PIONEERING COARSE PARTICLE FLOTATION – TRANSFORMATIVE INSIGHTS FROM FIVE YEARS OF OPERATION

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ABSTRACT

The mining industry has seen a shift towards sacrificing metal recovery for power intensity by simply coarsening primary grind. There is an economic limit to this practice which can be overcome by the adoption of new technologies. For Cadia, this meant a shift away from conventional, power intensive fine grinding flowsheets towards the adoption of coarse particle flotation technology. This new style of flowsheet has potential to deliver significant reductions in concentrator footprint, power and water demand and enable the future use of environmentally preferential tailings storage options like dry stacking or co-mingled deposition. Newmont Cadia took a significant step forward in proving the technical viability of coarser processing for base metals when a full-scale trial of the Eriez HydroFloat™ units were commissioned in August 2018 in a tailings scavenger duty. The success of the trial installation provided Newmont with an alternative technology case when pursuing mill expansions. Subsequent Newmont studies concluded that the expansion of coarse particle flotation (CPF) capacity delivered an improved business case over additional fine grinding and a second CPF project progressed to execution. Post completion of the expansion project in 2022, 75% of concentrator feed at Cadia is treated through coarse flotation systems. This has enabled Newmont to leverage this technology to exploit the material properties of the separated streams. The separated, fines deficient, tailings sands have value as embankment construction material and are a key basis of the tailings future at Cadia. This paper will examine the current reduction in power intensity being delivered by coarse flotation at Cadia and how the site tailings opportunity to further leverage the technology is being developed.

KEYWORDS

Processing, Coarse Particle Flotation, Sustainability, Cadia, Tailings

1. INTRODUCTION

The globe is marching towards a low-carbon economy that will require significant investment in renewable power generation, energy efficiency and electric vehicles. The rapid scaling of these technologies will be extremely material-intensive and demand for critical metals like copper is forecast to grow at a rate significantly higher than any demand increases seen over the past 30 years (Pickens, et al., 2022). However, supplying the resources for the carbon-neutral economy cannot be achieved by simply applying the same mining means in the same way. For minerals processors, there requires a shift away from conventional, power intensive fine grinding flowsheets. Some of the key emerging trends in minerals processing are:

- Dry comminution technology
- Coarse particle separation (bulk sorting, particle sorting, coarse flotation)
- Alternative tailings management practices (filtered/ dry stacked sand-slimes split tailings, tailings valorisation)
- Closing the loop on water and reagents

These trends and technologies can drive efficiency improvements in minerals processing plants, helping to meet the growing demand in a sustainable and responsible manner. The Technology Readiness Level (TRL) is used to assess the maturity level of a particular technology. The technology levels range from TRL 1 (lowest level where research may have begun to be translated into applied research and development) to TRL 9 (highest level where the technology has been proven under operating conditions). In the case of coarse particle separation, industry is at TRL 9 (ICMM, 2022). The mineral processors who can then leverage new technologies to exploit the full value stream opportunity from mine to tailings will be competitively placed to sustainably operate into the future.

Sustainability in the context of ore processing refers to the measures taken by mining companies to ensure that minerals are extracted and refined in a way that minimises damage to the environment and the local communities in which they operate. This includes reducing greenhouse gas emissions, reducing waste and tailings, preserving water resources, and ensuring the health and safety of employees and wider communities (Vollert, et al., 2023). Project evaluation processes need to be disciplined when prioritising these longer term objectives; which can be diluted during an early stage net present value project optimisation (Lane, et al., 2019). One of the largest lifecycle costs to an operation will be the tailings and water facility; through construction, operation and into closure. Consideration of the life of facility size, stability, water recovery and operability should be incorporated into the mineral processing flowsheet equipment selection trade-offs. As large tailings or water savings may be overlooked in pursuit of conventional flowsheet ideas, ideas that can also curtail the economic mine life early. The mining industry fails on average two tailings' dams per year globally; high profile failures in Brazil in 2015 and 2019 resulted in significant fatalities and involved major mining companies (Williams, 2020). The loss of trust in industries' ability to safely manage tailings is placing significant pressures on the sustainability of operations, both future and existing. The Chilean government banned upstream tailings dam raises in 1970 following a significant tailings failure at El Cobre (Barrera & Caldwell, 2015); government regulators and company boards are increasingly drawing a line in the sand that they will not permit or approve upstream designs. Cadia operation suffered a tailings dam failure in 2018, which catalysed a prohibition on future upstream raises within the company. Insurers and investors are also paying closer attention, all of which impacts on the sustainability of mining operations or projects (Williams, 2020).

Copper and gold mining account for over 50% of the tailings generated globally per annum. The opportunity exists now within these industry sectors to pioneer new, more sustainable, tailings solutions as the commodity demand increases. South American operations are already innovating tailings dam design and demonstrating the economic value of water efficiency to project development (Cacciuttolo & Valenzuela, 2022). From demonstration scale innovative solutions such as hydraulic dewatered stacking at El Soldado (Newman, et al., 2023) to implementation of a hybrid water recovery tailings solution at the 90ktpd Caserones operation. The potential operations` sustainability improvements through these innovations in tailings solutions shouldn't be overlooked. Equally, with increasing research into the possible valorisation opportunities, transformative ideas are coming to the tailings space.

The Australian market for Sand and Aggregates is 700M AUD/annum and over 100M AUD/annum in national exports (Segure-Salazar & Franks, 2023a). Internationally, demand for aggregates has tripled over the last two decades as emerging economies develop, and mature economies undertake, expansive infrastructure renewal projects. After water, these materials represent the second largest resource extracted and traded on a volume basis (Segure-Salazar & Franks, 2023a). 'Ore-Sand' has been coined as a new product opportunity with green wings, with Vale S.A. finding a market for its 'Ore Sand' produced from the Brucutu iron ore mine in Minas Gerias, Brazil. Researcher partners, the University of Queensland and University of Geneva, demonstrated the greenhouse gas (GHG) emissions from equivalent 'Ore Sand' generated by Vale S.A. was up to ten times lower than traditional sources (Figure 1) (Golev, et al., 2022). Extensive 'Ore-Sand' testing completed on Quebec sand (Benarchid, et al., 2019), Vale S.A. sand (Golev, et al., 2022) and Cadia Sand (Seguara-Salazar & Franks, 2023b) showed in all cases that the 'Ore-Sand' product was non-toxic, non-acid forming and meets the AS2578.1:2014 standards for construction sand typically used in concrete.

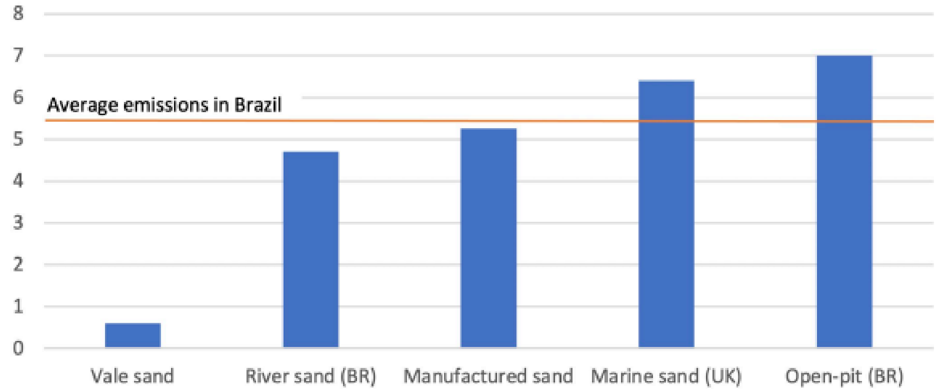

Figure 1 - GHG Emissions from Sand Extraction (grams of CO2-equivalent per kg sand) (Golev, et al., 2022)

Separation of coarse particles using coarse particle flotation is no longer to be considered novel. Proven at scale in isolation, the opportunity presented now is to leverage the material properties of a coarsened grind across the value chain.

