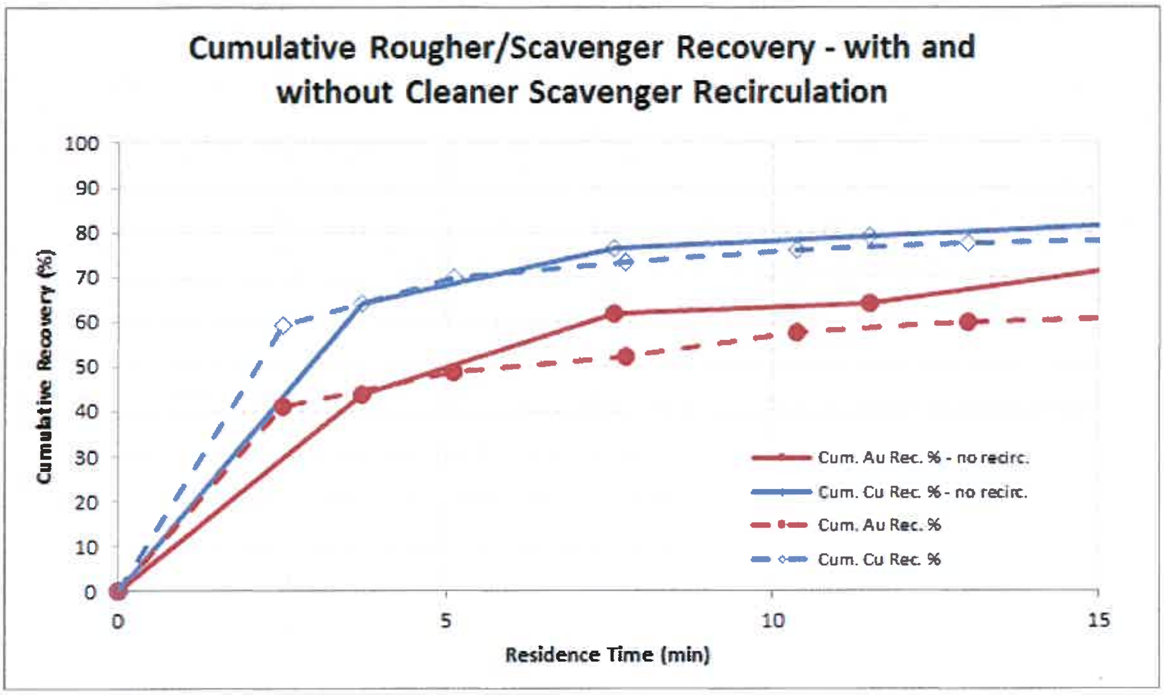

Figure 11 – T1 residence time with and without circulation of CST.

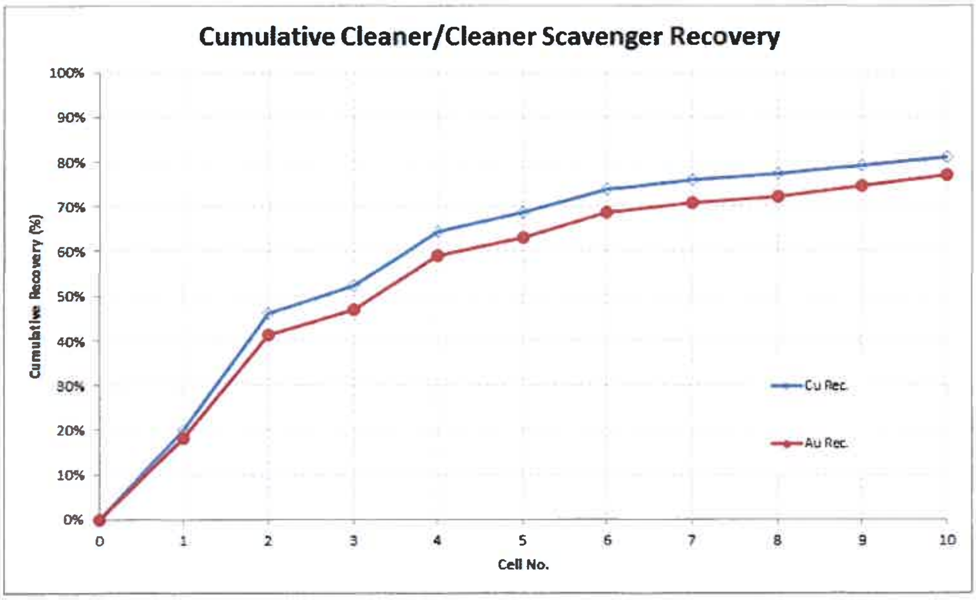

Figure 12 – Stage recovery for Concentrator 1 cleaner/cleaner scavenger circuit.

Cleaner circuit hygiene

In 2014, the throughput rate and copper feed grade often exceeded the design capacity of the Concentrator 1 flotation circuit. This exposed several bottlenecks in the concentrate handling system such as overflowing launders, overflowing distribution boxes and overloading trash screens (refer to Figure 13). As a result the flotation circuit suffered from lower copper and gold recovery and unnecessary circulation of concentrate through the circuit sump pumps creating process instability and generally poor plant hygiene. Ultimately these events reduced operator confidence in the process and distracted them from optimising the circuit. Several modifications were made to improve concentrate handling in these areas of the circuits including increased launder depths, modified screen designs and modified pipework. None of which eliminated the requirement for additional cleaner capacity.

