Debottlenecking Concentrate Dryer Feed Using a Machine Learning Approach

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ABSTRACT

WGA worked with site metallurgists to address challenges in accurately predicting the performance of a concentrate dryer in a smelter plant during periods of low throughput. Working closely with site metallurgists and guided by their operational expertise, WGA used machine learning to identify the key drivers impacting the plant's performance at low throughput states, to identify opportunities to improve throughput and debottleneck the plant.

WGA extracted a large amount of data over a 10-year period, including instrumentation and assay results. The data was cleaned and pre-processed to improve its quality, and several machine learning algorithms were trained on the data to generate a model that could predict the expected dryer throughput. Operations personnel guided interpretation of correlation versus causation relationships and applied their operational metallurgical expertise to ensure the model made 'metallurgical sense'. This novel approach of using machine learning provided a more comprehensive understanding of the factors that influence smelter operation, beyond what was possible with traditional stoichiometric models.

The model was then deployed in Excel, allowing the operations team to understand the expected dryer throughput at current conditions and make adjustments to optimise its performance. The model is used to answer the question – is the dryer behaving as expected at this low throughout, and if not, is there a key driver that is not at a 'normal' state that points to the bottleneck.

This approach of using machine learning to identify the key drivers of performance and predict outcomes in complex systems is an effective solution to many operational challenges. The ability to consider a large number of variables and interdependent relationships, combined with the accuracy of the predictions, makes machine learning a valuable tool in optimising performance in industrial settings.

It is All in Scope

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ABSTRACT

Navigating the new era of sustainability reporting for mining and minerals. It's all in scope with new Australian legislation coming in 2024.

Globally and in Australia, legislators, shareholders, investors, employees and market sentiment have aligned to demand sustainability reporting transparency, particularly for energy-intensive industries. Driven by the International Sustainability Standards Board (ISSB), leading European Union (EU) bodies, the U.S. Securities and Exchange Commission (SEC), and the Safeguard Mechanism in Australia, new standards will require disclosures on sustainability indicators such as GHG emissions across Scopes 1, 2 and 3, water, energy, air quality, waste, hazardous materials, pollutants, nature-related risk factors, Product Carbon Footprint (PCF), Life Cycle Assessment (LCA) and TNFD impacts.

The need for periodic reporting in a machine-readable digital taxonomy, scenario analysis and forward-looking statements means that data-driven technology is the only solution to meet evolving compliance standards. Manual spreadsheets simply cannot capture or process the volumes of data needed to deliver immutable, unalterable and auditable sustainability reports.

This keynote paper explains how to leverage the latest machine learning technology to centralise asset-wide industrial data, dynamically simulate your operation as a process digital twin, perform an asset-wide mass and energy balance, and deliver granular, finance grade reports across sustainability indicators. It also explains how metallurgical accounting, production accounting and sustainability reporting go hand in hand for the mining and minerals industry.
Sustainability reporting is rapidly elevating to be on equal footing with financial reporting in terms of accountability and priority. With the Australian Securities and Investments Commission (ASIC) already cracking down on greenwashing with strong civil penalties, shareholder activists demanding action by boards, and share prices and capital markets hinging on ESG credit ratings, the time to prepare is now.

Use of On-line Digital Twins for Processing Plant Optimisation

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ABSTRACT

Digital twin technologies developed for the mining industry create new insights into the material flows and metallurgical processes. This provides an opportunity to optimize the operations of processing plants over the full production chain to manage impacts of variability in the feed materials, metallurgical processes, and the business environment. Digital twins with AI algorithms for automatic adaptation of physical process models are reliable for improving efficiencies and lowering emission footprints in daily operations. Recipe matching to variable ore types allows for significant savings in energy, water, and chemical utilisation per ton of product produced. With the ability to test and evaluate any process configuration and operating strategy before execution, the risk of environmental, financial or safety issues is greatly mitigated.

Increased knowledge and situational awareness of the process allows for better decision making and planning within the plant, resulting in better recovery and process optimization. Transparent tracking of material flows from the mine to the processing and refining plants with online material balances provide operations with information about material flows, as well as added confidence in the quality of data collected and reliability of assaying equipment and instrumentation.

This paper describes a case study where a modern science-based metallurgical digital twin was developed and deployed for the Dundee Precious Metals Inc Ada Tepe mineral processing plant in 2022. The case study discusses the key learnings and critical points in the implementation of a digital twin project. The paper further discusses the site's technical architecture with existing systems for process control and IT infrastructure. The impact on selected key performance indicators (KPIs) on metallurgy, sustainability and economics are also reviewed. Furthermore, the paper examines the future potential of metallurgical digital twins to deliver more sustainable solutions by reducing the mining industry's carbon and environmental footprint, as well as increasing the resilience for energy demand, water and materials.

Fine-tuning Mineral Liberation Circuit Performance through Machine Learning-Enabled Digital Twins

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ABSTRACT

Mineral processing circuits require continuous optimisation to achieve optimal performance. The use of digital twins and computational intelligence can greatly aid in this optimisation process. This paper proposes a novel approach to fine-tune the performance of mineral liberation circuits using machine learning-enabled digital twins.

Molycop Global has developed an intelligent computational framework for comprehensive mining of short-term and long-term historical processing data collected from liberation circuits to create versatile digital twins. The developed automated machine-learning platform is capable of preprocessing raw data, building data-driven models for various output variables and putting into practice the models for offline and real-time prediction, simulation and optimisation purposes.

Applying this platform, a digital twin of the mineral liberation circuit is trained and developed using historical data. Both classical and intelligent supervised, unsupervised, and reinforced learning algorithms especially metaheuristic ones can be applied to develop data-driven models including regressors, classifiers and clusterers to predict the key performance indicators of the circuit based on various input operating variables. Once developed, the digital twin is connected to the circuit's database management system and fed with the offline and/or real-time processing data, allowing for the simulation of the circuit under various conditions. Through this simulation, it is possible to analyse and predict the behavior of the circuit recalling the trained data-driven models and fine-tune the performance through the built-in plant-wide generalisation and optimisation engines.

Multiple case studies have been successfully handled amalgamating SCADA variables and Molycop advanced sensor technologies. The results show that the use of machine learning-enabled digital twins can significantly improve the performance of mineral liberation circuits. The proposed approach enables rapid plant-wide optimisation of the circuit, reducing the need for physical experimentation and improving efficiency.

Integrated flowsheet development for the Carmen de Andacollo Operation

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ABSTRACT

The Orica Digital Solutions team has recently developed a mine-to-concentrate flowsheet for the Teck Resources Carmen de Andacollo (CdA) operation using the Integrated Extraction Simulator (IES), a cloud-based platform designed to predict and optimize the performance of mining value chains. A combination of industry-standard phenomenological and Artificial Neural Network (ANN) models was used or developed for the blasting, comminution, and flotation circuits, respectively. The flowsheet was then used for life of mine (LOM) performance simulation, and the results were written back to the resource block model (block model conditioning) for various scenarios. The simulation scenarios, such as standard and less intensive blast designs, as well as the installation of a HPGR in the crushing circuit, were tested. Three levels of grinding circuit product sizes were also assessed in the study, in conjunction with the other scenarios. Finally, 3.6 million simulations were conducted in under a minute through the development of a MetaModel from the IES flowsheet.

The simulation results showed that the less intensive blast design had a minimal impact on plant throughput and metal production. However, installing a HPGR in the crushing circuit increased metal production by 10.6% at the optimum grind size. The paper outlines the steps involved in developing the integrated flowsheet and how it was used to generate bankable outcomes that can be used by CdA management to choose the scenario that maximizes their production over the remaining LOM.

Effect of Concorde Cell Technology Retrofit on a Self-Aspirated Flotation Cell

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ABSTRACT

Fine and ultrafine particles present challenges for recovery due to their slow kinetics and associated long residence times. However, the need to reclaim these particles increases as orebodies become more complex. The Concorde Cell™ was developed with the specific objective of overcoming these challenges for any given flotation application. The slurry is introduced at the top of the Concorde Blast Tube™ equipped with forced-air injection and maintained under pressure. The slurry reaches supersonic speed within the Blast Tube but reverts to sub-sonic conditions when discharged into the cell tank, thereby generating a shockwave before striking against an impingement bowl. This novel development opens up new possibilities for retrofitting into existing self-aspirated pneumatic flotation cells.

This paper summarises the Concorde Blast Tube upgrade into an existing self-aspirated pneumatic cell at an industrial application. Laboratory and pilot scale studies were conducted benchmarking the Concorde Cell to a self-aspirated pneumatic flotation technology already installed in the plant, leading to the subsequent replacement of said technology with the Concorde Cell. The metallurgical performance of both flotation cells at lab, pilot and industrial scale are discussed in detail.

Application of Depressant in Copper-Nickel Separation at IGO's Nova Mine

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ABSTRACT

Laboratory flotation testing conducted at the Nova Operation in June 2020 indicated that AERO® 7261A depressant was capable of replacing the triethylenetetramine (TETA) - sodium sulfite system in the sequential Cu-Ni flotation circuit. A plant trial, subsequently conducted in May-June 2021, demonstrated that AERO® 7261A depressant was a viable replacement for TETA in the copper flotation circuit, although the addition of sodium sulfite was still necessary for optimum performance. This paper details the plant trial methodology, the analysis of the plant trial data and the overall outcomes of the AERO® 7261A depressant plant trials.