2. COARSE PARTICLE RECOVERY: TECHNOLOGY TRADEOFF – BALL MILL vs HYDROFLOAT™

In 2015, an application to the New South Wales Department of Planning and Environment to modify the approval for the Cadia East Project was submitted. Aiming to increase the permitted upper limit for the processing plant's throughput. The subsequent study phases, publicly known as the Cadia Expansion Project (CXP), evaluated several expansion scenarios concerning the mine's capacity, processing facilities, and major infrastructure. Ultimately, the project scope for Concentrator 1 was divided into two stages:

Stage 1 aimed to ensure continuous production at Cadia while increasing processing throughput capacity. This stage involved the development of Panel Cave 2-3 (PC2-3), an upgrade to the mines material handling system, and debottlenecking of the Concentrator 1 comminution circuits.

Stage 2 focused on further boosting processing capacity with enhancing gold and copper recovery compared to Stage 1. This stage included the extension of coarse particle flotation.

During Stage 1 of the CXP, it was determined that the grinding circuit throughput for Concentrator 1 was constrained by the available grinding power and the size of the grinding circuit's product. The study concluded with some capital modifications plant throughput could be achieved at the expense of flotation feed size. However, with the current conventional tank cell flotation circuit and a coarser primary grind, gold and copper recovery would decrease, as illustrated in Figure 2 (Vollert, et al., 2023).

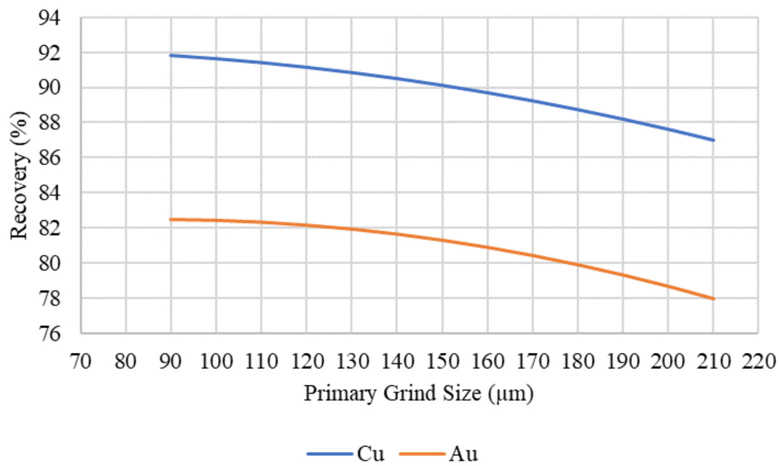

Figure 2: Grind Size vs Recovery for Cadia East Ore (without CPF) (Vollert, et al., 2023)

The two particle classes that contribute most to these losses are coarse particles (+150μm) with low surface exposure of sulfides and fine particles (-7μm) that are liberated but challenging to recover due to surface occlusions and slower flotation rates (Runge, et al., 2014). With the coarser primary grind resulting from the increased throughput delivered by CXP Stage 1, these coarse, low-grade composites became the primary target for recovery improvement in Stage 2. Traditionally, such losses are addressed by installing additional secondary or tertiary comminution power to reduce the grind size of the entire flotation feed stream. For Concentrator 1, the concept study determined that achieving a primary grind size of 110µm would require a fourth grinding train, including a 9.5MW ball mill in closed circuit with cyclones.

However, adding another ball mill train would involve high operating costs, primarily driven by the high cost of power in Australia, and would further complicate efforts to meet sustainability targets. By the time of the CXP pre-feasibility study in 2018, an alternative to the additional ball mill train had been successfully demonstrated through the metalliferous mining industry's first full-scale trial of coarse particle recovery using coarse particle flotation (CPF) technology at Cadia. Concentrator 1 operates three parallel ball milling-rougher flotation circuits, known as Trains 1, 2, and 3. In 2018, the newly commissioned Train 3 (T3) CPF circuit began recovering coarse, value-bearing composites from conventional flotation tailings without the need for additional upfront power to reduce particle size for better mineral liberation (Vollert, et al., 2019).

A factor of merit analysis concluded that extending CPF technology to Trains 1 and 2 (T1/T2) was the preferred option for the feasibility study. Although there was perceived to be increased technical risk due to the relative immaturity of CPF technology for sulfides, the analysis showed a more than 45% reduction in power consumption would be achieved equating to ~50% reduction in CO_2 emissions per kilogram of copper produced when all scope 2 and 3 emissions are considered (Figure 3). Combined with an overall recovery benefit across various throughput scenarios, CPF presented a stronger economic case. Other advantages of CPF over fine grinding, such as its impact on tailings storage and water recovery, were qualitatively considered, although no financial value was attributed to them. In retrospect, these considerations were critical for Cadia's long term sustainability as it enabled tailings optionality that would have been otherwise closed had a conventional ball milling design been pursued.

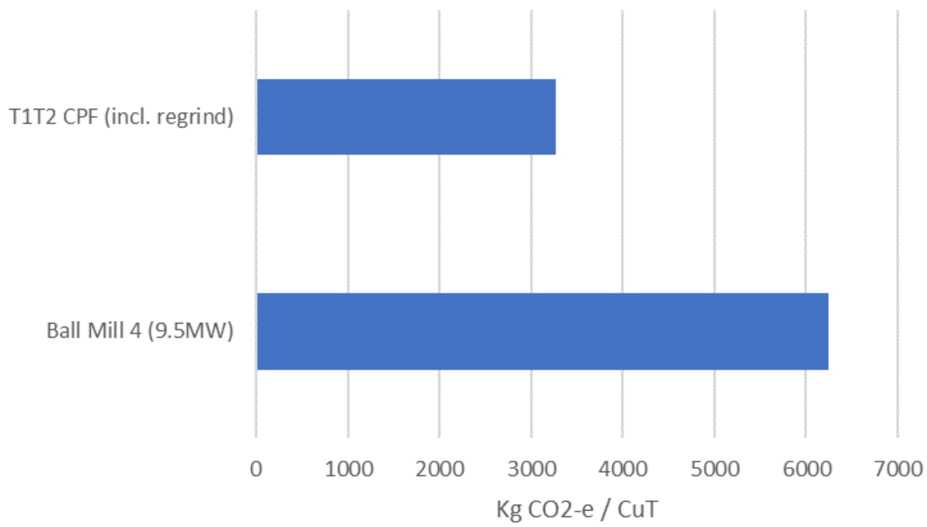

Figure 3 - Estimated GHG intensity of the two flowsheet options

2. TRAIN 1 AND 2 CPF FLOWSHEET DEVELOPMENT

Coarse particle flotation using the Eriez HydroFloat™ has been operating on T3 of Concentrator 1 at Cadia since its commissioning in mid-2018 (Vollert et al., 2019). The T3 CPF project was an industry first application of full-scale HydroFloat™ cells for the recovery of coarse composite copper and gold from tailings and provided the Cadia technical team with valuable learnings around design, operation, and metallurgical performance all of which were then incorporated into the CXP Stage 2 feasibility study for extension to Train 1 and 2 (Jaques, et al., 2021). Two significant design philosophy changes applied to the Train 1 and 2 design were the removal of Crossflow™ teeter bed separators ahead of the HydroFloat™ units and incorporation of dedicated CPF concentrate regrind and cleaning to the flowsheet.