Figure 13 – Left, overflowing cleaner concentrate launder, top right, overflowing concentrate box, bottom right, overloaded trash screen.

Circuit modification and modelling

An immediate response to relieving the cleaner circuit bottleneck was to open the circuit up and reduce recirculating loads. This was achieved by redirecting the cleaner scavenger concentrate directly to the recleaner circuit, rather than to cleaner feed, to give the material the shortest path to final concentrate and to double the residence time in the cleaner stage. In order to predict the response of this change, a basic floatability component flotation model was built of the Concentrator 1 cleaning circuit using a block survey conducted by site on the 17th September 2013. The model was based on the AMIRA P9 flotation modelling methodology (Harris et al, 2002) where the feed is split into a number of floatability fractions to describe the observed distributed flotation rate. Only the cleaner block was considered in the model and resulting simulations.

The recovery of a single floatability fraction across a single perfectly mixed cell is described by:

$$R = \frac{P * S_b * \tau * Rf * (1 - R_w) + ENT * R_w}{(1 + P * S_b * \tau * Rf) * (1 - R_w) + ENT * R_w}$$

Where: R is the recovery of fraction, P – the floatability of the fraction, S_b – the bubble surface area flux of the cell, Rf – the froth recovery of the floatability fraction in the cell, ENT – entrainment parameter (size dependent) and R_w – the water recovery across the cell.

A total of three components were used to describe the flotation of each mineral species – fast floating, slow floating and non-floating. *ENT* was estimated based on the particle size distribution using values reported by Johnson et al, 1974, and a simple water recovery was employed.

In order to simplify the model, the term $S_b{*}Rf$ was combined into a single cell scale up number, C for each bank of flotation cells. The C parameter is a measure of how hard the cell is pulled, which would be adjusted in practise by changing froth depth and/or air addition rate. Monte-Carlo style simulations were completed with the resulting model by varying the C parameter to develop grade-recovery curves for comparing different circuit configurations.

The survey and modelling process were initiated to address two key issues:

1. The cleaner circuit in C1 was underperforming, cleaner block recoveries were only ~80 per cent gold and copper versus well over 90 per cent as an industry benchmark; and
2. With the ramp-up of Cadia East, higher copper feed grades resulted in a bottleneck around the cleaners. The Cadia East feasibility study identified that the cleaning circuit would require expansion in future years, however no commitment to an implementation timeline or process design was made.

In the case of point 1, the model was primarily used to determine the benefit in reconfiguring existing equipment into different duties to improve the current cleaner block performance. With regard to point 2, the model was used to provide an estimate of when a cleaner expansion would be warranted as well as providing a preliminary equipment sizing. Based on the model Figure 14 shows the estimated cleaner block recovery loss with no further expansion to Concentrator 1.

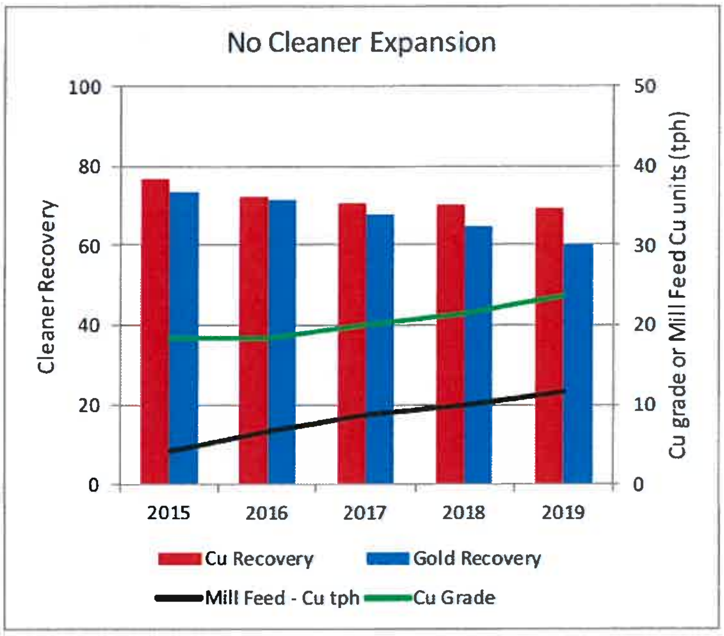

Figure 14 – Cleaner block recovery and grade over five years with no circuit expansion (and no mass transfer restrictions considered).

CLEANER CIRCUIT UPGRADES

Concentrator 1 cleaner upgrade - stage 1

From the cleaner flotation modelling it was identified that future copper and gold recovery would be significantly impacted if the capacity of the cleaning circuit was not increased. A project was instigated to expand the flotation capacity in the Concentrator 1 circuit. The intent of the expansion covered two main criteria:

1. Ensuring sufficient cleaner capacity for the next two years of operation until further cleaner expansion could be justified based on increasing mill throughput and copper feed grades; and
2. Effective rejection of liberated fluorite to ensure a more saleable flotation concentrate and reduction or elimination of penalties.