Design of Coarse Particle Flotation Circuits for Copper Projects

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ABSTRACT

The HydroFloat™ cell was first implemented in a hard rock copper-gold application at Newcrest's Cadia operation in 2018. Units have since been installed at Kennecott, El Soldado and Mogalakwena (PGE's). Other projects under construction include Cadia T1/T2 and Quellaveco.

The HydroFloat cell enables the recovery of coarser particles at lower liberation classes when compared to conventional flotation cells by exploiting the following mechanisms;

- particle-bubble attachment in a fluidized bed
- quiescent flotation conditions to ensure particles and bubbles remain attached
- upflow of water for hydraulically assisted flotation, and
- overflow of a liquid phase from the cell without a froth interface to minimise particle drop-back

The net result can enable coarser grind sizes, with energy savings of up to 30% for every tonne milled. Furthermore, water consumption per tonne milled can also be reduced, and the tailings system can be redesigned to take advantage of the coarser product to reduce the quantity of fine tailings and reduce the tailings dam footprint. The net improvements to recovery, coupled with reduced energy and water consumption can substantially improve the economics of greenfield and brownfield copper projects.

Over the last five years, engineering and design developments have improved the operation of the cell and enabled more efficient HydroFloat circuit designs at lower cost.

This paper presents an overview of the key decisions and engineering considerations for the design of a HydroFloat Coarse Particle Flotation (CPF) circuit and integration within an existing operation or greenfield project. The paper discusses testwork program design and interpretation, flowsheet configurations, classification circuit design, reagent conditioning, concentrate dewatering, regrinding and recovery of CPF concentrate to final concentrate. The paper also presents opportunities around tailings management and the potential benefits to tailings storage, water and power consumption and outlines the strategies to maximise the business case. The challenges related to integrating the project with conventional resource planning and business case modelling approaches are also discussed.

Enhancing Recoveries from Low-Grade Ores and Tailings Using the Reflux Classifier Concentrator

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Abstract

The resources sector is facing the challenge of declining ore grades and increasing demand for metals, which requires the processing of lower-grade ores and tailings. However, this can be economically challenging due to the low concentration of valuable minerals and the high concentration of gangue minerals. The Reflux Classifier Concentrator (RCC) offers an efficient and cost-effective technology for the density separation and concentration of low-grade minerals. The RCC is a modified version of the original REFLUX Classifier (RC) technology and includes two key modifications to the original design: a reduced mixing chamber area and the use of secondary fluidisation water. These modifications allow for better stratification of particles by density and the removal of light gangue particles before they even enter the bed.

The RCC was tested using a tailings sample from a tin producer, which had a low-grade composition of tin and tantalum. The test results showed that the RCC achieved significantly better results than the original Reflux Classifier, nearly doubling the upgrade ratios while maintaining high recovery rates. The high upgrade ratios for Ta_2O_3 and Sn indicate that the RCC has promising applications in the processing of other low-grade ores and tailings containing these minerals.

Case studies in operating sites are provided.

Replacement of Sodium Ethyl Xanthate Collector at Carrapateena

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ABSTRACT

Carrapateena is a copper–gold deposit hosted in a brecciated granite complex located in the Gawler Craton, South Australia. The deposit is currently mined using the sub-level cave (SLC) mining method, with future mining to incorporate a block cave beneath the sub-level cave. The ore is processed by a conventional sulfide flotation concentrator, producing a copper gold silver (Cu-Au-Ag) concentrate with chalcopyrite and bornite as the main copper-bearing minerals.

In 2021, the then OZ Minerals engaged InterChem to investigate alternative collectors to Sodium Ethyl Xanthate (SEX), which had been utilised as the primary collector in the concentrator since commissioning. Although xanthates are commonly used collectors, their limitations can include lower selectivity against gangue minerals, OH&S concerns relating to classification as spontaneously combustible Dangerous Goods (Class 4.2) under the Australian Dangerous Goods Code, and dosage inefficiency resulting in higher reagent costs. Therefore, drivers for the project were to improve selectivity for copper whilst maintaining or improving flotation performance and product quality, improving Carrapateena's safety and risk profile by the removal of xanthates from site, and optimising dosage to target reduction in overall reagent costs.

This paper outlines the process followed to investigate a variety of reagents to replace sodium ethyl xanthate in the Carrapateena concentrator and the final selection. It will discuss the method of introducing the chosen collector into the plant across numerous stages with official implementation and cessation of xanthate usage as of 2023, as well as ongoing geometallurgical testwork to review its performance on future ore.

Pinto Valley Mine Copper Recovery Study with the NovaCell

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ABSTRACT

The NovaCell™ is a novel froth flotation machine, invented by Laureate Professor Graeme Jameson, that recovers valuable particles over a wider particle size range. Thus, coarse and fine valuable particles that were previously lost to tailings using the existing technologies can now be recovered by the same machine, potentially increasing the plant production. The coarse particle recovery also allows for larger particles sizes to be processed in the flotation circuit, reducing the specific energy consumption, the greenhouse gases (GHG) emissions per tonne of copper, and potentially improving the water recovery of the copper concentrator. To investigate these NovaCell benefits, samples from two existing copper operations were studied under laboratory conditions.

In this case study, the response of plant feed and tailings material from the Pinto Valley mine, located in Arizona, USA, to the NovaCell was investigated. The plant throughput is roughly 58 000 t/d, with a copper equivalent production of approximately 59 000 t Cu/a. The existing flotation circuit comprises of a combination of mechanical (self-aspirating) and column cells.

The paper details the NovaCell test work and size-by-size recovery results for copper and other elements of interest. It also discusses the potential impact of the NovaCell technology as a substitute to the existing technologies at Pinto Valley mine, showing potential to significantly increase the metal production by approximately 15 000 t/a of equivalent copper and to achieve a 15% reduction in equivalent carbon emissions per ton of copper equivalent.

Improving Energy Efficiency and Reducing Carbon Footprint at FMR Greenfield Operations

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ABSTRACT

Comminution is a highly energy intensive and major contributor to carbon footprint in the resources sector. It is estimated that the global installed motor capacity of Ball mills is approximately 67.6 billion kWh. Comminution accounts for 58% of the total estimated annual global electricity consumption of 116.5 billion kWh. With advent of the highly efficient discharge systems, a comprehensive study in laboratory and pilot has been carried out on grate discharge verses overflow mills since 2006 using the patented EEPL discharge system, which has demonstrated significant energy savings.

This paper discusses the operating results from a recently installed and commissioned project at FMR Greenfields Mill Operation in Australia and summarises the energy savings and other benefits achieved at other operations.

Greenfield Mill Operations circuit consists of three overflow ball mills – Mill#3 (3.8 x 6m x 1325kw), Mill#2 (3.32 x 5.18m X 875kw) and Mill#1 (2.7 x 4.8m x 500kw), all in closed circuit with one cluster of hydrocyclones, which draws 2350 kWh to process 140 tph (F_{80} of 7 - 8mm) to produce P_{80} of 125 - 130 micron product. In first phase of the project, only Mill#2 has been converted from overflow to grate discharge using the EEMS discharge system, which has resulted in achieving the same performance using two mills (mill#2 and Mill#3) instead of three mills. The circuit has been successfully operating with two mills since March 2022, and consistently saving more than 500 kWh in addition to the operating and maintenance cost of Mill#1. The total estimated carbon savings based on energy and media savings is ~3000 tons per annum.

In the second phase of the project, Mill#3 will be converted to the EEMS grate discharge system and an additional energy savings of 300kWh is estimated to be achieved. With both Mill#2 and Mill#3 operating with EEMS grate discharge system, total energy savings are estimated to be in the order of 800 kWh (34%) with ~4500 tons reduction in carbon footprint per annum.

The Intersection of Mining and Decarbonisation: Challenges and Opportunities

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ABSTRACT

Mining is a significant contributor to global greenhouse gas (GHG) emissions, accounting for approximately 4 - 7% of scope 1 and 2 emissions, and up to 31 - 34% when including scope 3 emissions. The comminution circuit is one of the primary electricity consumers in mining, while coal mining is the primary GHG emitter. Despite the environmental impact, mining is crucial for society's development and maintenance. Therefore, it is important to identify the types of technologies that are viable to use to achieve environmental goals while maintaining the benefits that mining provides.

This paper analyses the initiatives taken by Canada and the world to reduce carbon emissions and meet the targets set by the Paris Climate Accord and IPCC. The paper evaluates the effectiveness of various decarbonisation technologies such as wind, solar, nuclear, hydrogen, and electric cars, and provides a cost-benefit analysis. The analysis includes the cost of building new projects, cost of generated power, and the materials required per MW of power generated.

Moreover, the paper examines the impact of the increased demand for critical metals, considering transportation and electric/hydrogen-powered vehicles, if all carbon-emitting systems are replaced with renewable sources. The paper also explores alternative strategies to minimise the strain on the mining industry while still achieving GHG reduction targets.

