P29 TECHNOLOGY™

A CASE STUDY INTO THE FUNDAMENTALS, ITS APPLICATION, AND ITS ROLE IN ENABLING ‘**NET ZERO**’

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CONTENTS

LIST OF FIGURES

WHO IS CIDRA?

CiDRA is a leader in industry innovation and has a proven track record of delivering novel technology-based solutions to the mining, oil & gas, concrete, power generation, water, biotech, and communication industries over the past 30 years. CiDRA works closely with industry leaders to identify step change opportunities and then leverages venture capital to rapidly innovate and commercialize novel sustainable solutions. Over this time CiDRA has spun out four CiDRA division which were acquired by multi-national industry-leading companies (Weatherford, Illumina, Buckman and Expro). Consistent with its track record of industry innovation, CiDRA Minerals Processing Inc. (CiDRA Minerals) has developed, deploys and supports the novel SONARtrac™ flowmeter and the CYCLONEtrac™ real time particle size analysis system to the mining industry. Over 50% of the world's copper production flows through CiDRA's SONARtrac flowmeters and 15% of the global copper grinding circuits are currently being optimized by measuring real-time particle size with CiDRA's CYCLONEtrac system.

INTRODUCTION

CiDRA Minerals has developed a novel mineral separation solution called Grind Circuit Rougher™ (GCR) which leverages CiDRA Minerals P29 Technology™ platform (P29). This novel technology has been specifically designed to help address many of the critical challenges facing the mining industry and is covered by a broad patent portfolio of the core P29 technology and its application space. Lower head grades, harder ore, rising energy costs, scarcity of water, forecasted base metal supply deficits, and the drive towards greener mining is forcing the industry to adjust.

The GCR solution enables mining operators to increase plant throughput and net metal production by reducing the amount of work that is required in the grinding circuit to process a ton of ore. GCR recovers the same amount of material from a ton of ore as a flotation process, but at a far coarser size, up to 3mm. Coarse particle recovery from the grind circuit significantly reduces the grind specific energy (kWh/t) and therefore also potentially reduces the scope 1 and 2 greenhouse gas (GHG) emissions per ton of metal produced, while the coarse tails from GCR enable a higher overall water recovery.

IF IT CAN'T BE GROWN, IT MUST BE MINED

Minerals are essential to life on this planet, not only for all forms of life to exist and thrive but also everything we depend upon in today's world is either made from minerals or relies on minerals for its production and distribution [1]. The adage of "if it can't be grown, it must be mined" reminds us that as the world transitions towards 'Net Zero', the technology needed to do so, electric vehicles, alternate energies, a green economy, etc., all require minerals [2]. The World Bank study indicated a four-fold increase (400%) of mineral demand from 2020 to 2050 to provide the low-carbon technologies to limit global warming to 2°C [2]. It needs to be noted that in this adage it's implicit that 'mining' includes processing the mined ore through to final usable product.

The first stage of processing the mined ore is concentrating the low-grade ore to a higher-grade concentrate that can then be processed by smelting and refining to produce the final pure metal that is then consumed by the end user, Figure 1. For base metals a common form of this concentration process is froth flotation [3], Figure 2, and it is estimated that 85% of the base metals produced are concentrated via froth flotation, [4].