Based on this criteria, Jameson cell technology was considered to be the best option for expanded cleaning circuit capacity. This was principally due to the documented benefits of the unit in the cleaner flowsheet as well as the ability to reject entrained non-sulphide gangue, in this case fluorite, by a combination of deeper froth and wash water. While there was limited information on the performance of the technology when specifically applied to fine free gold flotation, Newcrest was able to leverage from previous experience of de-bottlenecking the Telfer cleaning circuit by installation of two (E3432/8) Jameson cells (Seaman et al., 2012).

To confirm the ability of the Jameson cell to deliver on these criteria, a pilot cell was installed within the Concentrator 1 flotation circuit. Results from the pilot installation found a fluorine upgrade ratio between 0.2 – 0.35, compared to a 1:1 ratio in the existing circuit, and a copper stage recovery of up to 70 per cent. Confirmation of the technology led to the installation of a 24 downcomer Jameson cell (B6500/24) primarily in a cleaner scalper duty (refer to Figure 15).

Several options were considered in the design phase including the addition of two smaller Jameson cells; one as a cleaner scalper and the other as a recleaner. Ultimately the decision was made to add the Jameson cell in the cleaner scalper duty to maximise cleaner recovery in the first instance and defer capital for a final recleaner cell to improve grade when higher copper feed grades/tonnage necessitated. As an interim compromise, an option was built into the design to allow the conventional recleaner concentrate to report to the single Jameson cell rather than to final concentrate. The benefits of the Jameson cell in a cleaner scalper duty have been well documented (Bennett et al, 2012; Seaman et al, 2012; and Huynh et al, 2014). Principally, the short residence time and high flotation rates of the Jameson cell capitalise on the fast floating particles with cleaned surfaces immediately exiting the regrind stage. The application of froth washing in the Jameson cell significantly improves the rejection of fine gangue otherwise recovered by entrainment, particularly fluorite in this application. Piloting and analysis was completed in February 2014, with commissioning of the new circuit taking place in November the same year.

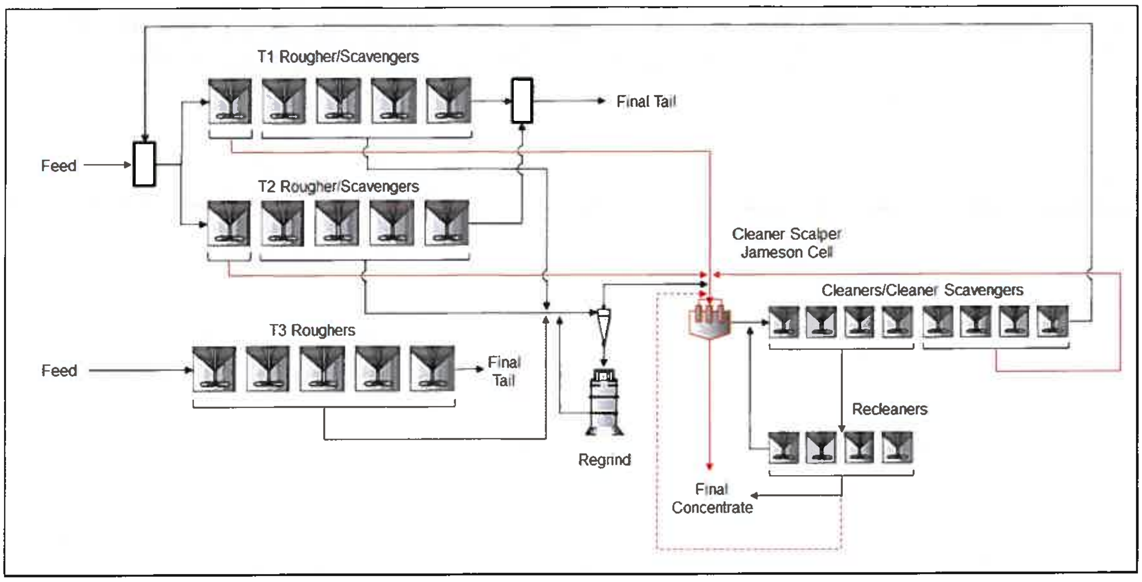

Figure 15 – Concentrator 1 cleaner circuit upgrade – stage 1, installation of cleaner scalper Jameson cell.

Commissioning of the new Jameson cell highlighted several challenges that were not anticipated in the original design. Pumping of concentrate posed the most significant issue as the froth produced by the Jameson cell concentrate was far more tenacious than expected. Significant upgrades to the concentrate pump and feed hopper were instigated post commissioning to accommodate the high froth factor. The froth also significantly impacted the final concentrate thickener, with surface froth that was difficult to disperse. The installation of a de-aeration unit to the feed-well was finalised in 2015, successfully breaking down the froth and reducing occurrences of dirty thickener overflow.