The paper is structured into five parts. Firstly, it provides an overview of climate change and its effects. Secondly, it defines the temperature and GHG goals to minimise the impact of climate change. Thirdly, it evaluates the initiatives being taken to achieve these goals. Fourthly, it analyses the critical metals demand and the mining industry's ability to meet this demand. Finally, it discusses the effectiveness of carbon tax and policy in promoting decarbonisation and reducing carbon emissions.

Energy Savings and Carbon Footprint Reduction - Jameson Vs Conventional Copper Concentrator

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ABSTRACT

Traditional concentrator design involves the use of large mechanical cells of up to 630 m^3 to provide sufficient residence time for flotation of ever finer, more complex and lower grade ore bodies. However, growing calls for decarbonisation and energy efficiency have brought this approach into question. Increasingly, companies are required to release ESG disclosures for projects and demonstrate savings in both scope 2 and scope 3 emissions. However, until recently very few benchmarks in terms of emissions have been published.

An alternative approach using the Jameson Concentrator has previously been demonstrated at New Britannia, Philex and Ozernoye which combines both IsaMill and Jameson Cell technology into a full-concentrator flowsheet to drastically reduce footprint, power, OPEX and CAPEX requirements. However, the benefits in terms of scope 2 and 3 emissions have yet to be determined.

This paper addresses this issue by presenting a comparative case study between the Jameson Concentrator and a conventional copper concentrator. Each design is performed on a consistent basis and the benefits in terms of plant footprint, height, CAPEX, OPEX as well as scope 2 and 3 carbon emissions are quantified.

The results demonstrate that the Jameson Concentrator approach results in savings in power consumption, footprint, CAPEX and OPEX. In addition, both scope 2 and scope 3 emissions are reduced. This demonstrates that the Jameson Concentrator may provide a safer and more sustainable solution for meeting the future needs.

Commercialisation Pathway for Low Energy Gyratory Rolls Crusher Technology

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ABSTRACT

Comminution accounts for over 5% of global energy consumption and an innovative Gyratory Rolls Crusher (GRolls^{TM}) technology has been developed in South Australia to reduce energy and water consumption, providing dry and wet crushing from ~20mm to 20-micron fractions without media, replacing up to two stages of size reduction. The GRolls is a compression-based particle size reduction device, designed to generate fine and ultra-fine products from coarse feeds, by simultaneously applying pulsed compression and shear forces to a packed particle bed. The breakage mechanisms initiated by these forces include impact breakage, inter-particle compression, induced tensile failure and particle shear forces generated by a gyrating roll.

The paper presents the commercialisation pathway of the GRolls technology, from "proof of concept" to laboratory scale Alpha prototype and upscaled 3-5 t/h Beta prototype for a pilot plant. A systematic progression of laboratory scale testing of a wide range of feed materials through the Alpha prototype was undertaken to confirm the "proof of concept" design and identify the many design variables and operational configurations that affect the GRolls crushing and energy performance. The test results were evaluated against some of the currently available comminution solutions such as the High Pressure Grinding Rolls (HPGR) and Vertical Rolls Mill (VRM) that the sector is moving towards to provide more economical dry comminution and a progression towards partial to fully dry process flowsheets.

The commercialisation pathway has confirmed the broad performance range and energy consumption of the GRolls which could be modularised in the near future to support new and existing low grade mining operations including critical minerals, potentially unlocking resources located in remote areas restricted by limited water and power infrastructure.

Representative Measurement Using PGNAA to Digitalise Conveyed Ore Flow Quality

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ABSTRACT

Average ore grades for most commodities are declining and processing costs are increasing. Mining companies look to technologies for improved sustainability: reducing energy, water, and reagent consumption, tailings generation and GHG emissions. There has been little focus on the main asset: the orebody. Ore quality variability affects metal recoveries by up to 10 - 15%. Measurement is required in order to manage ore quality effectively. Major mining companies have recently begun to see value in sensing ore quality in real time to better understand its implications and assess potential benefits. Real time measurement to digitalise conveyed flow quality using proven technologies has been implemented with minimal risk.

High performance Prompt Gamma Neutron Activation Analysis (PGNAA) has been used successfully in the minerals sector for over twenty years for representative, continuous, real time multi-elemental measurement of conveyed flows in over a dozen commodities. The technique is suitable for primary crushed rock and is unaffected by particle size, belt speed, mineralogy, dust, layering and moisture content.

Recent developments include direct measurement of gold in conveyed ore using GEOSCAN-GOLD. Measurement times have reduced with smaller parcels being measured at good precision allowing decisions to be taken with a high degree of confidence. The technology has been successfully applied in bulk ore sorting where increases in ore grade have been recorded and 5 to 20% of the mined ore is rejected as waste. The diverted coarse waste has saved up to 20% of GHG emissions in comminution, mainly due to elimination of milling, with only minor metal losses.

The paper presents multi-elemental data's utility in improving ore blending, diverting waste from plant feed, enabling feed-forward control for process operators, and facilitating ore reconciliation and metal accounting. It showcases successful installations with gold, copper, and iron ore examples and discusses risk reduction strategies for assessing and implementing this technology.

Sequential t-testing in Plant Trials – a Faster Way to the Answer

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ABSTRACT

It has long been established that the best way for a metallurgist to undertake a plant trial comparing two process conditions is to run the trial as a sequence of short duration pairs, each pair incorporating the 'on' and 'off' conditions in random order. The results are then analysed using a paired t-test. The number of pairs required, and the duration of the trial, can be calculated from a formula which includes the expected difference in performance between the two conditions, the expected standard deviation of the data, and the choice of decision-making risks. This, however, sometimes leads to trials of long duration.

This paper proposes the use of a modified sequential paired t-test for mineral processing plant trials of this kind. The principles of such tests have been known for many years but for some reason are rarely applied. Rather than generating the number of paired results prescribed by the sample size formula and then carrying out the t-test, sequential testing involves inspecting the results after each data pair is acquired and terminating the trial when one of two pre-calculated boundaries has been reached, concluding either that an improvement has been achieved, or not.

The paper explains how to apply the method and demonstrates this in a number of real case studies. It is shown that in most cases this leads to a significant decrease in the number of pairs required to achieve a statistically robust decision, and thus a reduction in the duration and cost of the trial. It is therefore recommended that sequential paired t-testing be adopted in place of conventional paired t-testing in plant trials.

Carbon Inventory Management in a Carbon-In-Leach Circuit

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ABSTRACT

Morobe Consolidated Goldfields Limited (Harmony Gold), the developer of Hidden Valley Gold and Silver mine in Papua New Guinea have over the past two years (2021/2022), evaluated the benefits of installing six of Mintek's online carbon concentration meters (C^2 Meters) in their Carbon-In-Leach (CIL) circuit. The C^2 Meters developed by Mintek and supplied by Process IQ use the principle of sound attenuation to determine the carbon concentration in CIL tanks in real-time, providing a reliable measurement for use in an automated carbon management strategy.

Manual sampling of the non-homogenous mixture of carbon in a CIL tank is challenging, and measurement accuracy is influenced by a variety of factors such as the sampling method, position and frequency of measurement, operators' errors, and inconsistencies during sampling. In addition, the time between manual samples dictates the rate at which decisions can be made on moving carbon between tanks, to achieve the desired carbon profile and prevent excessive soluble gold losses to the tailings stream. On the other hand, the continuous measurements from the C^2 Meters mitigate the sources of error and provide a more accurate and repeatable real-time estimate of the total carbon inventory in the tanks.

Significant benefits were achieved both in terms of overall carbon management in the circuit and in consistently reducing soluble gold losses to the CIL final tails. Thanks to the real-time measurements of carbon concentrations in the leaching tanks that are provided by the C^2 Meters, the site experienced an 89% reduction in both the fresh carbon consumption rate and reduced the gold solution losses into the CIL final tails solution stream by 45%.

Real-time measurements of carbon concentrations in the CIL tanks provided an opportunity to automate the carbon management strategy. Previously, the carbon concentration measurements were done manually on four-hourly intervals to monitor and manage carbon in CIL tanks. The control room operator (CRO) manually inputs the measured carbon concentration data into the distributed control system (DCS) and activates the carbon forwarding sequence from the main control room.

After commissioning of the C^2 Meters , manual entry of carbon concentration was eliminated and manual sequencing of carbon movement was replaced with an automated system. The integration of the existing manual controls into automatic controls was a significant upgrade initiated and implemented onsite, which was one of the main driving forces behind optimizing metal recoveries and carbon management at the CIL circuit.

The MagoPulp Extended Plant Trial at Prominent Hill

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ABSTRACT

A concept demonstration trial was conducted on the Jameson Cell using algorithms based on data collected using MagoPulp (formally known as PCM®) combined with plant data to manipulate collector, air and level to obtain the best metallurgical response produced encouraging results (Holden *et al*, 2021). It was agreed to progress to an extended plant trial in early 2021. Unfortunately, the project stalled because of COVID and a number of other issues, however the project team remained enthusiastic and have worked hard during the intervening months to improve the algorithm and trial plan.

The algorithm has been modified such that the operator can type in the target concentrate grade or recovery. At Prominent Hill, the algorithm will suggest changes to the Jameson Cell collector, air and/or level based on changes in the pulp chemistry to achieve the target concentrate grade at the best recovery.