The CrossFlow™ demonstrated at full scale to produce a very efficient cut with minimal fines bypass, however the benefit was outweighed by operational stability issues and reduced circuit flexibility. A dual stage cyclone classification circuit was pursued for Train 1 and 2. A loss in classification efficiency and increased fines presentation to the HydroFloat™ was a technical risk with a dual stage cyclone circuit (Figure 4). The technical risk being primarily excess fines leading to increased viscosity in the freeboard zone resulting in unselective recovery of coarse fractions to concentrate due to their inability to settle. The HydroFloat™ unit process is a teeter bed separator with air injection to prompt bubble particle attachment. Any fine (-75um) particles present will be fluidised into the overflow, in addition to creating settling and/or selective separation issues due to changes in cell viscosity. This was derisked by completing necessary field trials and laboratory testing on Cadia East Ore during the project development phases (Vollert, et al., 2023). The standard Newmont design for future CPF installations will use dual stage cyclones to prepare HydroFloat™ Feed instead of CrossFlow™ Classifiers.

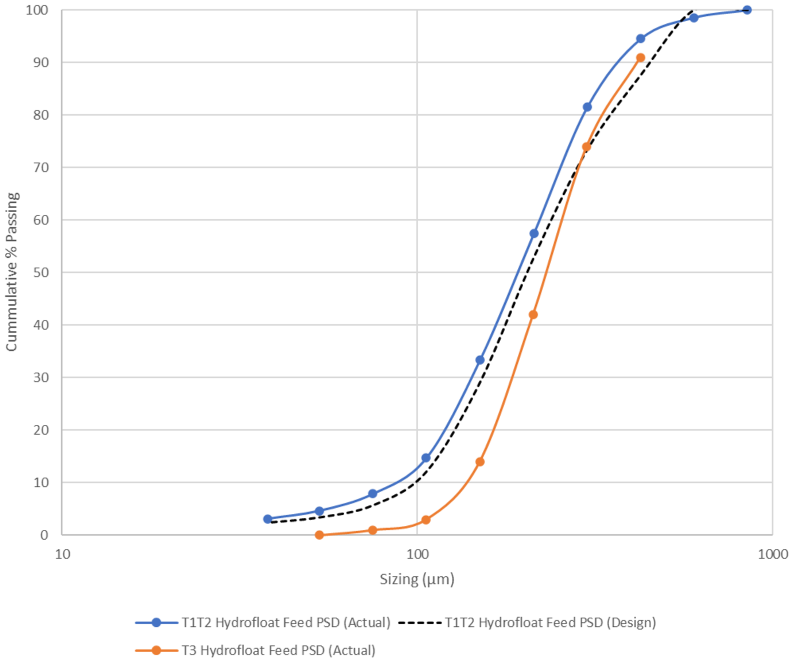

Figure 4 - HydroFloat™ Feed PSD's

The decision to upgrade the HydroFloat™ concentrate via a dedicated regrind and cleaner flotation cell is aimed at maximising CPF circuit recovery whilst also reducing the mass flow back into the existing Train 1 and 2 regrind and cleaner circuit. Leveraging the learnings from the T3 demonstration CPF circuit where concentrate regrind treatment is in combination with conventional rougher-scavenger concentrate. This creates a suboptimal bi-modal size distribution feeding the conventional cleaning regrind circuit which reduces the overall liberation achieved through the regrind circuit (Figure 5). The Train 1 and 2 CPF circuit Jameson cell targets 80% recovery of the copper and gold from HydroFloat™ concentrate into 2% of the mass, producing approximately 2 tph of final CPF concentrate at concentrate grade of ~18-20% copper.

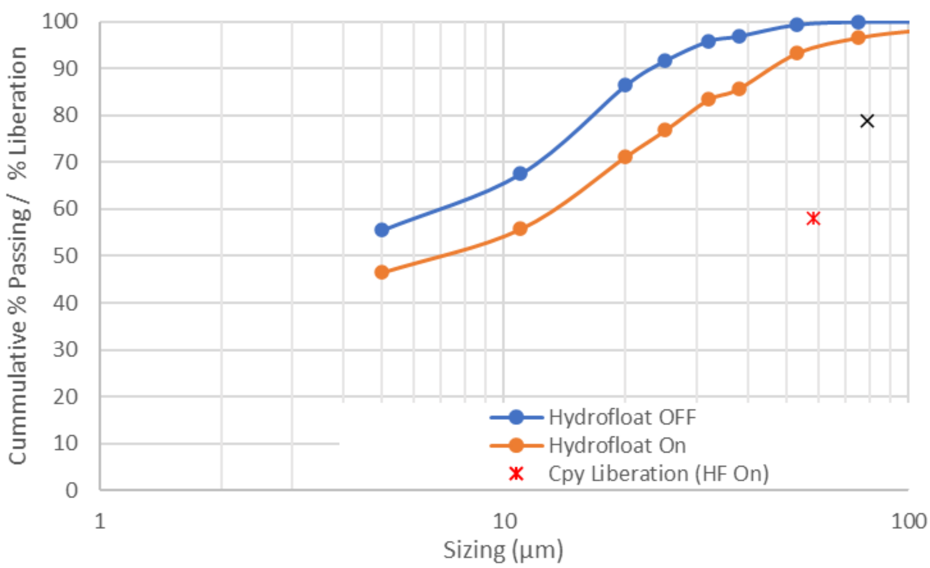

Figure 5 - T3 Regrind Cyclone Overflow with HydroFloat™ Concentrate On vs Off

Lab flotation test work (Figure 6) using the dilution method to simulate Jameson cell performance was conducted during the feasibility study on bulk samples of coarse concentrate from the T3 HydroFloat™, with varying re-grind product size distributions. The goal was to determine the regrind product size and hence quantum of dedicated grinding power needed to achieve sufficient liberation for upgrading the coarse concentrate. As anticipated, the flotation recovery of copper from the HydroFloat™ concentrate increased with a decrease in grind size, which improved mineral liberation. To produce a final concentrate copper grade directly from the CPF circuit, a regrind product size of 24µm would be necessary. However, the target recovery can be attained with a grind size of 38µm. With the significant reduction in mass, the intermediate-grade stream can then be returned to the existing T1/T2 cleaner circuit for further regrinding and upgrading along with the rougher concentrate stream. However, design optionality was also included to easily redirect the Jameson concentrate to final concentrate.

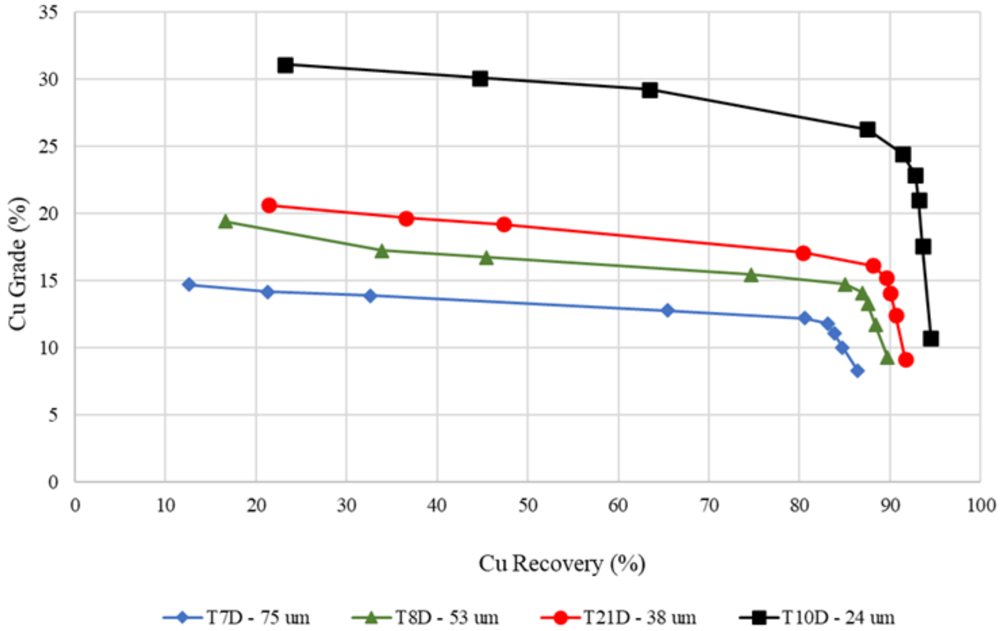

Figure 6 - Cadia East Ore; HydroFloat™ Concentrate Regrind Copper Grade-Recovery Curve (Vollert, et al., 2023)

A Vertimill® was selected for the regrind duty mill due to the product target size, reduced footprint and commonality with existing mills on site. Equipment sizing for a Vertimill® in this duty is challenging. The fines deficient feed and significant reduction ratio introduce uncertainty in the results of the different laboratory methods. Mill sizing was assessed using a number of different methods during the Feasibility stage, determining to exclude the Metso Jar mill test results and take the average of the specific energy from the Nippon-Eirich Tower mill test, Levin Test and Modified Levin Test corrected for Vertimill®. (Vollert, et al., 2023). The mill selected and installed was a VTM4500 (3350kW), an increase in the mill sizing due to uncertainty in the mill power demand and the known under sizing issues inherent with vertical screw type mills (Figure 7). The actual operational specific energy is higher than predicted, with the operational work index 10% above design. However, due to the conservative equipment selection no detrimental impact to regrind product size has been observed.