It was also found that the Jameson cell was highly sensitive to the copper metal units in the concentrator feed. When the feed units to Concentrator 1 dropped below the design (9 tph of copper in the flotation feed) the cell would struggle to form a consistent froth. A short term solution for operators was to increase the units internal recycle load and allow mineral to build up in the froth. This was not sustainable as it lead to cycles of high copper and gold reporting to CST. A longer term solution was devised which involved the installation of moulded rubber sections that slide over the concentrate lip, to reduce lip length and improve froth mobility. In contrast, when high copper units were fed to the Jameson cell, for example when the conventional recleaner concentrate was fed to the unit with the rougher concentrate, it was difficult to effectively 'unload' the Jameson cell leading to large recirculating loads and a drop in overall circuit recovery.

In spite of the post commissioning issues, the value of the project was immediate. A multivariable regression analysis of the pre and post installation, using the Jameson cell operation as the dummy variable, showed a significant copper and gold recovery increase of 2.85 per cent$\pm$0.82 per cent and 2.23 per cent$\pm$1.15 per cent respectively at a 95 per cent confidence interval. To validate the statistical analysis, these results were compared to other statistical methods including t-test and comparison regression which produced similar results. Final flotation concentrate grade for the same dataset showed a significant increase in copper grade of 1.05$\pm$0.55 per cent at a 95 per cent confidence interval. Similarly this analysis was repeated using alternate statistical approaches giving the same result. It is important to note that some of the final concentrate produced within this period came from the conventional recleaner circuit (~20 per cent by mass) and therefore the actual upgrade of copper on the Jameson unit in isolation was even higher.

A full plant flotation survey was conducted in June 2015 post the stage 1 cleaner upgrade to confirm the improvement in fine free gold and liberated copper recovery by installation of the Jameson cell unit. Figures 16 and 17 show a significant reduction in the fully liberated gold and copper particles respectively reporting to the cleaner scavenger tail. Tables 3 and 4 summarise the mineral calculated cleaner block recovery increase for each carrier of gold and copper, respectively. The balanced plant survey data from which the deportment samples were derived shows gold recovery in the cleaners increased across all size fractions with the installation of the Jameson cell (refer to Figure 18).

Gold Carrier	Gold Recovery (%)	
	with Jameson	without Jameson
Free gold grains		
>7µm	99.9	99.7
<7µm	94.0	73.0
Free sulphides		
>7µm	99.0	92.0
<7µm	98.0	92.0
Composites	76.0	82.0
Global Au Recovery	**96.0**	**90.0**

Table 3 – Cleaner circuit gold recovery by gold carrier, based on mineral count.

Copper Carrier	Copper Recovery (%)	
	with Jameson	without Jameson
Free Cu Sulphides		
Cpy >7µm	99.0	99.0
Cpy <7µm	96.0	91.0
Bnt >7µm	99.0	98.0
Bnt <7µm	96.0	77.0
Composites	84.0	71.0
Gangue Composites	63.0	68.0
Global Cu Recovery	**97.0**	**91.0**

Table 4 – Cleaner circuit copper recovery by copper carrier, based on mineral count.

As per the statistical analysis of the whole circuit recovery, the effect of the increased cleaner capacity was also evident in the gold and copper deportment in the final tail of T1 and T2. Figure 19 shows a comparison of the survey conducted in 2013 pre Jameson cell and 2015 post Jameson cell. Both free gold and gold associated with free sulphides reduced.

Survey data in 2015 demonstrated the ability of the Jameson cell to reject fluorine producing an upgrade ratio of 0.25. A detrimental effect of the Concentrator 1 circuit configuration, however, was large circulating loads of fluorine in the downstream conventional cleaning circuit. This had the net effect of feeding higher fluorine grade to the conventional recleaners, that contributed ~20 per cent to the final flotation concentrate with a 1:1 fluorine upgrade, placing upward pressure on overall flotation concentrate fluorine grade. This meant the circuit design did not maximise fluorine and non-sulphide gangue rejection. In addition, fluorine feed grades increased significantly between 2013 and 2015, by approximately 50 per cent.

Although the fluorine rejection for the circuit was not maximised the Jameson cell did significantly reduce the free fluorite to the final concentrate. This is illustrated in Figure 20 which shows the 2015 survey fluorine deportment of the CST, final concentrate and Jameson cell concentrate. The data confirms the rejection of free fluorite to the CST and reduction in free fluorite reporting to the final concentrate and in particular the Jameson cell concentrate.

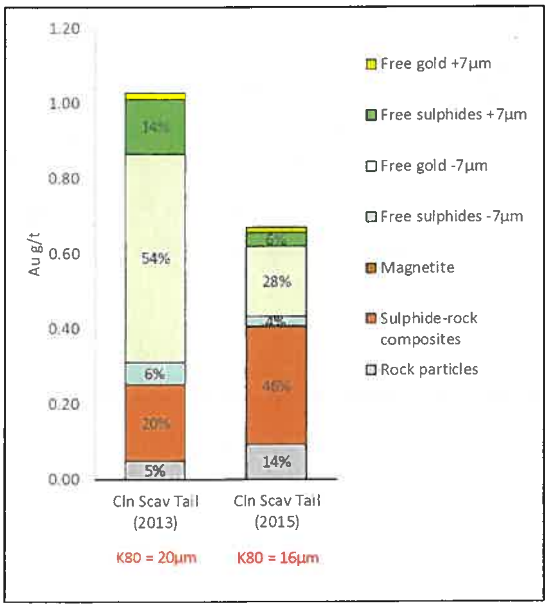

Figure 16 – Cleaner scavenger tail gold deportment post Jameson cell installation.