Further, the statistical analysis of the trial, based on the shift mass balanced data, was conducted live. That is, as the shift data became available it was added to the data set and the statistical analysis completed. It is anticipated that this approach will both shorten the trial time and make it possible to adapt to changes more quickly.

This paper quantifies the consumable savings and recovery benefits the MagoPulp and algorithm have provided Prominent Hill.

Flash Furnace Throat Accretion Reduction through Settler Oxygen Injection

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ABSTRACT

The Olympic Dam Flash Furnace smelts high copper containing concentrates directly to Blister Copper & high Copper Fayalite Slag. During operation, the section between the Flash Furnace and Waste Heat Boiler progressively builds up with a solid precipitate (generally referred to as "accretion") from the process, which is typically a mixture of Cuprospinel [$CuFe_2O_4$], & Delafossite [$CuFeO_2$]. Removing this material requires Flash Furnace downtime. If the build-up is too large in size, its removal methodology changes and exposes operators to hazardous environments, i.e. exposure to acidic dusts, hot furnace gases and significant manual handling risks. Historically, the throat required clearing every two days for an hour to manage the build-up size.

The Flash Furnace "off gas" consists of gases (primarily SO_2, N_2 with small amounts of O_2 & CO_2) and "dust" (entrained particles containing a mixture of copper and iron with chemically bonded oxygen and sulfur). The offgas phase equilibria can be described through the Cu-Fe-S-O system. A review into this system indicated that an increase in oxygen partial pressure would result in a decrease in the liquidus temperature of the dust particles making the material more liquid and less likely to form build-up

Oxygen was injected into the settler freeboard through the ports of non-operational fuel oil burners to provide the process with sufficient oxygen ($pO_2 > 10^{-3}$ atm) as a trial to form more liquid phases. Continuous oxygen injection in the settler has enabled a safe and productive reduction in frequency of throat accretion removal, from two to four days with the same 60-minute downtime.

Geometallurgy- When Should Deposit Characterisation Commence?

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KEYNOTE ABSTRACT

Geometallurgical characterisation should commence prior to drilling the first hole. Once drill hole targeting starts, the astute exploration geologist should also be considering if viable processing options exist for the deposit style (i.e. IOCG, porphyry Cu, orogenic Au, sediment-hosted Pb-Zn, regolith-hosted ion-absorption REE, etc.) and which minerals/elements are known to cause processing challenges, impact on final product quality or could be co-/by-products? It is likely that these minerals/elements may also overlap with the those which are useful for determining vectors to potential mineralisation. Hence, these elements should be part of the extended suite of elements measured on the drill core samples. Even though geologists are good at determining the presence of minerals and relative abundances in drill core, identifying the presence and abundances of some minerals, particularly the clay group of minerals, is really beyond the capability of even the best geologists. This leads to the necessity of using mineralogy measurement technology as early as practically possible in a drilling campaign.

Geometallurgical testing should commence post the discovery hole. Even with only a few mineralised samples available, the technical team (e.g. geometallurgy, geology, metallurgy, environment, mine planning) should be formulating a list of potential processing fatal flaws and commence the testing to determine if the ore properties related to the processing fatal flaws are present. As drilling continues and the project progresses through the various study phases, the number of drill core samples available will also increase. Therefore, geometallurgical testing can progressively expand to measure processing responses to the inevitable variability which exists across all ore deposits. Testing needs to be conducted on a full spectrum of possible grade ranges and mineral combinations, not just the highest-grade parts of the deposit. Additionally, testing must also be conducted on tailings, mine waste and low-grade ores to determine the possible environmental impacts of storing these materials on the surface.

This paper provides examples of geometallurgical characterisation and testing discussing several case studies, including Olympic Dam.

Plant Modifications and Operating Strategies to Improve Concentrate Quality at Carrapateena

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ABSTRACT

Carrapateena is a copper–gold deposit hosted in a brecciated granite complex, located 460 km north of Adelaide, South Australia. The Kokatha people are the traditional owners of the land. The deposit is currently mined using the sub-level cave (SLC) mining method, with future mining to incorporate a block cave footprint beneath the SLC.
The copper mineralogy present is chalcopyrite and bornite. Deleterious non-sulfide gangue (NSG) minerals are present as ultrafine intergrowths (<5 µm) in both host iron oxide breccia and valuable sulfide minerals. A flotation concentrator produces a high-grade Cu-Au-Ag concentrate, with trace smelter deleterious non-sulfide gangue (NSG) minerals.

The concentrator, as commissioned in 2019, consisted of a rougher bank, High Intensity Grinding (HIG) Mill for rougher concentrate regrind, a Jameson Cell as a Cleaner Scalper and a three-stage conventional cleaning circuit. Jameson Cell and conventional third Cleaner concentrates were combined to form the final Cu-Au-Ag concentrate.
Regrind to a notional 20 µm target is critical to liberate sulfide grains sufficiently for cleaning. Jameson Cell froth washing reduces entrainment of NSG present as slimes to the flotation concentrate. However, the conventional Cleaner circuit did not have that functionality and slimes reported to the third Cleaner concentrate. Insufficient installed HIG mill power impeded regrind to a finer target of 15 µm, as required by some ore types.

Following commissioning, the installation of a second Jameson Cell in the conventional Cleaner circuit resulted in all final concentrate undergoing froth washing; and installation of a second HIG mill expanded regrind capacity, enabling finer regrind targets.
With the completion of a second Jameson Cell and a Cleaner circuit reconfiguration, a staged approach was taken to optimise individual unit operations for both copper recovery and NSG rejection. Two different operating strategies were established, and a longer-term trial conducted, confirmed the effectiveness of these operating strategies and circuit modifications.

This paper gives an overview to the process to optimise the Carrapateena flowsheet to improve concentrate quality by rejecting NSG, including the installation and commissioning of the second Jameson Cell, a Cleaner circuit reconfiguration, expanded regrind capacity and the creation of flexible operating strategies.

Design and Commissioning of the Newmont Ahafo Mill Expansion

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ABSTRACT

The Newmont Ahafo Mill Expansion project was successfully commissioned in the third quarter of 2019 and centred on the addition of a second primary crusher and a new 34 ft. diameter single stage SAG mill to complement the existing SABC circuit, commissioned in 2006. CIL circuit capacity was also increased in the expansion to accommodate the projected increase in mill throughput by over 50% to nearly 10 Mtpa. The expansion of the Ahafo processing plant will support increased gold production at Ahafo to 550,000-650,000 oz/a through to 2024, as well as reducing life of mine processing costs and supporting an extended mine life.

The comminution flowsheet selection considered both duplication of the existing SABC circuit and the addition of secondary crushing, prior to selecting the final configuration. Flowsheet selection and circuit design is discussed in the context of a highly competent ore source, and the basis for the CIL circuit expansion is reviewed.
The paper reviews early start up experiences and lessons learned.

Maximising Concentrator Throughput at Cadia During SAG Motor Drive Replacement

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ABSTRACT

Concentrator 1 at Newcrest's Cadia Valley Operation is responsible for approximately 75% of Cadia's total milled production, with all material being treated by the primary SAG mill within a unique HPGR-SABC circuit. In July 2021, the scheduled replacement of the Concentrator 1 20 MW SAG mill gearless motor drive took place. Spanning five months the SAG mill motor replacement necessitated a major reconfiguration of the process circuit to maintain production during the extended period of the SAG mill outage.

The SAG gearless motor drive was installed in 1997 and had been identified as a material risk to production since 2015. Following a significant motor failure event in 2015, infrastructure was installed to enable HPGR product to be re-directed from the SAG mill to one of the three secondary ball mills, thus converting the concentrator to a more conventional HPGR-ball milling circuit. This flowsheet is known as the 'SAG bypass' configuration, and prior to the SAG outage had only been in operation for a single ten day period. In the 18 months leading up to the SAG motor replacement, the site Metallurgical team initiated a 'SAG bypass' throughput maximisation project, to exceed the previously demonstrated SAG bypass throughput rates. The execution of several initiatives, together with revised operating strategies, resulted in production rates far exceeding expectations. This paper examines the plant modifications and operational strategies that maximised throughput utilising a novel HPGR-ball milling circuit flowsheet.

29Metals Golden Grove Triple Sequential Flotation Expansion

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ABSTRACT

The Golden Grove Concentrator is located within the Murchison region of Western Australia. The Processing Plant treats ore mined from multiple polymetallic orebodies. Historically, ore treatment campaigns depended heavily on cleanly segregating copper ores from lead/zinc ores during mining. The concentrator only had sufficient residence time and capability to produce two concentrates sequentially. As mining progressed, mixed copper/lead/zinc zones became more prevalent, with ore classification becoming reliant on copper to lead ratio to identify segregation and processing route. This resulted in payable metals misreporting to a stream where they were an unwanted diluent, and generally, no payment was realised.

In 2021, an additional copper flotation circuit was commissioned. This facilitated the sequential production of three separate concentrate streams. This improved metal recovery and concentrate quality from mixed mineralised zones and simplified the mining requirements. The retrofit to the brownfields operation required creative solutions to balance metallurgical, operational and maintenance-friendly considerations to achieve the final project requirements.