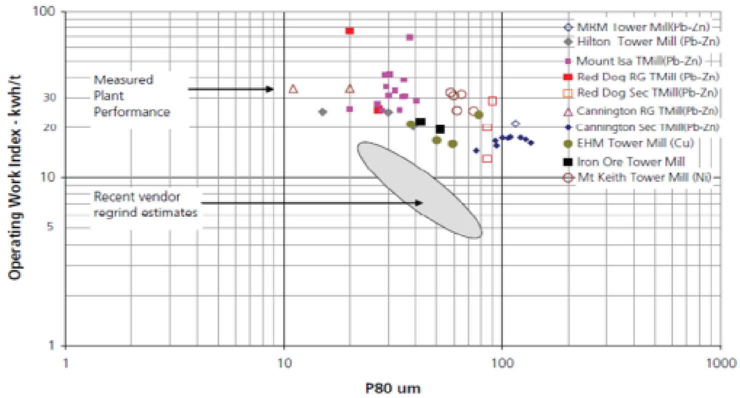

Figure 7 - Tower Mill Work Index Summary (Pease, 2010)

The Train 1 and 2 CPF circuit (Figure 8) consists of two stages of cyclones in series to remove -75µm particles before presentation to four 4.26-meter (14 ft) HydroFloat™ cells to recover the coarse value mineral particles into a concentrate. This concentrate stream is then dewatered before it is ground in a dedicated closed circuit regrind Vertimill® and then further upgraded in a Jameson cell before returning it to either the existing T1/T2 cleaner flotation regrind circuit or final concentrate. The tailings stream from the Jameson cell is returned to the primary cyclone feed hopper. The coarse tailings from the HydroFloat™ cells combine with the fine material from the primary, secondary and dewatering cyclone overflow streams to make up the final plant tailings which is thickened and pumped to the tailings storage facility.

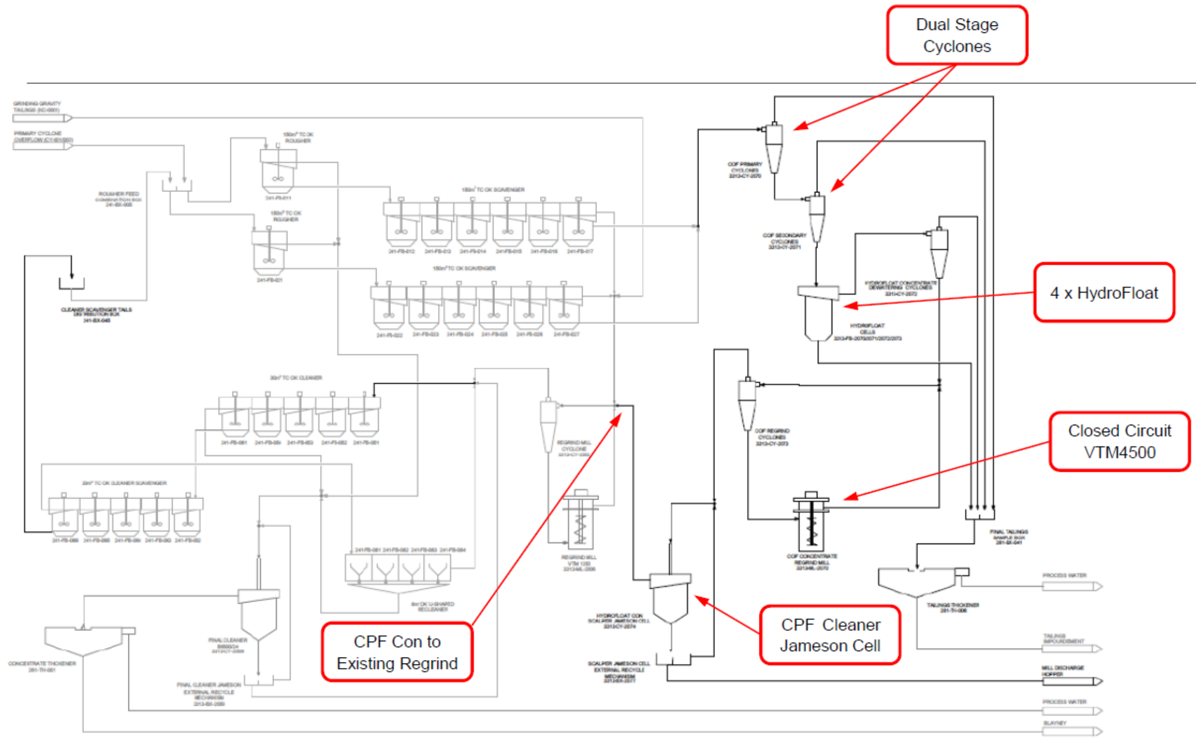

Figure 8 - Train 1 & 2 CPF Circuit Flowsheet

3. TRAIN 1 AND 2 METALLURGICAL BASELINE PERFORMANCE

Application of the lessons learnt from the T3 demonstration CPF circuit (Vollert, et al., 2023) (Jaques, et al., 2021) into the design of the T1/2 circuit has delivered an improved circuit which exceeds design and was ramped up to design recovery within three months (Figure 9). The new T1/2 CPF plant was handed over from the project team to operations for slurry commissioning in November 2022. The mantra for slurry commissioning was 'go-slow to go-fast' and an extended 4-week period was taken during commissioning to robustly test the full system again on water. The process control sequencing and instrument tuning was given significant attention prior to any slurry introduction. The design CPF circuit target of 30% gold and copper recovery and 93% availability was achieved within the first 100 days of commissioning.