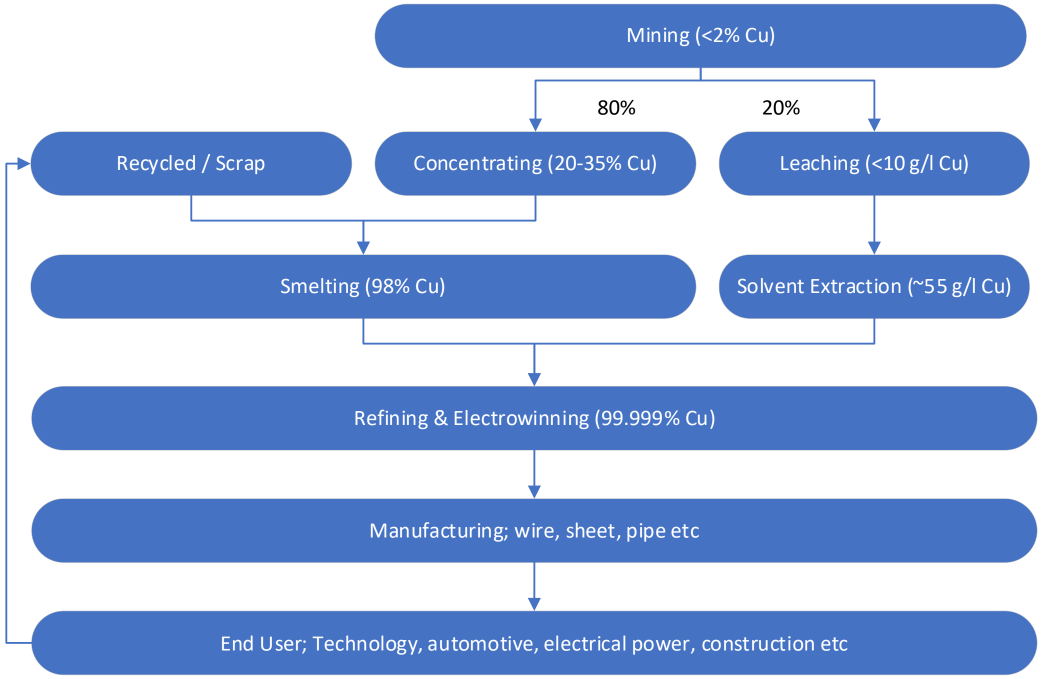

Figure 1 Simple copper lifecycle from mining to end user showing approximate grade of copper through the lifecycle

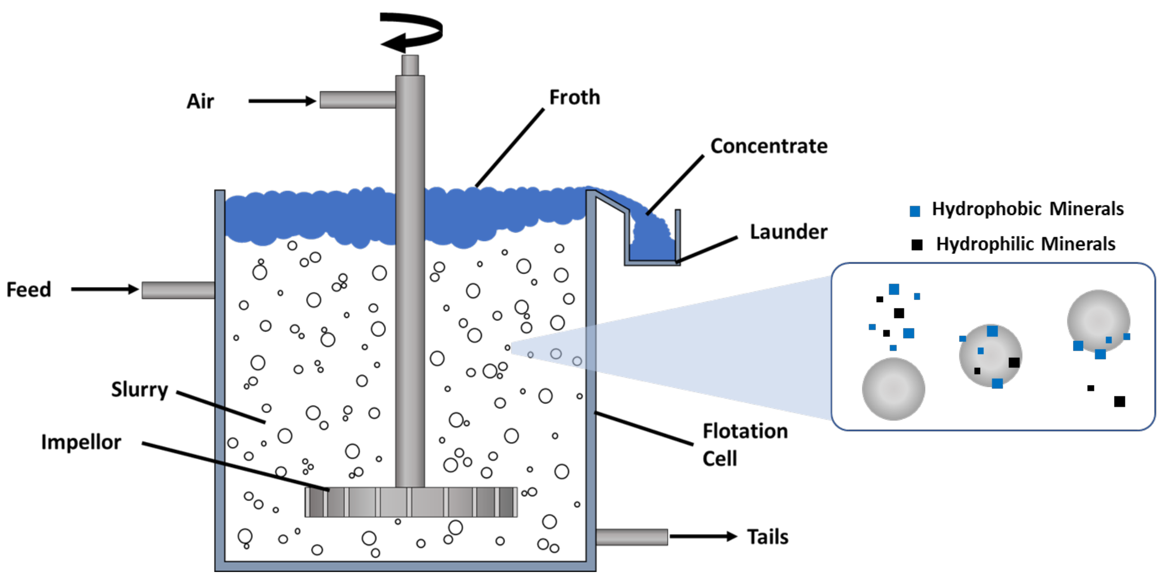

Figure 2 Simple overview of the froth flotation process / equipment, with the mineral captured in the froth and being recovered in the concentrate launder