SAG Mill Stability and Control Improvements at the Nova Nickel-Copper Operation

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ABSTRACT

Strategies introduced at IGO's Nova operation have improved stability and control in the SAG milling circuit. These strategies relate to the development of a prediction model for SAG mill media volume (ball charge), and improvements to the SAG mill charge weight (total load) controller.
Prior to these improvements, poor control over SAG media charge volume and charge weight had resulted in process instability, downtime and overall reduced throughput.
Media overcharging and lack of control was tackled by development of a power-based model and a media consumption rate model of the SAG mill. These models are used to control media addition rates on a day-to-day basis to target the desired media charge.

Control of the SAG mill charge weight was improved by incorporating modelled disturbance inputs into the existing PID loop. The disturbances included were derived from an online mill feed particle size distribution measurement and a proxy for ore density/hardness, both of which were determined to be significant predictors of future mill weight changes. The issue of reducing mill weight resulting from liner wear over the reline cycle, rather than changes in actual charge weight, has also been compensated for using an adjustment to the mill weight setpoint based on measured liner consumption rates.

Following the introduction of these improvements, the issues resulting from overcharging and unstable weight control have greatly diminished resulting in improved overall throughput, reduced average SAG specific energy (kWh/t) and greater downstream stability within the flotation circuit. These models and controllers require occasional re-calibration but have proved robust over time.

Mineralogy, Chemistry and Recovery: The New Century Story – Venturing into Extremes

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ABSTRACT

New Century Resources Ltd commenced processing the 77.3 million tonnes of Century 3.0% zinc tailings in August 2018 following a comprehensive sampling and testing program. Plant re-commissioning followed a staged approach, with tailings hydraulic reclamation capacity increasing concurrently with progressive refurbishment of flotation capacity. Plant metallurgical performance did not match expectations from the laboratory test work, in particular zinc recoveries and zinc concentrate grades were lower than anticipated. The causes for the lower zinc recovery and concentrate grade included a lack of cleaner flotation capacity, particularly in the second cleaner stage immediately following ultrafine milling (UFM) of the first cleaner concentrates. To increase cleaner flotation capacity and therefore increase cleaner block zinc recovery, the second cleaner feed was redirected to an existing and refurbished B22/6500 Jameson Cell in a cleaner scalper duty in May 2021. After commissioning, the Jameson Cell achieved very little and no changes to cell settings (pressures, flows) or reagents made any significant difference to mass recovery or zinc recovery.

Investigation into the causes of the poor Jameson Cell performance determined that regrinding the UFM cyclone underflow to a P_{80} of 4.5 microns to liberate sphalerite from silica created pulp/surface chemistry conditions that severely impeded sphalerite flotation. This phenomenon was noted in the second cleaner, with flotation not really starting until half-way down the bank. Further, a size reduction to 80 percent passing 4.5 microns increased the sphalerite particle surface area by a factor of approximately 10. Therefore adding "normal" quantities of activator and collector were insufficient to activate and recover the ultrafine sphalerite.

Laboratory tests addressing each critical part of sphalerite flotation (liberation, pulp chemistry and reagent addition) separately did not improve zinc recovery at all. It was not until all three parts were satisfied did the sphalerite flotation response improve. This paper describes the Century tailings process development and challenges created in ultrafine particle flotation after pulp chemistry changes induced by ultrafine regrinding.

Pre-concentration: An ESG pathway to processing magnetite

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ABSTRACT

Significant interest lies in magnetite as a key feedstock for low emissions steelmaking, replacing hematite in both existing blast furnaces and future direct reduction iron making processes. However, beneficiation of magnetite is significantly more costly and energy intensive than hematite.

'Pre-concentration' refers to the upgrade of an ore prior to its entry into the main wet processing plant, and can be undertaken as a bulk ore sorting process or particle-by-particle ore sorting. Fortunately, certain magnetite ores are amenable to particle ore sorting through the use of straightforward magnetic separation techniques.

The ability to pre-concentrate magnetite ores offers major energy savings, optimisation of the downstream concentrator throughput and improved ESG in tailings management through the use of dry stacking.

This paper focuses on SIMEC Mining's pre-concentration project at their South Middleback Ranges mine and 2.2 Mt/a concentration plant in South Australia. Recent test work performed on secondary crushed ore has demonstrated appreciable rejection of non-magnetics with minimal loss of yield via a 'dry' magnetic separation circuit.

SIMEC engaged GPA Engineering to assist with the development of the pre-concentration facility and integration into the existing brownfield plant. A feasibility study, together with a demonstration plant, has been conducted, with the aim of capturing environmental, operational and financial project metrics. Particularly, dry processing exposes numerous materials handling challenges that have been addressed through extensive 3D modelling and innovative application of virtual reality technologies for plant design.

The demonstration plant confirms suitability of the pre-concentration facility in achieving key project objectives such as

- improvement in magnetite ore grade
- minimal rejection of magnetics to dry tails
- materials handling design data and dust mitigation methodologies
- autonomous operations
- integration of beneficiated ore to downstream concentrator operations.

One Plant's Trash is Another Plant's Treasure; a Synergistic Approach to Novel Uses for Tailings Streams

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ABSTRACT

The Mount Isa Mines (MIM) copper concentrator has been supplying the on-site copper smelter with silica flux for decades. The silica-rich stream is sourced from the tails of the flotation circuit which would otherwise be directed to one of the backfill plants, or the tailings dam. This synergistic approach to the use of tailings not only provides the smelter with low-cost flux material but also allows for an increase in copper recovery by reusing tailings.

The production of silica flux from tails began in the 1990s and the process has gone through several iterations over time and different concentrator streams have been used as flux sources. Changes in ore mineralogy as well as smelter requirements have driven various modifications and upgrades of this circuit, intending to produce the highest quality silica flux possible. The success of the silica circuit is highly dependent on the silica grade of the ore and in recent years this has declined to the extent that the silica circuit was no longer a viable source of flux.

In 2020 the silica circuit was upgraded to include a reverse flotation stage to further increase the upgrade of silica in the tails. However, consistently low flux quality drove the search for a new source of silica to meet smelter demand. Tailings from a new ore type, Black Rock Cave (BRC), were found to be a suitable source of flux and modifications to the silica circuit were made to utilize this stream.

This paper reviews the history of the circuit operation as well as the novel approaches that have been taken to produce a high-quality product from a waste stream and how these changes impact downstream operations.

First Principles Modelling of Treatment of Mining Wastes

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ABSTRACT

As environmental regulations associated with operation of mining operations become more stringent and water scarcity increases, water re-use and effective treatment of mining waste waters is increasingly important. Around the world, nations are adopting tougher standards for the treatment of mine wastes. Furthermore, the quality of available ores is declining with higher contaminant loadings, resulting in greater complexity in the treatment of produced wastes.

In addition to operating mines, the remediation of legacy sites no longer in operation is a major issue requiring attention now and into the foreseeable future. This paper presents a first principles thermodynamic approach to the modelling of water treatment. The conventional ferric sulfate and slaked lime treatment of mining wastewater is simulated via a multicomponent, multiphase co-precipitation and adsorption model for the removal of typical contaminants including aluminum, nickel, molybdenum, arsenic, uranium, and sulfate. Surface complexation of both ferrihydrite and gibbsite secondary minerals are considered in the adsorption model. The resulting model is used to optimise the treatment of typical mining wastewater streams to meet environmental regulations while minimising tailings volume and treatment cost.

Review of reflux classifier performance across multiple commodity applications

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ABSTRACT

Fine or sand size particle beneficiation is still a key focus area across the mineral processing industry with significant effort by researchers, suppliers, and producers to ensure efficient and cost-effective recovery of what is commonly the most difficult size fraction of material to upgrade. Having installed fine beneficiation circuits utilising spirals, teetered-bed separators, reflux classifiers, gravity concentrators and WHIMS, Sedgman takes a reasonably technology agnostic approach to equipment selection for each project. Quite often the competing benefits of each technology offering is relatively important depending on the specific characteristics of the feed and the required quality of the product.

Sedgman has designed, installed, commissioned and/or operated over 50 reflux classifiers across seventeen projects spanning a range of commodities and global regions. The first interaction with this technology was the installation of a full-scale trial unit in a coal processing plant in central Queensland in mid-2009. The technology and its commodity applications have come a long way since that time, but there is still quite a lot of uncertainty and hesitancy particularly with respect to the applicability and operability of the units.

Because Reflux Classifiers are a relatively new technology, the circuitry and control functionality is continuing to develop. Each project delivered has provided valuable information and understanding on the idiosyncrasies of this technology. The units themselves have continued to develop based on operations feedback, and the surrounding circuitry is more robust and more operable than the earlier installations. This paper aims to highlight some of those developments and make observations, where possible, on the performance of the units across some of the commodities where it is currently being utilised or is being considered. Recent interest in iron ore ultrafines processing studies suggests that the enhanced processing of iron ore tailings offers multiple advantages. Apart from a potential reduction in tailings volume, associated with safer containment, lower environmental impact and improved water management, the prospect of increased revenue from additional desirable mineral recovery presents supplementary motivation for iron ore players to embrace this approach, as further elaborated in this paper.