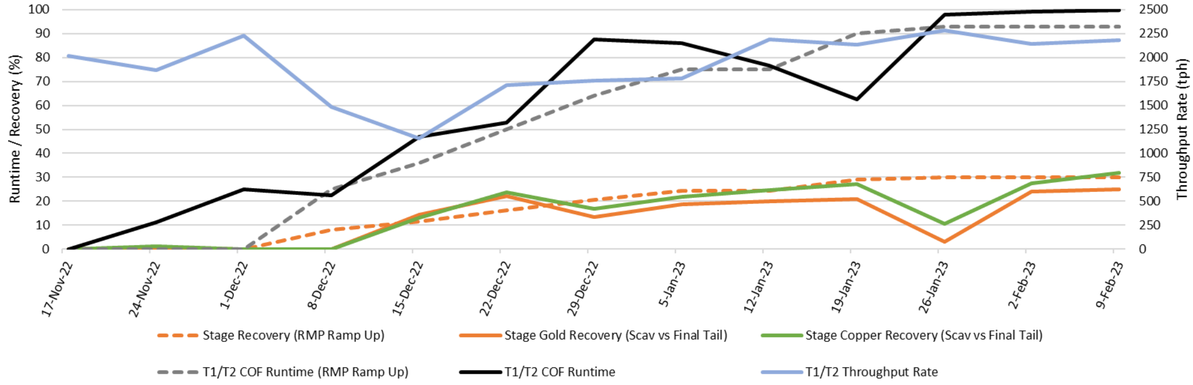

Figure 9 - Train 1 and 2 CPF ramp up curve, 7-day aggregated data

A detailed metallurgical survey was completed on the 8th February 2023 to baseline the circuits performance prior to commissioning completion. Selective recovery of the target metal species through the flowsheet is illustrated in the Sankey charts (Figure 10 and Figure 11). The circuit is achieving 0.1% mass recovery at >30% copper recovery to Jameson cell concentrate. Above the design target of 30% copper recovery. The concentrate grade delivered from the single Jameson cell is 20 - 24% copper at an enrichment ratio of 25; above the design concentrate grade target of 18-20%. A high enrichment ratio and above design concentrate grade is enabled by above design mineral liberation achieved by the dedicated regrind mill. The HydroFloat™ mass pull achieved is slightly below design, which increases the specific energy available in the dedicated regrind mill. The measured regrind circuit P80 is 30µm, below the design of 38µm. This presents an optimisation opportunity to push the overall circuit beyond the design recovery parameters through increased selective HydroFloat™ mass pull.

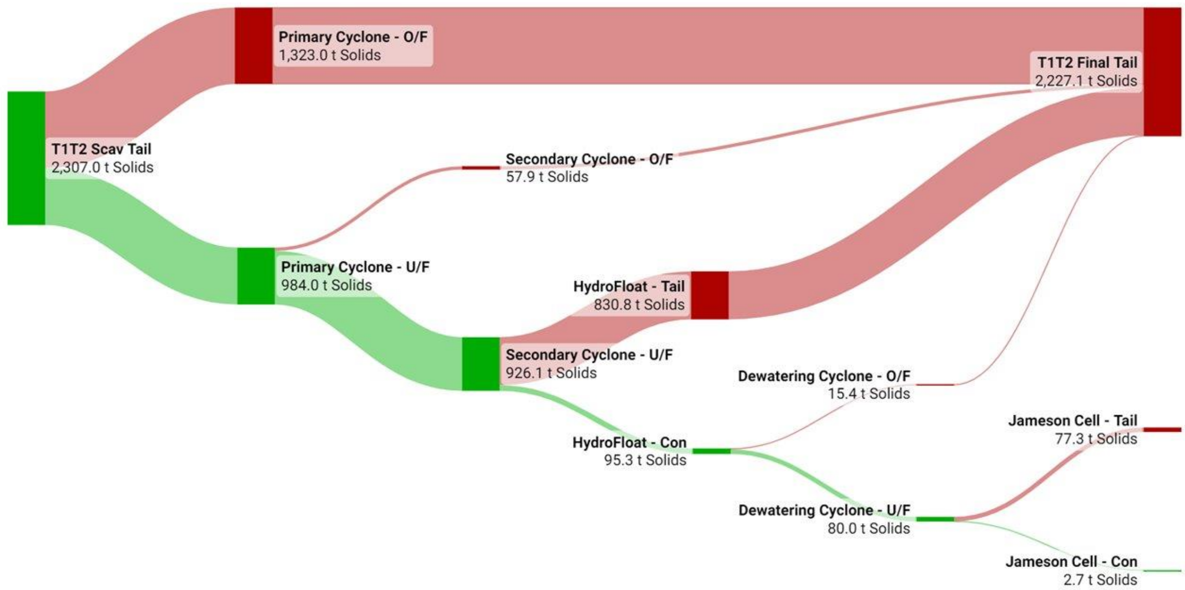

Figure 10 - CPF Mass Recovery by Unit Operation

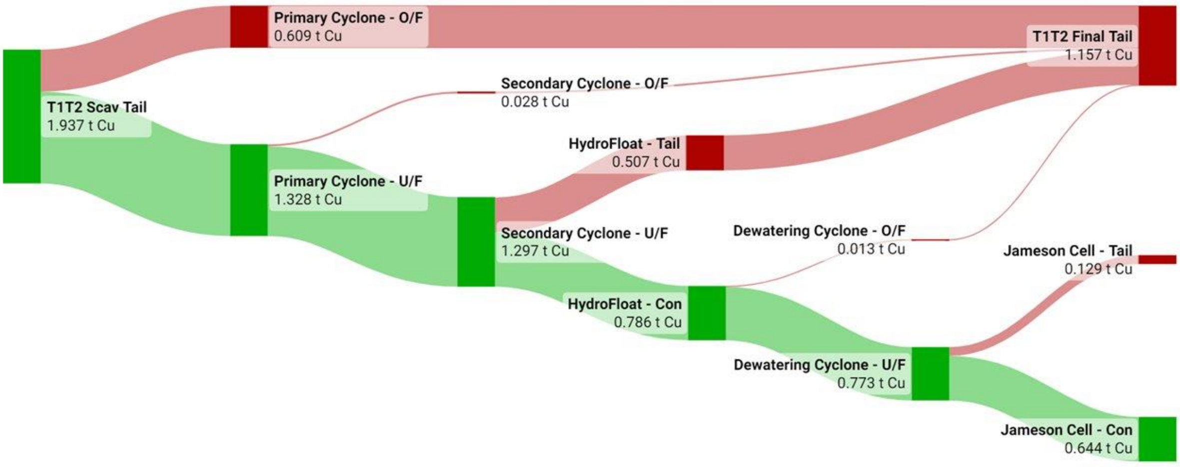

Figure 11 - CPF Copper Metal (t) recovered by unit operation

The T1/T2 CPF design recovery was determined from the T3 metallurgical size by recovery. The T1/T2 CPF circuit has delivered above design recovery on a size by recovery basis for coarse particles (+150µm) and below design for fine particles (-106µm) (Figure 12). The target recovery size classes for the CPF circuit are +150µm. Particles in the size classes below 150µm should be recovered within the conventional circuit, with any losses in these size fractions addressed within the conventional circuit itself.

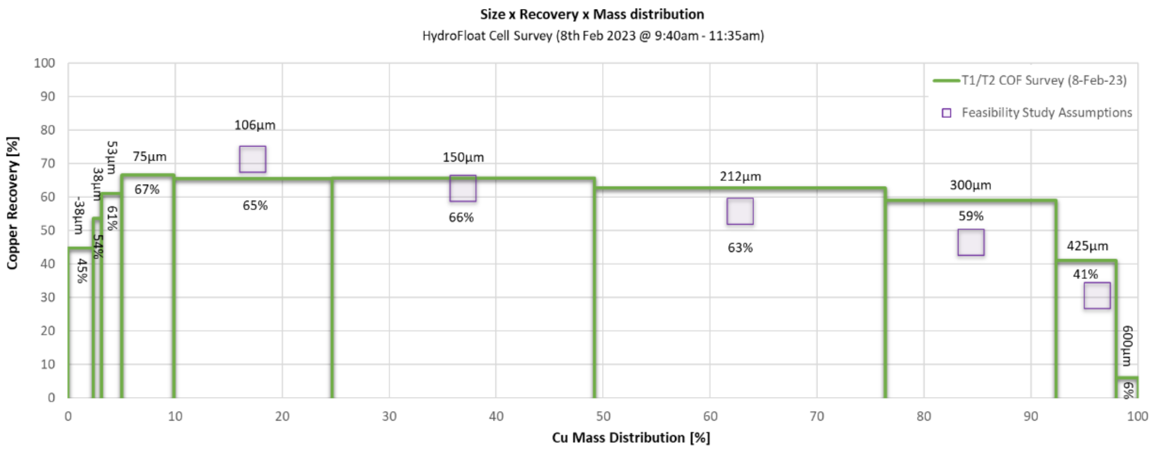

Figure 12 - Train1 and 2 CPF Size by Recovery

4. TRAIN 1 AND 2 CIRCUIT OPTIMISATION

The successful deployment of the T1/T2 CPF circuit has shifted the liberation-recovery relationship, flattening the tradeoff between recovery and grind size for copper and gold. The flattening of the recovery-grind size tradeoff opens the possibility to challenge the economic breakeven point for throughput in T1/T2, beyond the design expectations of the circuit. However, several areas existed for operational optimisation that would lead to improved metallurgical outcomes. A dedicated optimisation process was completed over 12 months, targeting the key areas identified in collaboration with Eriez, Group metallurgy and site.