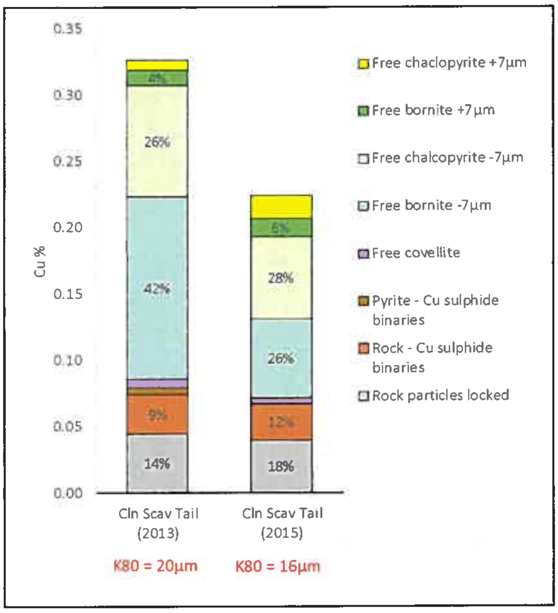

Figure 17 – Cleaner scavenger tail copper deportment post Jameson cell installation.

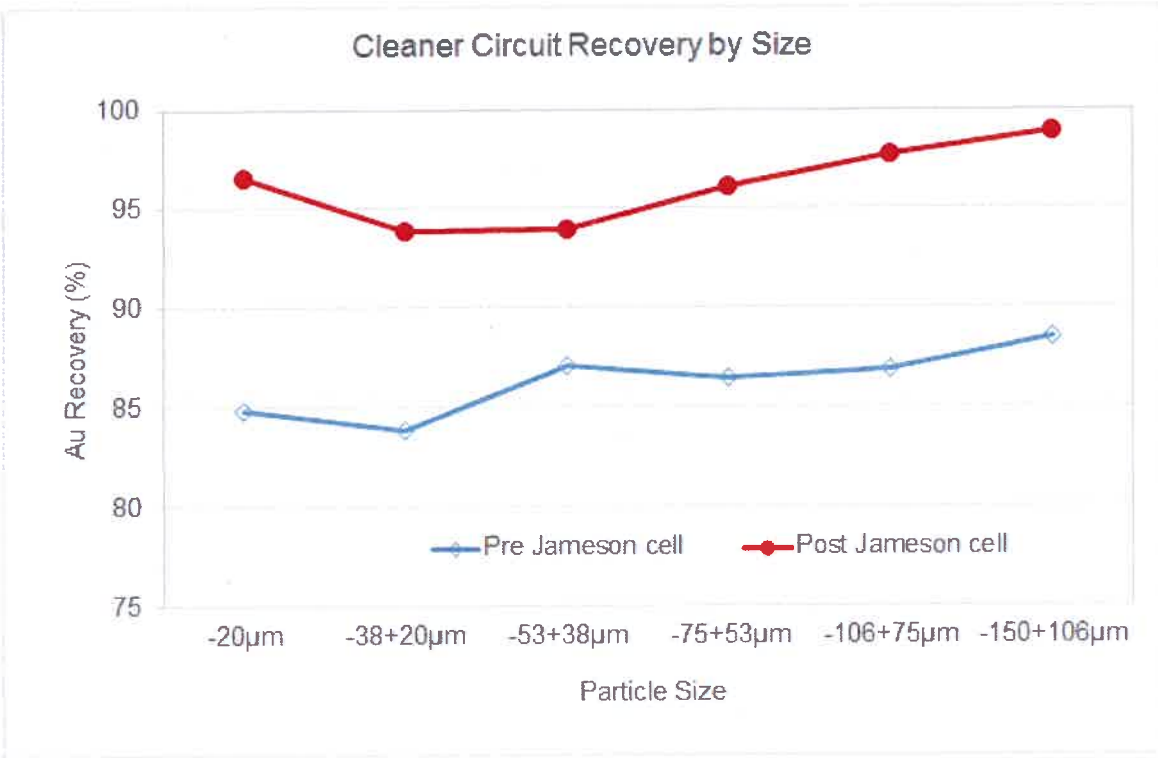

Figure 18 – Cleaner circuit size by recovery pre and post Jameson cell installation, balanced plant survey data from 2013 and 2015.

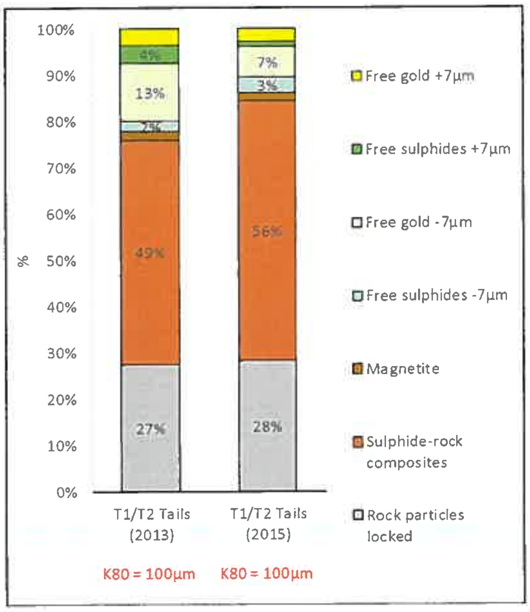

Figure 19 – Train 1 and 2 Tail gold deportment post Jameson cell installation.