Comparison of Dry VRM Milling with AG and Ball Milling for Magnetite Ore

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ABSTRACT

Loesche's Vertical Roller Mill (VRM) has achieved superior pilot plant comminution outcomes on hard Southdown Magnetite ore, owned by Grange Resources in Western Australia compared to a conventional AG and ball milling circuit. Comminution with VRM has a number of significant advantages over both wet milling circuits and dry milling alternatives such as the use of HPGRs in series. An industrial VRM can accept feed as coarse as 125 mm, make a single-pass 30 µm product, operate dry, dry the feed if wet, efficiently classify internally and enhance the liberation of minerals. VRMs are dust free in operation, readily controllable, simple to maintain and utilise hydrostatic breakage to emulate HPGR power efficiency.

For Southdown magnetite ore, the dry classifier oversize, known as grit (-3 mm+75 µm) is extracted continuously then magnetically separated. Magnetic grits are returned the VRM and dry non-magnetic grits rejected to tailings. The novel Loesche VRM plus magnetic separation pilot plant was 33 to 36% more energy efficient than pilot AG/Mag/Ball milling while rejecting 31 to 41% of feed mass as non-mag grits and significantly upgrading the P_{80} 85 µm product. VRM milling is compared with wet milling and HPGR alternatives in areas such as testwork, scaleup, CAPEX, OPEX and operability.

VRM Technology: A pragmatic approach to project risk versus reward profile for favourable ESG outcomes

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ABSTRAC T

The mining industry is working to enhance its ESG credentials, tackling challenges such as energy footprint reduction and decarbonisation, environmental stewardship of tailings, water and mine closure, all within the overarching constraint of cost pressures. Vertical roller mills (VRMs) have the potential to be a significant contributor to the improvement of virtually all these ESG characteristics; however, a low appetite for risk has often inhibited the uptake of new technology in the mining industry. An opportunity exists for the industry to change the technology evaluation process to focus on a broader, pragmatic risk versus reward profile in order to capitalise on the benefits of this innovative technology.

Most mineral processing plants rely on wet grinding, utilizing equipment such as SAG and Ball mills to promote liberation of minerals from ores. The process inherently has high electric power intensity and utilises significant amounts of water as the medium for the grinding process. Many industries outside of traditional mineral processing have utilised alternate grinding processes such as HPGRs and VRMs for dry grinding of feedstock. In these applications, dry grinding has historically been selected for multiple reasons, such as production of a final dry product, energy savings and water management. However, challenges like dust management and particle size classification are associated with smaller size fractions, due to high recirculating loads and materials transport systems.

The adoption of VRMs and similar technology in mineral processing offers many clear advantages to ESG project outcomes. However, the traditional risk/reward impact on the larger project outcomes (IRR) does not tend to present a favourable case. This paper highlights the pragmatic adoption of VRMs as innovative technology into minerals processing flowsheets for their ESG benefits, whilst facilitating a framework for the identification and evaluation of techno-economic risks and benefits for the larger project.

Designing Fine Grinding Circuits for Magnetite Concentrators

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ABSTRACT

The steel-making industry is moving towards a low-emission process that requires high-grade ore or pellets. Direct reduced (DR) iron is one of the ways to reduce carbon emissions during steel production. Pellet for DR requires 66 % iron content which is higher than the blast furnace-grade pellet. Lower grade ores such as magnetite, typically around 30 – 40 % iron head grade, can be upgraded to 69 % iron content, suitable for low-emission steel making. These magnetite deposits require fine grinding down to 20 – 25 µm to liberate the magnetite particles and produce a concentrate with 69 % iron. For the last 15 – 20 years, gravity-induced stirred mills such as the TowerMill have been used for the fine grinding duty.

Although the technology is well established, there are still opportunities to improve the circuit design based on the learnings from the current operating circuits, especially for highly variable ores. For example, the mill feed configuration, grinding media size, agitator tip speed, classification choice, and configuration (hydrocyclone and/or fine screen) are some of the variables that can be considered in addition to the grinding power requirement.

Fine grinding circuit audits show that there are opportunities to improve the grinding efficiency by 10 - 15 % if the circuit is designed considering these operating variables during the circuit design phase. Customised TowerMill design according to project requirements optimises layouts that reduce the steel and concrete requirement. The TowerMill circuit produces a narrow product size distribution, an essential criterion for long-distance slurry pipeline transportation. The tight top size control and minimal ultra-fines generation minimise the wear in the pipe and enhance the pumping process, as well as the dewatering at the port.

This paper discusses the TowerMill circuit design based on the experience gained from a current operating site and recent developments in the TowerMill design that will help to configure circuits to produce high-grade magnetite concentrate.

Benefits of Upgrading an HPGR with Flanged Roll Design and Advanced Mechanical Skew Control

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ABSTRACT

The flanged roll technology has been shown to significantly improve the performance of HPGRs. The flanged roll design diminishes the edge effect. One 2.4m HPGR has recently been retrofitted with the Metso Outotec flanged roll design and an Advanced Mechanical Screw Control upgrade package. To unlock the significant benefits of the flanged roll design, the Advanced Mechanical Skew Control holds the key, providing a reliable solution to mechanically control the crushing forces and eliminating any excessive skew events. The effects and reactions of the mechanical skew control have been measured and recorded using load sensing pins, providing operational data to prove the efficiency of the mechanical skew control and to validate the Finite Element Analysis (FEA) models, created during the design of the retrofit kit.

This paper discusses the effect of flanged rolls in a 2.4 m HPGR, and how this technology supports the demand to plant performance and efficiency improvements to meet future targets regarding increased throughput projections. It shows the direct comparison between HPGRs with and without flanged rolls in the same grinding circuit. The paper further highlight the immediate and direct response of the Advanced Mechanical Skew Control, while validating the reliability and effectiveness of this system.

Designing Grinding Plants to Maximise Mill Availability During Relining

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ABSTRACT

Grinding mill relining typically represents between 2 – 5% lost mill availability annually. With continually increasing production demands there is ever increasing production pressure, thus making it highly beneficial to reduce the relining duration to achieve higher mill availability.

While grinding mill maintenance often dictates the plant shut duration, it is rarely made a priority when designing concentrator plants. Other important factors such as mill geometry, drive selection, other processing equipment and costs tend to have the largest influence on plant features that can negatively impact relining and other maintenance activity durations. Mill availability is a direct function of relining and other maintenance activity durations as they require the mill and associated equipment to be taken out of service for said activities. Further to this, cost and project schedule constraints encourage plant design features to be copied with little to no time to study the impact on relining and maintenance activities and durations. However, mine owners who insist on optimising relining and other maintenance activities see benefits in both faster relines and reduced safety risks to the relining crew.

Russell Mineral Equipment (RME) has engineered over 550 Mill Relining Machines (MRMs) since 1990, with a large portion of these machines going to Greenfield and Brownfield expansion projects. RME assists many end users and designers to understand which plant design aspects facilitate relining best practices and ultimately lead to increased mill availability. In one example, RME has supported a mine owner's engineering team to increase their mill availability by almost 2.2% through plant design improvements that facilitate faster and safer relines.

This paper provides advice on the best practice in plant design for relining and contains:

- Examples of reduced mill availability when sites did not consider and implement mill relining best practices
- The relationship between the mills charge height and the platform height around the outside of the mil and its impact on relining performance and safety
- Examples of good and poor space around the mill to facilitate relining activities such as MRM insertion, feed chute removal, liner staging zones and bolt knock-in activities.
- A case study showing the impacts of implementing the topics within this paper and how an additional 2% of mill availability can be achieved for a 36' Semi-Autonomous Grinding (SAG) mill.

We Need to Talk About Engineering

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ABSTRACT

The efforts of those in minerals sector to reduce emissions should include management of undesirable impurities during processing. The growing issue of arsenic in copper concentrates will be discussed. Inevitably, this requires considerations of commodity demand, comminution, fertilisers, construction, artificial Intelligence (AI), recycling, motorcycles, desert ecosystems, and the zombie apocalypse.

Such a path inexorably leads to an uncomfortable conclusion: *we need to talk about engineering.*

Real-Time Monitoring and Control of Gold Processing Plants

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ABSTRACT

A range of real-time instruments for use in gold processing circuits has been developed in collaboration with Gekko Systems. These instruments, the OnLine Gold Analyser (OLGA) and Carbon Scout (CS) are used to measure and monitor metallurgical process parameters, including such as gold concentration, carbon concentration, slurry density, pH, dissolved oxygen, and gold loading on carbon in real-time. The output process data are mapped, visualised, and fed into process control platforms, enabling process plant operators and metallurgists to monitor and track critical operating factors. Installed in processing plants globally, these real-time instruments have been proven to benefit operators in plant performance and safety.

The OLGA, by measuring gold concentration and slurry density in real-time, provides operators with a quicker and more frequent turnaround time, enabling expedient metallurgical process control reactions. The CS, by monitoring and tracking carbon concentration in adsorption tanks, helps prevent adverse occurrences such as carbon leakage and provides more frequent and periodic gold-in-circuit data that would otherwise occur weekly or monthly. Additionally, the X-Ray Fluorescence (XRF) analyser on the CS creates opportunities for operators to track carbon loading in the circuit to maximise gold loading prior to elution.

This paper discusses installations where these real-time monitoring instruments have been in operation, providing notable value and benefits to the operators.