Since the late 1800's froth flotation has fundamentally remained the same, and so have its limitations. There is a sweet spot in particle size of the mineral for peak performance in froth flotation, which varies according to the specific gravity of the mineral, see Figure 3, [5] and [6]. There is a continuous trade-off in performance between the coarse and fine particles, with the coarse favoring short residence time and the fines favoring long residence time. This phenomenon is commonly observed by the coarse particles easily detaching from the air bubble, due to their size and mass, and hence need a short residence time with less opportunity to detach. The fine particles on the other hand, require the correct particle/bubble interaction for the low mass fine particle to have enough kinetic energy to overcome the surface tension and energy forces of the air/water interface for the hydrophobic collector to be effective, Figure 4, [7]. With traditional flotation equipment at particle sizes below 30 μm and above 100μm, recovery starts to rapidly drop.

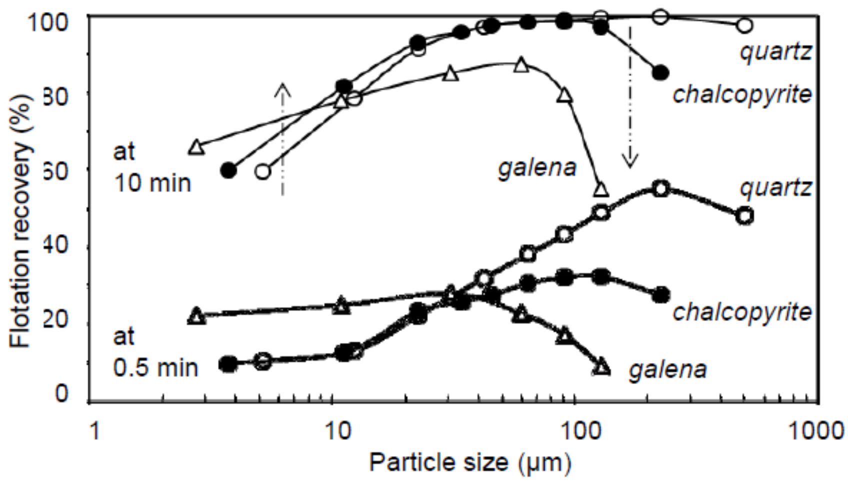

Figure 3 Flotation recovery of quartz, chalcopyrite, and galena (density of 2.6, 4.3 and 7.6 g/cm3 respectively) as a function of particle size at 0.5 min and 10 min residence time. The vertical arrows show the change in recovery with increasing mineral density, [5]

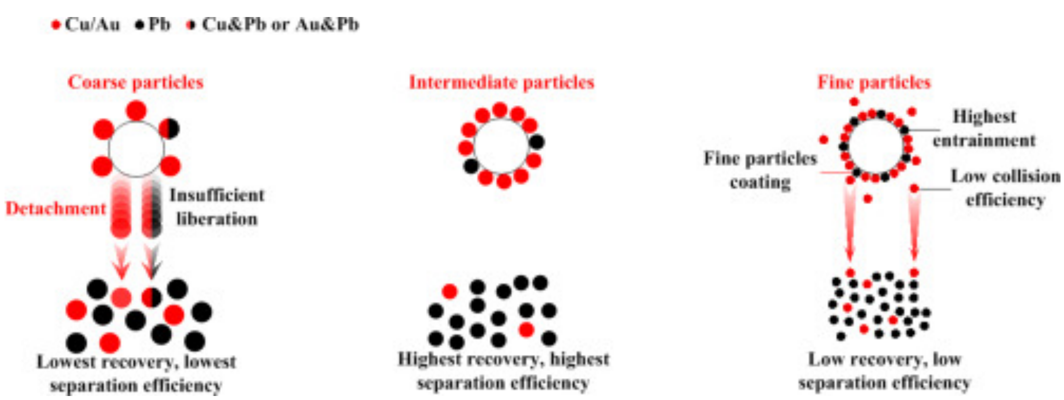

Figure 4 Summary of impact of particle size on froth flotation [7]