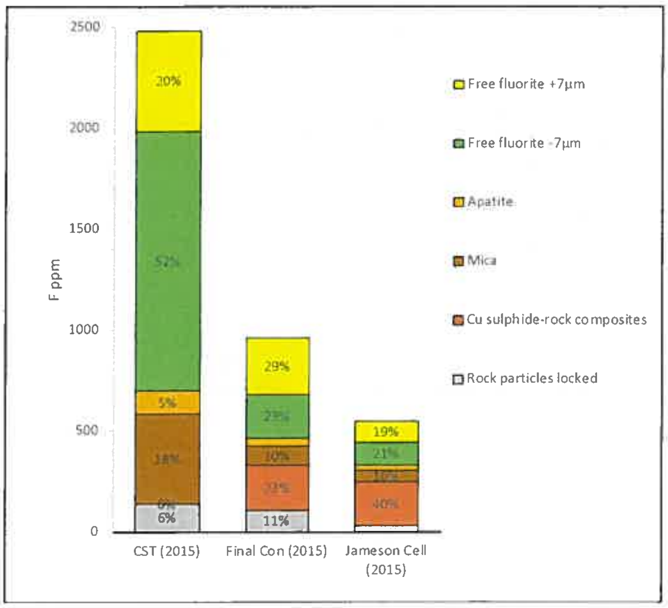

Figure 20 – Concentrator 1 fluorine deportment post Jameson cell installation.

Concentrator 1 cleaner upgrade - stage 2

As forecast in the original Cadia East upgrade project and confirmed by the flotation modelling discussed earlier, the cleaner capacity in the Concentrator 1 circuit was expected to be the flotation bottleneck by the end of FY17. Since the commissioning of the first Jameson cell in Concentrator 1 in November 2014, the preferred cleaner flowsheet for Cadia used both conventional tank cell flotation technology to produce the bulk cleaner concentrate and Jameson cell technology to produce a final flotation concentrate. Using data from the previous installations, along with key learnings from operating the stage 1 upgrade, the concepts were combined to produce the final Concentrator 1 flowsheet, shown in Figure 21.

The objective of the second Concentrator 1 cleaner upgrade was to effectively handle feed metal unit rates at the maximum of the expected life of mine schedule including expected variation in milling rates and feed grades. Circuit capacity post the first cleaner upgrade was 9 tph of copper in feed. To justify the expansion, the existing Concentrator 1 flotation model was updated using the full plant survey information from 2015 and included the new Jameson cell installed in 2014. Using this as the baseline recovery it was estimated that the recovery would decrease at an average rate of ~ 0.8 per cent for both copper and gold per metal unit above 9 tph of copper feed to Concentrator 1. Given metal units were predicted to peak at an excess of 12 tph from FY17 the expected recovery losses with no further upgrade were estimated to be in excess of 2.6 per cent for both copper and gold. A comparison of the predicted cleaner block recovery for Concentrator 1 with and without the installation of the proposed flowsheet is shown in Figure 22.

The final installation included the following equipment:

- 1 x B5400/18 Jameson cell;
- 1 x E2532/6 Jameson cell;
- 6 x e50 Outotec tank cells;
- 1 x VTM-650 Metso Vertimill;
- 1 x FLSmidth hydrocyclone cluster (8 cyclones);
- 1 x Falcon SB2500 gravity unit; and
- 1 x final concentrate trash screen.

Based on the nominal flow sheet in Figure 20, the existing T3 rougher concentrate is diverted to a new regrind circuit. The product of the regrind circuit feeds a new 18 downcomer Jameson cell producing a final concentrate. The tail of this cell feeds 3 Outotec e50 cleaner cells followed by 3 Outotec e50 cleaner scavenger cells. The cleaner concentrate then feeds a 6 downcomer Jameson cell with the tail recirculating back to the head of the cleaners. The cleaner scavenger concentrate reports to the regrind circuit and cleaner scavenger tail reports to the head of the T3 roughers. This circuit layout is similar to that proposed and supported by Huynh et al, 2012.

Concentrate grade was also expected to increase from the cleaner expansion, as all final concentrate from Cadia would be produced from Jameson cells, ensuring maximum fluorine and non-sulphide gangue rejection. Commissioning was completed in July 2017. While the current performance is meeting expectations, at the time of writing this paper the plant is yet to be tested at the full design capacity.