Application of Stirred Milling in the Expansion of Production at Martabe Gold Mine

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ABSTRACT

The Martabe Gold Expansion project was an upgrade project designed to increase throughput with the existing plant while utilising minimal footprint and the fewest significant modifications to site possible.
As the Martabe project has developed and been optimised, plant capacity has increased to well above the original design point and the P80 feeding the leach plant has gradually become coarser as the capacity has expanded. Additional milling capacity has been added to the plant to return to that optimal product size and further increase capacity.

Site conditions create unique challenges including limited footprint, seismic hazards, coarse product size targets, and hard, competent ore. To meet these challenges, Metso has supplied a VTM-4500-C for the application. The VTM-4500-C is the largest Vertimill® installed in the Asia-Pacific region. The mill operates in closed circuit with hydrocyclones and has been designed to minimise the footprint of the expansion while offering the maximum throughput increase.

This paper discusses the design philosophy, machine selections, challenges of commissioning, and progress through the ramp-up period. In addition, the paper discusses the impact on the overall comminution circuit and changes required to the operational philosophy to incorporate the new machine into the plant.

Refractory Gold Concentrate Treatment Hub for Toll Treating

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ABSTRACT

Gold hosted in refractory sulfides has historically been overlooked in preference of easily recoverable gold which requires less upfront capital. However, as reserves of these ores become depleted in the face of continuously increasing gold demand, opportunities arise for forward-looking companies to capitalise on the requirement for pre-treatment of sulfide-hosted gold.

Gold hosted in refractory sulfides requires pre-treatment to oxidise the sulfide minerals, releasing the gold and making it amenable to recovery via traditional Carbon-In-Leach processes. Several established options exist to liberate sulfide hosted gold, but the key to maximising this opportunity lies in the selection of an approach that is sufficiently flexible to manage variations in feed whilst still achieving high recoveries.

This paper focuses on Glencore Technology's Albion Process™ as a robust pre-treatment solution for refractory gold feeds that may vary significantly in their throughput and mineralogy and contain high levels of impurities such as arsenic. The Albion Process uses a combination of mechanical and chemical liberation of the gold via ultrafine mineral grinding and oxidative leaching at atmospheric pressure. The simplicity of this process combined with the tight size distribution achieved using the IsaMill™ and high oxygen utilisation afforded by the HyperSparge™ and OxiLeach™ reactor designs allows for significant variability in the feed to any Albion Process plant without compromising recovery. This opens the door for an Albion Process plant refractory gold treatment hub capable of toll treating concentrates produced from a multitude of external ore bodies. Real world examples are used to demonstrate how one Albion Process plant can accept significant variation in feed composition and rate and still achieve high gold recoveries.

Evaluation of a High-Shear Leach Reactor at the Kencana Gold Mine

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ABSTRACT

Aachen high-shear leach reactors have been of benefit to gold and silver leaching processes for over a decade, with 80 installations worldwide currently. The benefits are significant increases in recovery (*ca.* 2 - 6%) combined with reductions in usage of cyanide, lime, and oxygen (ca. 10 - 50%).

The PT Indo Muro Kencana gold mine in Indonesia has identified serious challenges in maintaining production performance due to recent variations in the ore properties. Such changes resulted in a reduction of recoveries by 4% for gold and 7% for silver. Also, the addition of hydrogen peroxide (H_2O_2) was implemented to compensate for lowering dissolved oxygen levels (DO) in the leach (below 10 ppm). To overcome these issues, an Aachen REA450 high-shear leach reactor was installed and surveyed for one year under different operating conditions. The trial was proven successful by improving the efficiency of oxygen use (DO-levels above 30 ppm), allowing the stoppage of H_2O_2 addition. In addition to those benefits, the recovery of gold and silver was improved by 2% and 4%, respectively.

This paper presents the in-depth theories behind the technology together with the installation and operating strategy of the Aachen REA450 high-shear leach reactor with a special focus on the presented work. Finally, the technical and economic evaluations for this case study proved the benefits of using the Aachen technology, leading to its permanent acceptance.

Effects of Clays on Solid-Liquid Separation Processes

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ABSTRACT

Dry stacking of filtered tailings usually requires a low cake residual moisture to meet the specifications from geotechnical engineers. The growing demand for minerals has resulted in lower and more complex grades of ores being mined and processed. Many such ores contain varying amounts of clays. The filtration process can be hindered by the presence of clays and it is therefore important to understand the filtration characteristics of these ores early in the flowsheet design stage.

Other solid-liquid separation processes can be affected by the presence of clays, including thickening. Thickening, even in the beneficiation stage, can be severely compromised, leading to lower process efficiencies downstream (e.g. leaching). Poor thickening performance caused by non-ideal mineralogy (particularly clay content) can force the process designer to consider filtration as a more appropriate solid-liquid separation option (in some cases, even replacing counter-current decanting thickeners).

Some clays affect solid-liquid separation processes more than others. A comprehensive characterisation of the ore that includes detection and identification of clay types is important. Standard physical-chemical characterisation of mineral slurries includes tests for density, solid concentration and solid (and liquid) specific gravity. More thorough characterisation can include tests for yield stress, particle size distribution and morphology, as well as element analysis and mineral phase detection. Some of these tests require sophisticated instruments and highly experienced technicians.

Phyllosilicates (clays) are one of the most common components of mineral ores and tailings, together with quartz, feldspar and other aluminosilicates. The presence of clays, even in small concentrations, can influence slurry behavior, filter cake permeability and moisture content. A comprehensive study of clay detection and quantification, including correlation with dewatering properties was recently carried out by Diemme Filtration's R&D laboratory. This paper presents some of the results and conclusions and also uses real project examples to illustrate how the presence of clays in mineral ores can change the flowsheet design and influence the sizing of filtration equipment.

Concentrate Filter Cake Washing for Chloride Removal at Carrapateena

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ABSTRACT

Carrapateena is an iron-oxide-copper-gold (IOCG) mine located in the Gawler Craton, South Australia. Carrapateena is owned and operated by BHP. The ore is processed by a conventional sulfide flotation concentrator producing a copper silver gold (Cu-Au-Ag) concentrate. Ultrafine grinding of rougher concentrate to a 15-20µm P80 target liberates deleterious non sulfide gangue (NSG) from sulfide minerals prior to cleaning. The resulting copper concentrate is thickened and reports to the concentrate filter, a Metso:Outotec VPA 2040-32 filter press.

Raw water for use in the milling and flotation processes is sourced from borefields located within an 80km radius of the Carrapateena site. This water is hypersaline, containing >20,000ppm Chlorine (Cl). Fresh water, containing <500ppm Cl, is produced onsite from the bore water via an energy intensive reverse osmosis (RO) process.

Chlorides are present in the copper concentrate due to the use of the hypersaline process water. Chlorine is considered a deleterious element and is removed from the concentrate during filtration by washing the filter cake with fresh water. Cake washing occurs during a dedicated step in the filter cycle.

The as-commissioned filter press inconsistently achieved the required chloride removal, at the desired throughput rate. A key challenge was poor cake permeability imparted by its ultrafine particle size distribution.

This paper outlines the modifications to the filter press and its control strategies that were required to achieve satisfactory removal of chlorides, whilst minimising the volume of fresh water utilised, without compromising final cake moisture content, and maximising throughput.

Sustainable Pump Operation in Mineral Processing Plants

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ABSTRACT

Understanding sustainable pump operation in mineral processing starts with understanding the contribution of pumps to the energy consumption. Earlier work has shown that pumps account for between 18 – 28% of the installed power, depending on the commodity being processed. What is not clear is the actual energy consumption of pumps in relation to overall concentrator consumption. With no available published literature, this paper sets out to answer this question and to clarify the impact of the sizing and selection of pumps and motors on the efficient use of this energy. The choices made at the selection stage can tie up natural resources and can have an impact on wear of the various components.

In addition, this paper explores the consequences of wear and quantifies the impact it has on increasing power consumption due to decreased pumping efficiency; it shows that it can be more cost and energy advantageous to replace worn parts rather than incur the higher energy consumption whilst running them less efficiently.

Finally, considering the embodied energy in producing the wear parts, in combination with the energy consumed during operation, total energy consumed and a CO_2 footprint for pumping in mineral processing plants are calculated for typical gold, iron and copper concentrators. These calculated values are supported by specific case studies. Finally, practical solutions are discussed on how to optimise pump and motor sizing and selection to reduce total energy and by extension the CO_2 contribution of pumps in mineral processing concentrators.

Increasing Paste Production at Prominent Hill through Debottlenecking of the Belt Filter

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ABSTRACT

The Prominent Hill copper-gold concentrator treats a combination of open pit and underground ore. As the open pit ore reserves deplete, Prominent Hill is undergoing the Wira Shaft Expansion Project, targeted at increasing the capacity of its underground mine. With this expansion, there is an increased demand for paste to fill underground voids. In 2020, the Malu Paste Plant (MPP) was commissioned with the intent of increasing paste production to meet current and future demand by upgrading the existing cemented hydraulic fill plant (CHF).

The new belt filter, a major component in the process flow at the MPP, was identified as a significant bottleneck to achieving increased paste production.