Over the past century there have been various technologies developed to improve flotation performance, but in general they focus on either fines or coarse, such as the Concorde Cell™ from Metso for fines or the HydroFloat® for coarse, Figure 5. It has been seen to be very difficult to optimize both the coarse and fines at the same time as the mechanisms holding back the flotation performance of each of these size fractions are not the same. CiDRA Minerals has developed a technology platform called P29 Technology™, a single unit operation that addresses these foundational limitations of froth flotation.

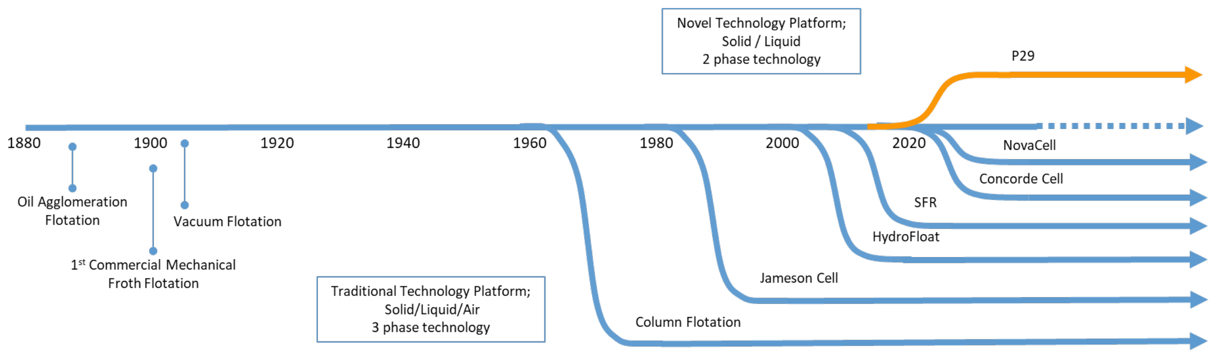

Figure 5 Example of key froth flotation technologies over the centuries

P29 TECHNOLOGY™

Since 2012 CiDRA Minerals has been developing a mineral recovery technology platform that utilizes chemistry and an engineered mineral collection media (high surface area to volume reticulated foam blocks) that replaces the air bubble in flotation. Replacing the bubble with the engineered media provides the ability to break down the critical process steps of mineral capture, transport, and release. Separating the foundational mechanisms for mineral recovery enables each of these mechanisms to be optimized independently. This differentiation has the potential to significantly improve the economics of a concentrator and can be applied to existing mining operations, greenfield projects and unlocking lower grade deposits that were otherwise uneconomical with traditional flotation technology. P29 currently leverages industry standard froth flotation pulp chemistry, therefore, if a mineral can be recovered by froth flotation then it can be recovered by P29. Future developments of the P29 solid/liquid two phase system will enable novel approaches to chemistry and mineral recovery that are not limited to existing industry aqueous reagent chemistries. This has the potential to address mineral separation of complex ore bodies that are not achievable with today's technology.

OVERVIEW (REPLACING THE AIR BUBBLE IN FROTH FLOTATION)

P29 is an evolution in mineral separation and utilizes common industry standard equipment along with a proprietary engineered hydrophobic coating on industrial reticulated polyurethane foam that replaces the function of an air/water bubble in froth flotation. A biodegradable non-ionic surfactant is used as a mineral release agent to release the mineral from the collection media. Both the collection media and release agent are then reused in the P29 process, Figure 6 and Figure 16.