The optimisation program focused particularly on the following key areas;

- Process Control & Instrumentation improvements targeting stability
- HydroFloat™ Parameters, Feed Properties & Wear
- Circuit Water Balance Optimisation

Not all aspects of this optimisation work will be discussed in this paper. However, the methods taken to address the changing operational behaviour due to the increased fines fraction will be discussed. Increasing fines content to the HydroFloat™ feed changes the hydrodynamic conditions within the HydroFloat™ cell. A teeter bed separator typically has an increasing density profile with depth from the concentrate lip. However, the -75um fines entrained will accumulate within the freeboard zone due to the fluidization of the teeter bed. This is observable in the Train1 and 2 HydroFloat™ units where the density profile is flat after the first 30cm of the cell depth, distinctly different to the Train 3 HydroFloat™ (Figure 13). This increase in density higher in the cell necessitates changes in the operational strategy and instrumentation requirements to optimally operate the cells in T1/2. The notable changes included repositioning the ball floats higher in the cells, modifying secondary cyclone internals to reduce the underflow density, feed and teeter water addition to a determined maximum and controlling cell feed density more actively. The results of these changes improved the cell surface dynamics and teeter bed stability, contributing towards the incremental circuit recovery improvements.

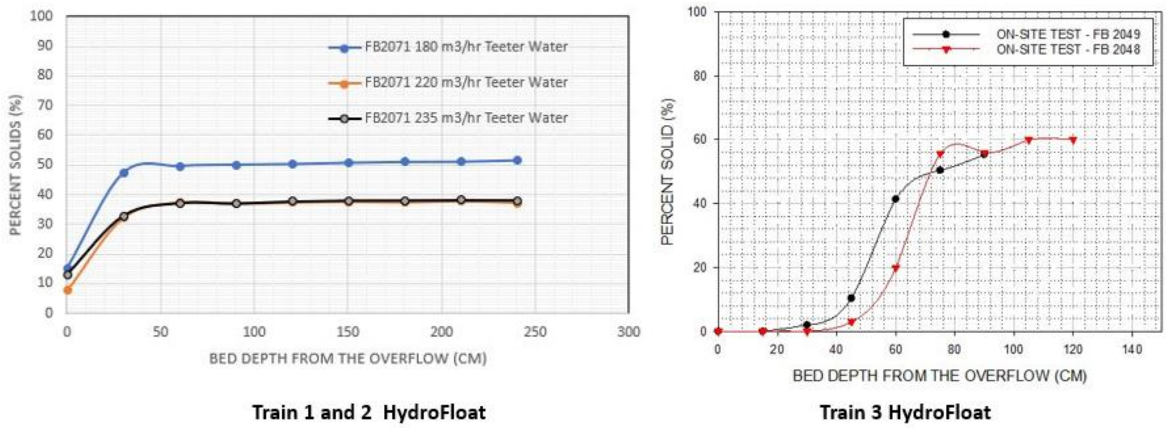

Figure 13 - HydroFloat™ Density Profile Comparison

A new design feedwell was developed and supplied by Eriez to counteract an increase in feed fines (-75um) presenting to the HydroFloat™. The principle of the feedwell was to dissipate energy from the feed slurry stream and help short circuit entrained fines to the concentrate. The feedwell is fed via a gravity flow which impacts tangentially due to the plant layout. The tangential flow dynamic caused issues with the teeter bed stability due to uneven distribution of feed into the HydroFloat™ from the feedwell, and accelerated localised wear within the feedwell. Modifications were made to the feedwell and retrofitted to the cells within the first 12 months of operation (Figure 14). The notable design changes included moving the dispersion plate closer to the feed pipe discharge point and ceramic lining the surfaces. An orifice plate was also installed into the feed pipe to assist in centralising the discharging flow onto the dispersion plate. The 'splash-skirt' was also removed as it was observed to be trapping entrained air from the slurry entering the feedwell and creating localised boiling, a phenomena counterproductive to recovery of coarse particles. The air was speculated to be entrained due to lack of energy dissipation occurring in the former design. The phenomena has not been witnessed since the skirt was removed.

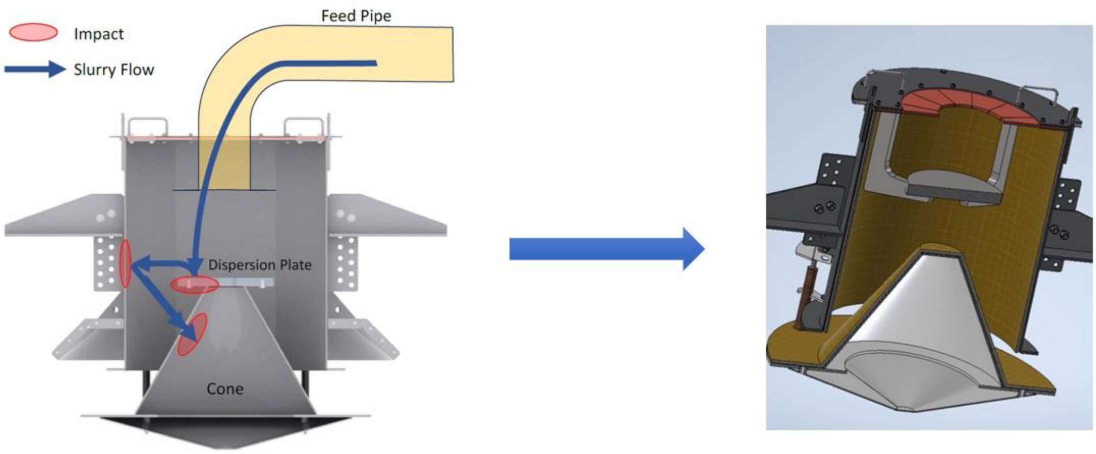

Figure 14 - 14ft HydroFloat™ feedwell supplied by Eriez

The expansive program of optimisation work built on the foundation of a robust plant design, which enabled design recovery within 100 days of project water commissioning completion. After 12 months of optimisation monthly HydroFloat™ recovery is 15%(rel.) above the design point for copper. To date the circuit copper recovery has outperformed gold recovery by 2-3%(abs.), both remain well above design. The driver of the slight recovery bias for copper over gold has not yet been defined, with diagnostic metallurgical work ongoing.

5. FUTURE TAILINGS & WATER OPPORTUNITIES

Improving mine tailings management is an industry imperative to a sustainable future. Newmont is committed to the Global Industry Standard on Tailings Management with the goal of zero harm to people and the environment. Conventional wet tailings dams are increasingly difficult to permit, build and operate. Embankment design is increasingly moving towards downstream or centerline methods for wet dams; requiring large volumes of competent, non-acid generating rock-fill. The block caving mining technique used on the Cadia East Ore body generates minimal levels of development waste rock. Sub-economic underground draw points are turned off and the waste left in-situ. This creates very low cost mining but presents long term challenges to tailings dam construction. The existing tailings storage facilities at Cadia were constructed using waste fill from the Cadia Hill pit which ceased operations in 2014. The surface tailings storage facilities do not have sufficient capacity to meet the operations life of mine tailings demand meaning Cadia will require additional storage in the future.