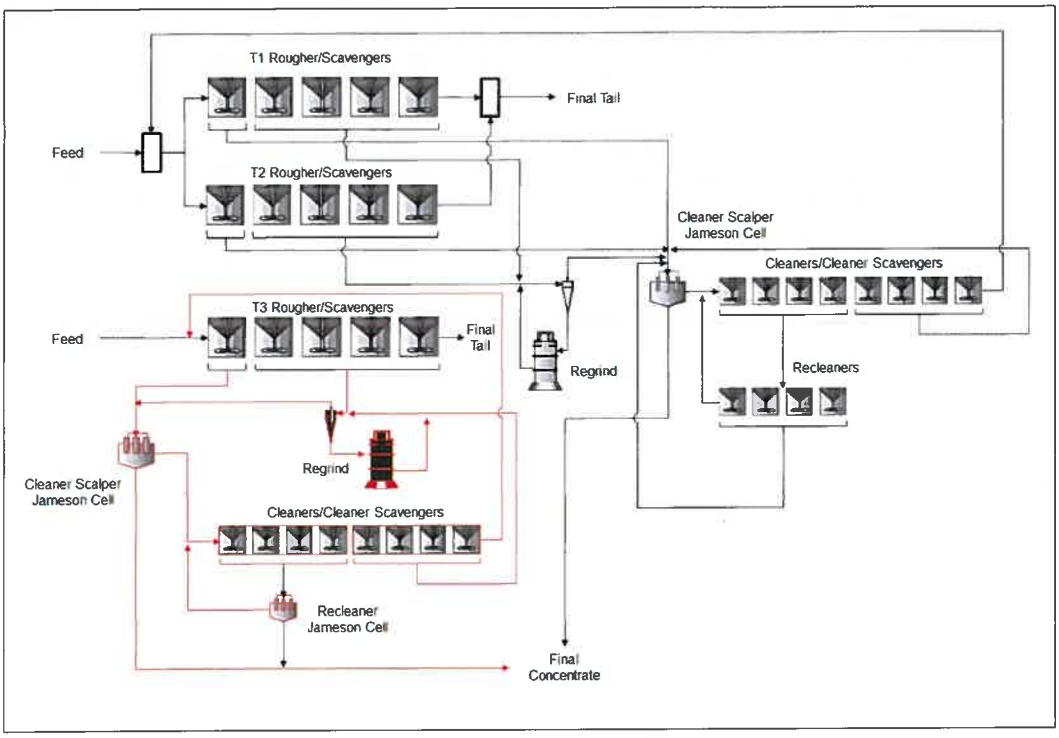

Figure 21 – Concentrator 1 final Cleaning circuit configuration.

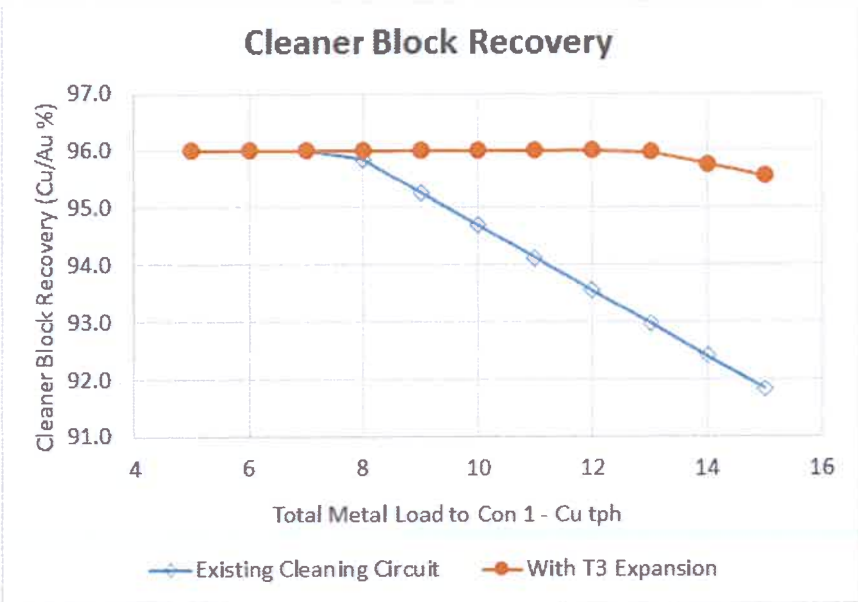

Figure 22 – Comparison of cleaner block recovery between existing cleaner circuit and proposed T3 cleaner circuit expansion against feed metal units.

Concentrator 2 cleaner upgrade

Concentrator 2 at Cadia was initially designed to treat Ridgeway ore, a sublevel cave and later a block cave operated at Cadia from 2002 until going into care and maintenance in March 2016. From this point the plant transitioned to also being fed with ore from the Cadia East block cave. A clear opportunity existed to implement Jameson cell technology to manage the fluorine levels in the Cadia East ore reporting to the concentrate.

In January 2016, capital expenditure was approved to install a Jameson cell (E3432/8) as a recleaner in the Concentrator 2 circuit with the prime objectives being:

1. Rejection of fluorine from the flotation concentrate with a target fluorine grade below 400ppm; and
2. Rejection of approximately 75 per cent of the NSG (non-sulphide gangue) reporting to the flotation concentrate with an expected increase in the concentrate grade by 3.5 per cent, an improved net smelter return through reduced concentrate transport costs, TCRCs and a higher payable metal rate.