This paper discusses the identification of the limitations associated with the belt filter and details the subsequent design modifications and implementation of solutions which have put the MPP on track to meet current and future demands of the underground mine. Data is presented to quantify the outcomes which include a marked increase in throughput and improved process control, leading to enhanced autonomous operation of the MPP.

Filtered Tailings – An Iron Ore Experience

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ABSTRACT

Transitioning to a green future requires the mining industry to adopt sustainable practices.
Filtered tailings are become a key expectation of the communities we operate in and are growing in a number or mining commodities including bauxite, nickel, gold and iron ore.
The filtration technologies required range from dewatering screens to vacuum and pressure filters. Particular challenges faced in iron ore applications include large scale which means several units of large size are often required. In addition, a high specific gravity that cause sedimentation issues and a high abrasion level make demands on achieving reliability level at above 90%.
This paper describes the testing, selection criteria and specific features required to provide a rational option for equipment and plant design. An example of how this has been applied in an iron ore application in Brazil is used to demonstrate a successful outcome. This project installed four overhead beam filter presses each producing around 200 t/hr utilising a recessed chamber plate, feed pressures up to 15 bar, cake thickness of 50mm.
The moisture lower than 20% that was produced was considered to provide material with handling and geotechnical properties to guarantee a safe stacking.
Regular high pressure washing at 100 bar was considered imperative to maintain cloth life and process performance.
The correct management of the system (OPEX control) by PLC control ensures a balance between machine potentials and plant needs. With this equilibrium it is possible to limit mechanical wear preserving equipment lifetime.

Optimising Process Performance of Existing Thickeners and Clarifiers with Technology

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ABSTRACT

Thickeners and clarifiers are used in mineral processing for solid liquid separation. Water is recovered for reuse within the plant. Thickened underflow is collected from the thickener for further processing or placement in a tailings storage facility - where the stability of that material is of high importance for environmental and safety reasons.

One aspect of the thickener that is critical to thickener performance is the feed system. That is where the incoming feed slurry is received, conditioned, and mixed with flocculants which enhance the materials' settling characteristics. Superior feed system design enables thickeners to be operated at high loading rates and deliver improved process performance – that is high underflow densities and optimal water recovery. For this reason, the thickener feed system has been referred to as 'the heart of thickener performance" *(Reference: R.A. Triglavcanin "The Heart of Thickener Performance", 11th International Seminar on Paste and Thickened Tailings - 2008).*

Water is becoming an increasingly scarce and more valuable resource in most locations where mineral processing occurs. The importance of reliable, high-performing thickener technology, therefore, continues to grow. Another important consideration is that - as society moves towards circularity and reducing waste – the reuse of existing installed equipment through modernisation and upgrades is growing in importance. These demands drive thickener suppliers to invest in research and development and strive to create industry-leading technologies to achieve more sustainable thickener designs that take technical performance to the next level.

This paper discusses recent innovations in thickener feed system design. Following extensive research and development, including validation through modelling and testwork, this innovative design was implemented during recent upgrades of existing thickeners. These upgrades have enabled existing equipment to be repurposed to operate at higher loads while achieving improved process performance. Implementation of these upgrades is also discussed - including before and after operational results obtained from measurements of thickener performance at site.

Converting from Single Stage to Series Ball Milling at the Newmont Tanami Operation

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ABSTRACT

The Granites Gold Mine commenced operations in 1986 as a 300,000 tonnes per annum single stage ball milling, gravity/cyanidation plant. The process plant underwent a series of upgrades between 1989 and 2003, changing the flowsheet configuration initially to SABC and then back again to single stage ball milling at an ultimate capacity of 2.85 Mtpa. Following the completion of open pit mining and the exhaustion of open pit ore stockpiles, the milling circuit capacity was reduced to 2.3 Mtpa on the harder underground ore, with the grinding circuit often being mine constrained since that time. The configuration of the process plant prior to 2017 did not incorporate a leach feed thickener, which required grinding circuit classification efficiency to be compromised by high density operation to maintain adequate slurry viscosity in the downstream leach/CIP circuit.

The Tanami plant was expanded in 2017 to increase the plant capacity to 2.6 Mtpa, concurrent with the installation of a second decline to boost underground mine production. The process plant expansion included the addition of a secondary 4.8 m x 7.1 m EGL, (2.7 MW) variable speed ball mill to operate in series with the existing 5.5 m diameter x 9.3 m EGL, (4.7 MW) fixed speed Outotec shell supported ball mill. A leach feed thickener was also installed to decouple the grinding and leach circuits. Ore transfer between the two mills is managed by a combination of flat-bottomed 400CVXFB cyclones producing a primary COF P80 of around 250 microns and a bleed of the primary gravity circuit tailings to the secondary mill cyclone feed hopper.

This paper discusses the performance of the expanded grinding circuit since commissioning and compares the performance of the grinding circuit processing underground ore in both single stage and series milling configurations.

Batu Hijau – A Journey towards Further Optimisation

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ABSTRACT

PT Amman Mineral Batu Hijau has a long history as a site which has been at the forefront of technology, with a past including many well-delivered optimisation and improvement projects in conjunction with leading industry partners.

This paper details the strategy and outcomes to-date of a site-led optimisation program, with the aim to improve the performance of the existing 40Mtpa plant prior to the commissioning of the new 60Mtpa expansion plant. A multidisciplinary approach was taken to effect improvement across comminution and flotation circuits via means of changes in operational and maintenance strategy, improvement in regulatory and advanced regulatory control, advanced process control and instrumentation. The primary aim was to increase plant stability to improve performance and lower cost basis, while dealing with challenging ore feed types and difficult water chemistry conditions.

Unlike many operations, were global maintenance strategies are driven by SAG mill reline frequency, Batu Hijau has a unique circumstance where the plant shutdown schedules are driven by a mandatory bi-annual submarine tailings pipeline inspection. Historically, the Batu Hijau SAG Mill shell lifter design has been a steep face-angle top-hat design which was in place for more than a decade of operation. In 2022 as part of a broader site-led optimisation program, Amman Metallurgy team assisted by Metso decided to select a new design of SAG shell liner profile favouring SAG metallurgical performance and efficient rock breakage mechanism without sacrificing liner life. At the end of the trial campaign, the new design has demonstrated an improvement in specific energy and milling rate with finer product size. In addition to metallurgical performance benefit, the new design also allowed reduction in relining time due to decreased in liner pieces and a reduction in liner scarp weight at the end of life.

The programs of work being undertaken has also helped bolster the experience of a team of junior metallurgists prior to the upcoming expansion commissioning, which is due to commence in 2024. It is hoped this paper assists future metallurgists considering what they can do at their own sites to shift process operations outcomes towards best practice.

Expansion of Mandalay Costerfield's Flotation Circuit

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ABSTRACT

Eriez Flotation and Mandalay Resources have worked together to increase mill throughput and improve the recovery of fine gold and antimony at the Costerfield site in central Victoria. The scope of this expansion included increasing the capacity and flexibility of the flotation circuit and recovering additional gold from the flotation tailings.

To meet the challenge of limited real-estate, Eriez commissioned two different flotation technologies to expand both the up-front and back-end of the existing flotation circuit. Eriez StackCell® technology was implemented as a pre-rougher stage in order to reduce the load on the existing flotation circuit. The innovative two-stage StackCell design features a high-shear contacting chamber and quiescent separation chamber and improves recovery of fine particles and slow floating minerals with a 75-85% reduction in flotation volumetric requirement.

For Mandalay Resources, the StackCell pre- rougher enabled production of an immediate final concentrate, reducing the load on the downstream conventional cells. The StackCell's high-capacity and compact design was ideal to fit into a small footprint without major modifications to existing layouts. Installing two cells in series had the benefit of providing increased residence time and capacity to handle surges and future variations in ore blends and grind sizes. Two flotation columns, utilising Eriez' unique CavTube™ sparging systems, were installed to treat the plant final tailings. The objective of this was to recover the fine gold-bearing particles lost in conventional flotation, producing a concentrate to blend with that from the existing circuit.
This paper recounts the project from the early testing phases through to the commissioning and successful integration of the units into the Costerfield flotation circuit.

Ravenswood Gold Mine Expansion

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ABSTRACT

Ravenswood has an exceptionally long history of gold production with more than 4 million ounces mined since 1868. Ravenswood Gold currently owns the deposit with another 4 million ounces still in resource. Ausenco was approached in 2020 to explore expansion opportunities to increase the annual capacity from 2.2 Mt/year to 12 Mt/year, and a fast-tracked project was commenced. In only 30 months, the project progressed from initial scoping to final commissioning. The scope of work included a new crushing and screening plant, milling circuit, gold leaching circuit, expanded gold room, additional tails thickener, upgraded water and power services.

This paper explores the methodologies used to fast-track the design, construction and commissioning of the new circuits.

The new Ravenswood Gold processing plant can be operated efficiently across a range of capacities (between 5-12 Mt/year). Preconcentration is used to selectively upgrade the ore efficiently, early in the process, helping improve the operation's economics while significantly reducing water and energy consumption. Quick, accurate decision making was a priority in the initial scoping and concept development phase of the project and technoeconomic modelling was used to aid in this.

This paper presents examples of how these approaches were effective in determining the size and number of new leaching tanks needed, the optimum grind size, mill size and configuration, and the rejection rate of coarse waste that was required.