The salient long-term decision making during the technical tradeoff for CPF vs Ball Milling has enabled alternative options for tailings deposition and dam construction. Cadia is now applying to extend its operating license from 2031 to ~2050, inclusive of an extension to existing southern tailings storage facility (Minesoils Pty Ltd, 2024). The life of facility tailings storage extension will be constructed using a sand embankment, a method common in other areas of the world, particularly Chile. The quantum of sand possible to produce is proportional to the flotation feed size. In the case of nominal operations at a P80 of ~200µm, 33% of the tailings can be classified as 'Sand' suitable for embankment construction. This quantum is enough to meet the embankment design requirements of 27%, inclusive of design factors. However, in the alternative ball mill case where a target P80 of 110µm was proposed, 22% of the tailings may be suitable as sand (Figure 15). This is not sufficient volume for embankment construction and alternative material would need to be sourced and placed at additional cost.

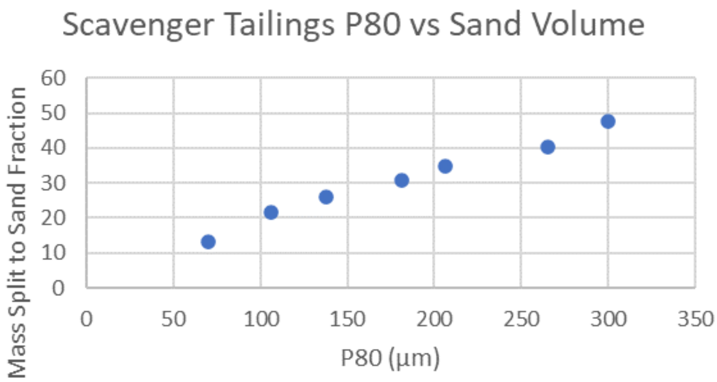

Figure 15 - Sand volumes generated assuming the efficiency curve of the Cadia CPF circuit

Tailings dam design has historically been one of four typical types; conventional wet tailings (un-thickened), thickened tailings, paste tailings or filtered tailings. The drivers of design selection are a combination of regulatory, economic and environmental. A key environmental and operational consideration is the site's water efficiency. Tailings dam design and management will dictate water recovery and subsequent demand of the site (Table 1). The water demand is measured as the meters cubed per tonne (m^3/t) of tailings deposited, or more recently shifting to meters cubed per tonne of valuable metal recovered. The latter metric better showcasing the reducing water efficiency observed as operations scale throughput higher to combat declining feed grades (Lane, et al., 2019). The majority of an operation's tailings return water is sourced from the supernatant, with minor seepage collection. Factors impacting water loss are principally entrainment to tailings, evaporation and uncontrolled seepage loss (Williams, 2020). Whilst it is acknowledged in the literature that conventional or thickened dams water recovery can match paste thickened, this is often restricted to the early years of operation when the dam rate of rise is high and the tailings surface stays wetted. After 10 years of operation when tailings embankment rate of rise slows, water recovery will drop, straining an operations water cycle during what are typically lower grade production years (Lyell, et al., 2008). South American operators Lundin at Caserones and Capstone at Mantos Blancos have been pioneering a new method of dam design which reduces the footprint and increases the water recovery relative to a traditional wet dam. Referred to as hybrid technology, the free-drainage properties of sand is exploited to uplift the total water recovery by separating the sand from the slimes and subsequently thickening the slimes. (Barrera & Caldwell, 2015). Similarly Anglo American at El Soldado is pioneering hydraulicly dewatered tailings (HDS) at a demonstration scale as an engineered co-disposal technology that increases tailings consolidation and reduces water entrainment. (Newman, et al., 2023).

Table 1 - Tailings Design Water Demand Best Practice (Barrera & Caldwell, 2015)

Tailings Dam Design Option	Water Demand m^3/t
Conventional (Un-thickened)	0.36 – 0.7
Thickened	0.3 – 0.6
Paste Thickened	Not reported
Filtered Thickened	0.2 – 0.4
Hybrid - Sand Slimes Split Tailings Technology (SSSTT)	*0.3 – 0.4*

Cadia has been practicing in pit tailings deposition since the 2018 northern tailings facility wall failure. Cadia's water demand during this period ranged between 0.56 – 0.75m^3/t, averaging 0.61m^3/t (Newcrest Mining Limited, 2024). Noting that external water was harvested following the 2019 drought, biasing the data high in the proceeding period. A demand of 0.47m^3/t during the drought years of 2018-2020 is considered the site best current practice water usage. The proposed life of facility tailings dam will utilise hybrid sand-slimes split tailings technology. If best practice water demand can be achieved, the water savings by moving to a technology of this nature is between 1800 – 4300 ML/annum of water measured against the baseline 0.47m^3/t.

A project shortcoming of the coarse particle recovery circuits at Cadia was failing to realise the value of keeping the CPF separated sand apart from the fines all the way through to tailings storage. The CPF design produces a tailings stream with a lower fines (-75µm) content than can be achieved in a conventional tailings cyclone station, due to multiple pre-classification stages followed by hydraulic classification in the HydroFloat™ cell (Figure 8). A typical specification for sand product requires it to have less than 20% passing 75µm in the sands (measured by screen analysis), Figure 4 is an example of the HydroFloat™ feed distribution from Cadia CPF, demonstrating less than 10% of the mass in that stream is passing 75µm. A view during CPF circuit design should be taken to maintain a separate valuable sand stream or design in this philosophy for future cases. In the case of Cadia, the sand stream from the HydroFloat™ will deliver a positive revenue impact to the operation through capital efficiency found in tailings construction. Operations utilising the block cave mining method in particular may be able to improve their operations economic and environmental sustainability by changing tailings embankment construction methodology by leveraging CPF.

Due to the design shortcomings in the CPF facilities at Cadia, separation of sand requires a brownfield retrofit. A pre-feasibility study focusing on brownfield modification to the existing CPF circuits was completed in 2024 and is progressing into Feasibility in 2024/2025. This project was initiated to find capital efficiency in the base case life of facility tailings project, which completed Pre-Feasibility in 2021, and recommended building a new dedicated sand separation plant and sand embankment dam. However, following the successful commissioning in 2022/2023 of the T1/2 CPF, renewed focus was applied to the sand separation achieved by the existing HydroFloat™ cells and an options study was initiated in 2023. Several options were considered, utilising conventional technologies for material separation and transportation, namely pipes, pumps and cyclones. The design incorporates optionality to switch back to the nominal thickened tailings flowsheet on the run. The selected process block flow diagram is detailed in Figure 16.

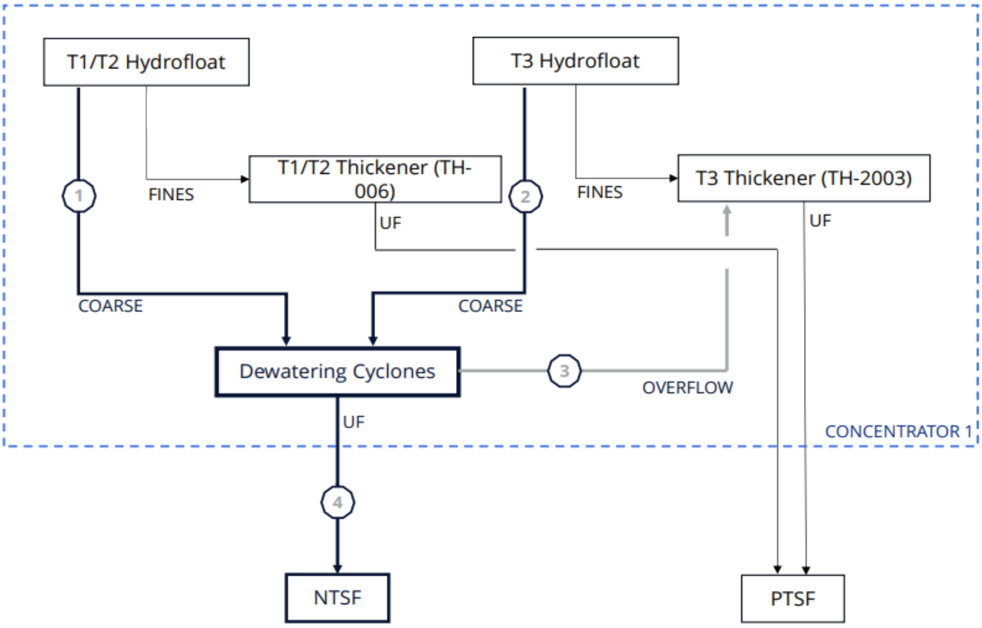

Figure 16 – Concentrator 1 Coarse Tailings Separation and Slimes Thickening flowsheet utilising existing process equipment.