Potential benefits in metal recovery were also considered likely from the upgraded cleaner flowsheet, however recovery uplift was not included in the financial evaluation. This was principally on the basis that the improvement in concentrate grade and fluorine rejection alone presented a robust business case for capital expenditure.

The installation of the Concentrator 2 Jameson cell as a final recleaner (refer to Figure 23) as opposed to a cleaner feed scalping unit was based on:

1. Sufficient existing cleaner capacity; and
2. Experience from the first Jameson cell installation in Concentrator 1 suggested excellent fluorine rejection (surveyed upgrade ratio 0.25).

A model was developed on the proposed flowsheet based on Concentrator 2 survey data and early Jameson pilot test work recoveries. This process identified the need to modify the existing circuit in order to maximise the Jameson cell attributes, specifically:

- Installation of froth crowders in the existing conventional recleaners (OK8), to reduce the surface area by approximately 50 per cent and subsequently increase the recovery and mass pull from these cells; and
- Modifications to the existing cleaner circuit to convert the first cleaner scavenger into an additional cleaner cell.

Learnings from the installation of the Jameson cell in Concentrator 1 highlighted the importance of designing a flotation concentrate handling system to manage high froth factors. In order to mitigate issues experienced with the Concentrator 1 installation the following design considerations were applied to Concentrator 2:

- The physical positioning of the cell allowed Jameson cell concentrate to gravity flow to the existing final concentrate hopper rather than transfer by pump; and
- A bespoke de-aeration hopper was installed ahead of the final concentrate pump with the intent of breaking down the froth prior to it discharging into the hopper; and
- Internally designed spray bar on the feed box at the Jameson cell prevented the feed box overflowing into the tails box.

On completion of the Concentrator 2 cleaner upgrade, fluorine grade in the flotation concentrate was reduced to less than 250 ppm. The Jameson cell increased the Concentrator 2 flotation concentrate grade by 4.4 per cent at a >99 per cent confidence interval by rejection of non-sulphide gangue with no loss to copper or gold recovery (compared to 3.5 per cent estimated in the original business case).

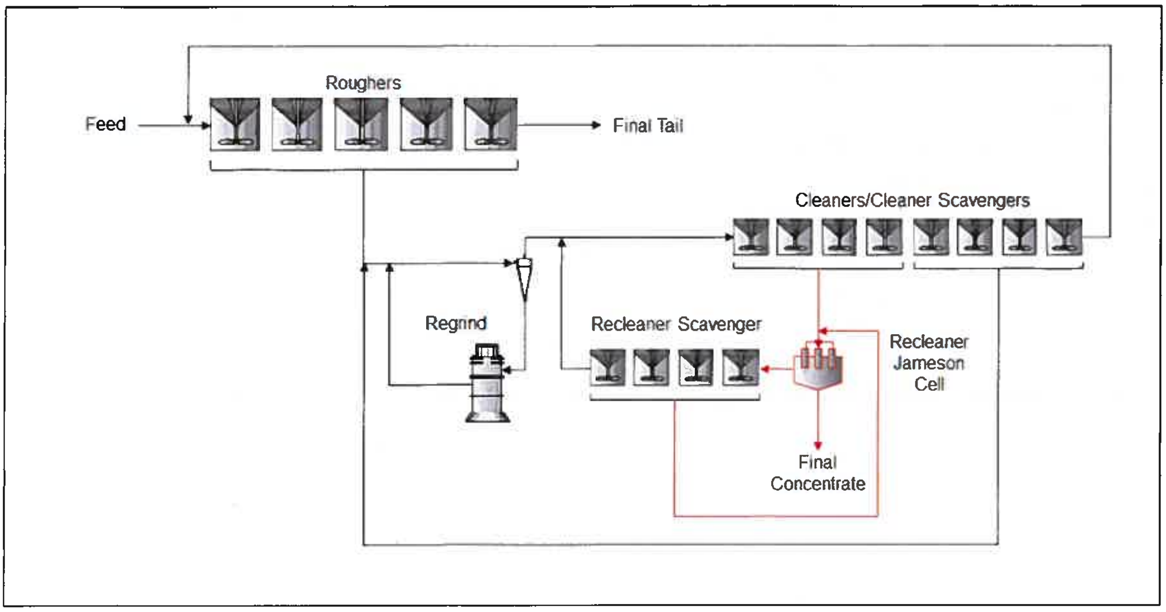

Figure 23 – Concentrator 2 Cleaner upgrade flowsheet.

CONCLUSIONS

The application of Jameson cells into the Cadia flowsheets successfully improved both recovery and concentrate grade. The various upgrades also achieved the objective of removing the entrained fluorite reporting to the concentrate via conventional flotation technology. Several lessons were learnt progressively though the individual upgrades to Concentrator 1 and Concentrator 2, particularly regarding the concentrate handling system. Modelling the proposed circuit flowsheets proved critical to achieving the business case goals for recovery, concentrate grade and reduction of deleterious elements in the concentrate. Mineralogical analysis was used as the basis for, and subsequent proof of the investment and a fundamental mechanism to optimise circuit performance.

ACKNOWLEDGEMENTS

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The Ore Treatment department at Cadia for actively engaging in the commissioning and operation of the new flotation circuits, with all the challenges; and

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