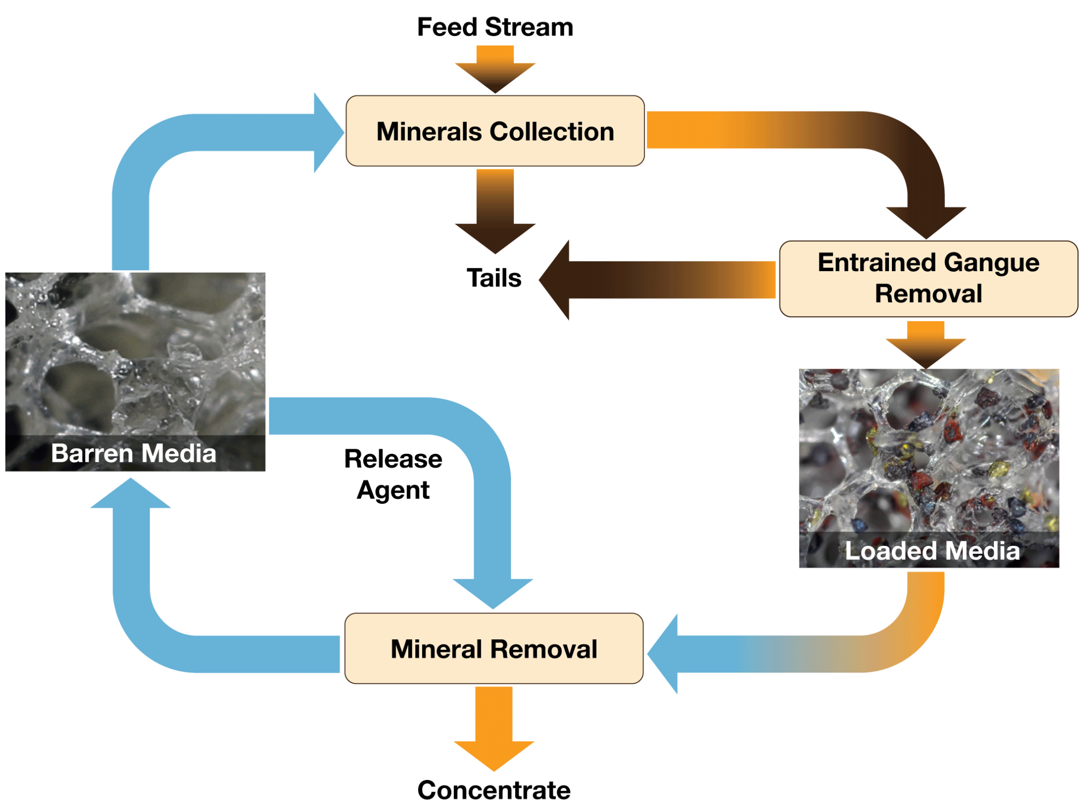

Figure 6 High level overview of the P29 process

Standard froth flotation collectors are used to make the mineral hydrophobic. When the hydrophobic mineral and the hydrophobic collection media are brought in contact with each other in water the mineral will 'attach' through Van der Walls forces, Figure 7. The hydrophobic/hydrophobic attraction mechanism is similar to froth flotation, but unlike flotation, the particles are stuck to the surface of the collection media. The attachment of the mineral to the collection media surface is rapid and strong, and the surface properties of the media can be tailored for a specific application. The collection media surface properties such as contact angle, compliance, toughness, and tackiness are a few of the engineering levers available to optimize the media collection properties.