1. New pipeline for T1/T2 to a new dewatering cyclone located within the footprint of the existing concentrator
2. New pipeline for dewatering cyclone overflow to the existing T3 tailings thickener
3. New cyclone overflow pipeline of fines to T3 tailings thickener
4. New coarse sand hopper, pump station and pipeline to the tailings storage facility

Following project completion Concentrator 1 will transition from producing two thickened tailings streams at a nominal P80 of 200um to three tailings streams. The existing two tailings thickeners remain and transition to a 'slimes' thickening duty at a ~40% lower flux rate (m^2/t/h) and >90%wt -75um feed when operating as per Figure *16*. The remaining 'coarse tailings' stream generated is ~15%wt -75um, well within the geotechnical placement parameter of 20%wt -75um which is pumped directly to the tailings facility at ~60%wt solids. The process fundamentals for the design proposed are robust. Streams 1 and 2 present for dewatering at densities <30%wt solids and <20%wt -75um, enabling efficient classification and minimal fines entrainment to underflow. This contrasts with conventional cyclone sand facilities operating at feed densities >40wt% and higher fines contents. The design currently can produce sufficient sand to meet the embankment requirements for the life of facility tailings dam embankment. Creating opportunities for tailings placement such as terraforming sand stockpiles, increasing the tailings embankment factor of safety or finding a market for the excess 'Ore-Sand'.

6. TAILINGS VALORISATION

'Ore-Sand' is a relatively new term to describe the value that can be derived from mineral processing tailings or mine waste streams. Vale S.A. has recently produced Ore-Sand at the Brucutu iron ore mine in Minas Gerais, Brazil (Golev, et al., 2022). In 2022, samples from Cadia's T3 CPF facility were collected and tested at the University of Queensland to characterise physical, chemical, geotechnical, mineralogical, and environmental properties (Seguara-Salazar & Franks, 2023b).

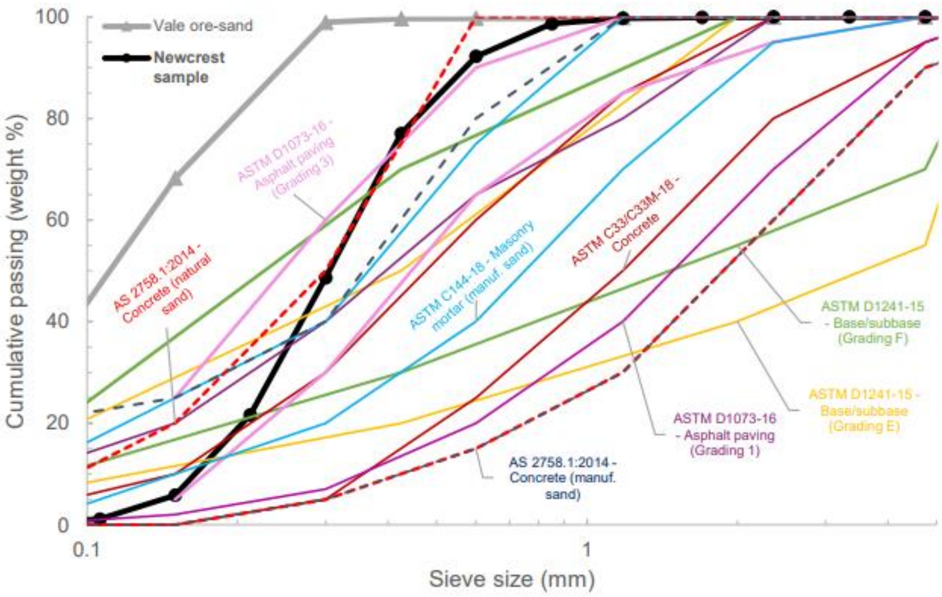

Figure 17 - PSD of Cadia CPF sample (Black line) vs specifications of construction sands (Seguara-Salazar & Franks, 2023b)

Cadia CPF product (Figure 17) is close to complying with the grading requirements for applications such as asphalt paving (grading 3) and is within the grading envelopes for natural sand in concrete as recommended by the Australian standard (AS 2758.1:2014). Modal mineralogy determined sulphide species present as pyrite and chalcopyrite at 0.03wt% and 0.15wt% respectively. Sulphides are deleterious to concrete manufacturing and European standards set limits of Sulphur (exclusive of pyrrhotite) at <1.0wt% S_{tot} (Benarchid, et al., 2019); Cadia's sand product is well within this specification. The size-by-assay sulphides observed are consistent with Benarchid findings on a Canadian Ore-Sand. Similarly, the Toxicity Characteristic Leaching Procedure (TCLP) findings are of inert or non-hazardous based on comparisons with local regulations for metals. (Seguara-Salazar & Franks, 2023b). Based on the physical, chemical, mineralogical, geotechnical and environmental characterisation, it is inferred that the analysed sandy sample from Cadia's HydroFloat™ equipment is a material that can potentially be used as a novel alternative sand (i.e., Ore-Sand) in the construction sector.

There are, however, some barriers to be overcome for the uptake of Ore-Sand in practice, such as customer support for the product, transportation economics and government support. Selection of the right transportation mode and identifying the right markets will be the defining variable in making Ore-Sand a sustainable and economic alternative for any potential producer. The analyses of Ore-Sand's greenhouse gas (GHG) footprint conducted on Vale S.A product found it to be ten times lower than conventional sand quarrying methods (Golev, et al., 2022). The same research also demonstrated that a delivery distance greater than 35km using small trucks will erode the GHG emission abatement achieved. Selection of the right transport mode is critical to a sustainable product. Ore-Sand will not be viable for all mining operations due to their distance to market and logistical complexities which create inefficiencies from the GHG perspective. These are variables which compound to make Ore-Sand a less competitive and less sustainable alternative. Cadia is 22km by road to the nearest train terminal, and from there ~300km to the nearest export port in Sydney, additionally there is demand for sand from central west regional infrastructure projects which may present opportunities. Cadia is currently permitting an extension to the operating license from 2031 to ~2050. Whilst the customer market and logistical pathway is not fully defined now, the foundation will exist to test 'Ore-Sand' as an additional revenue stream within the lifetime of Cadia.

7. CONCLUSIONS

Improving the operations' sustainability within the context of ore processing requires operators to invest in research and development and be open to new ideas. Early adoption and demonstration scale research and development at Cadia with regards to coarse particle flotation enabled a more sustainable process selection to be made during the plant expansion. The selection of coarse particle flotation not only delivered a 48% reduction in green-house gas emission potential versus the fine grind alternative but also unlocked a more sustainable tailings future. Coarse particle flotation circuits in a scavenger duty can utilise dual stage cyclones as HydroFloat™ feed preparation and should consider dedicated HydroFloat™ concentrate regrind and cleaning. The coarse particle flotation circuit is also an effective sand separation process, the value or potential value of the sand stream should be considered during project development phases as a future opportunity.

The technology readiness of coarse particle flotation using the HydroFloat™ is proven in base metals and should no longer be considered a novel technology. The opportunity now is innovating towards more sustainable processing and tailings dam designs from the opportunity presented.

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