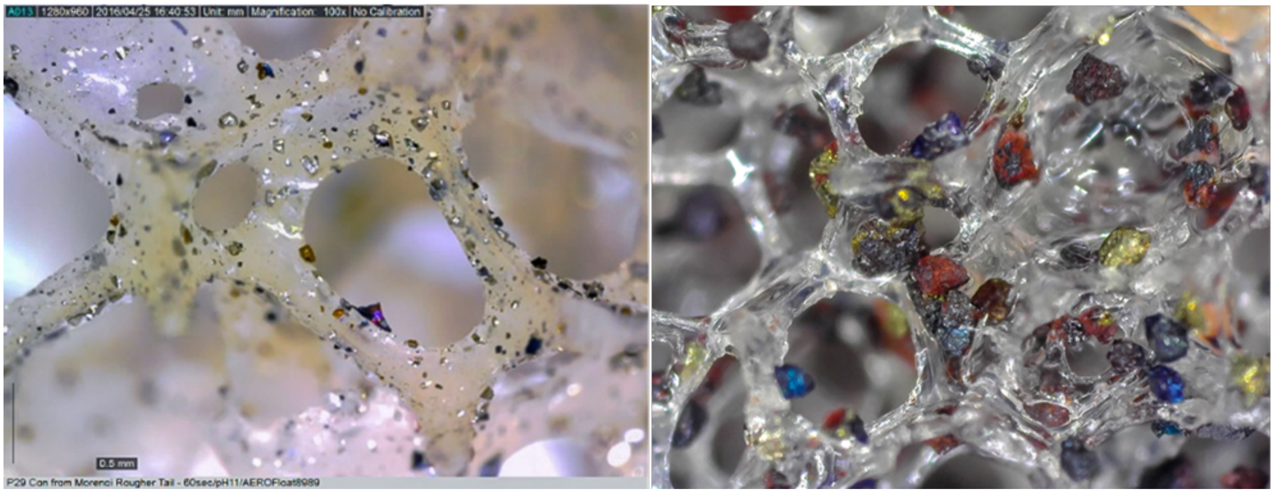

Figure 7 P29 mineral loaded collection media

The mineral is released from the collection media by using a combination of the release agent and mechanical agitation which can be as simple as pumping the collection media. The surfactant gets between the collection media and the collectorized mineral as the mineral particle is nudged by the mechanical action within which prevents the collectorized mineral from re-attaching to the surface of the collection media. The barren collection media is rinsed to recover the release agent, which in turn is recovered from the water by centrifugation and/or nano filtration, to be reused in the stripping step of the process. The barren collection media is then reused in the collection phase of the process, Figure 8. The P29 concentrate stream is then dewatered by normal minerals processing techniques and sent to the plant's regrind mill and cleaner circuit.

Figure 8 Barren collection media post stripping and washing, close up on the left and a 12.5mm media cube on the right

The structure and pliability of the collection media enables the recovery of very large particles, up to 3mm, and with the high surface energy of the media recovers minerals with very low exposed mineral surface of less than 1%, see Figure 9 through to Figure 11. The strength of the media/mineral bond is such that the loaded media can be vigorously washed to remove any entrained gangue that is caught within the foam structure, resulting in high selectivity with a low mass yield to concentrate and a high upgrade ratio.

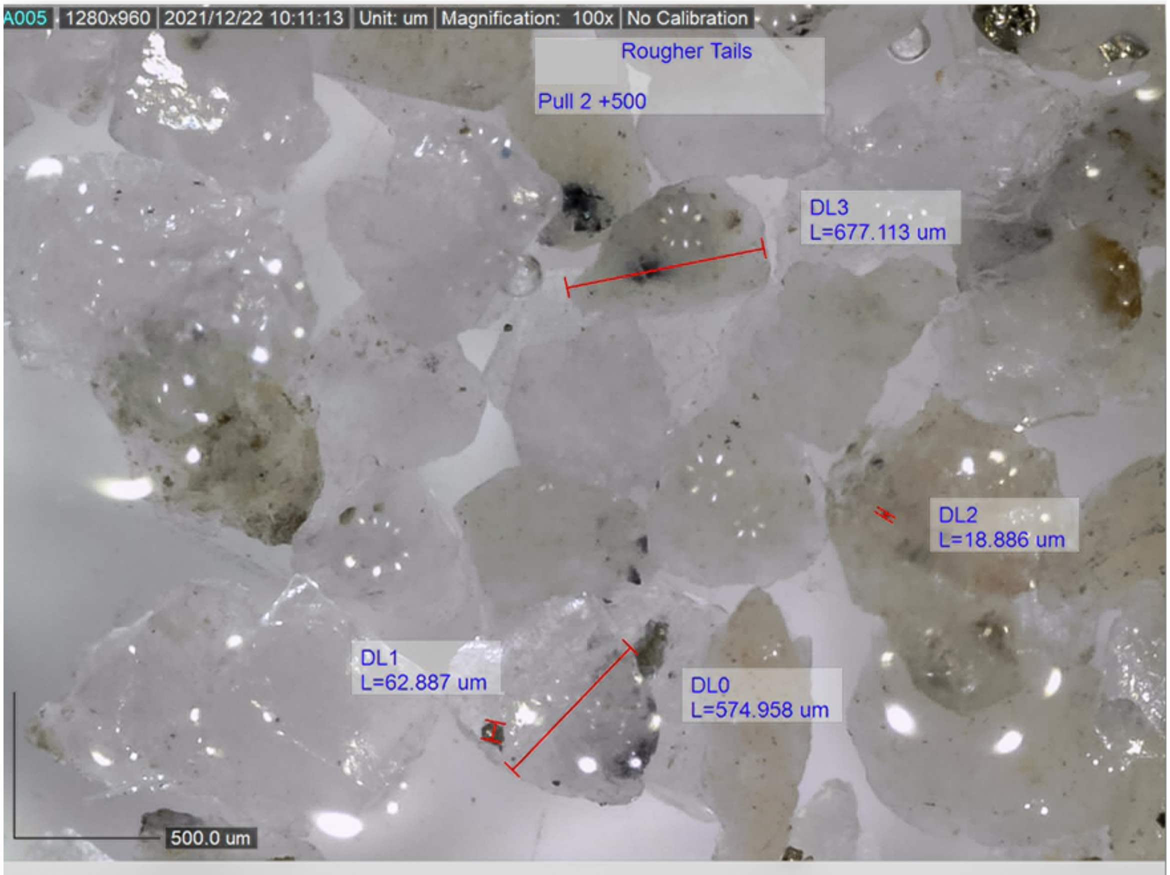

Figure 9 P29 concentrate from scavenging rougher tailings at a size fraction of +500µm

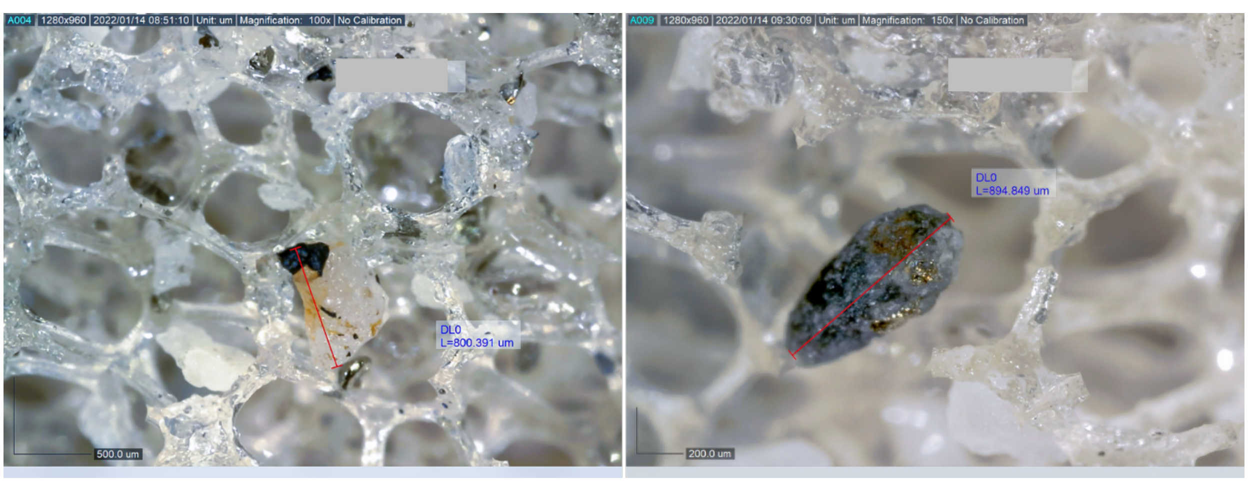

Figure 10 Partially liberated coarse particles adhered to the collection media surface

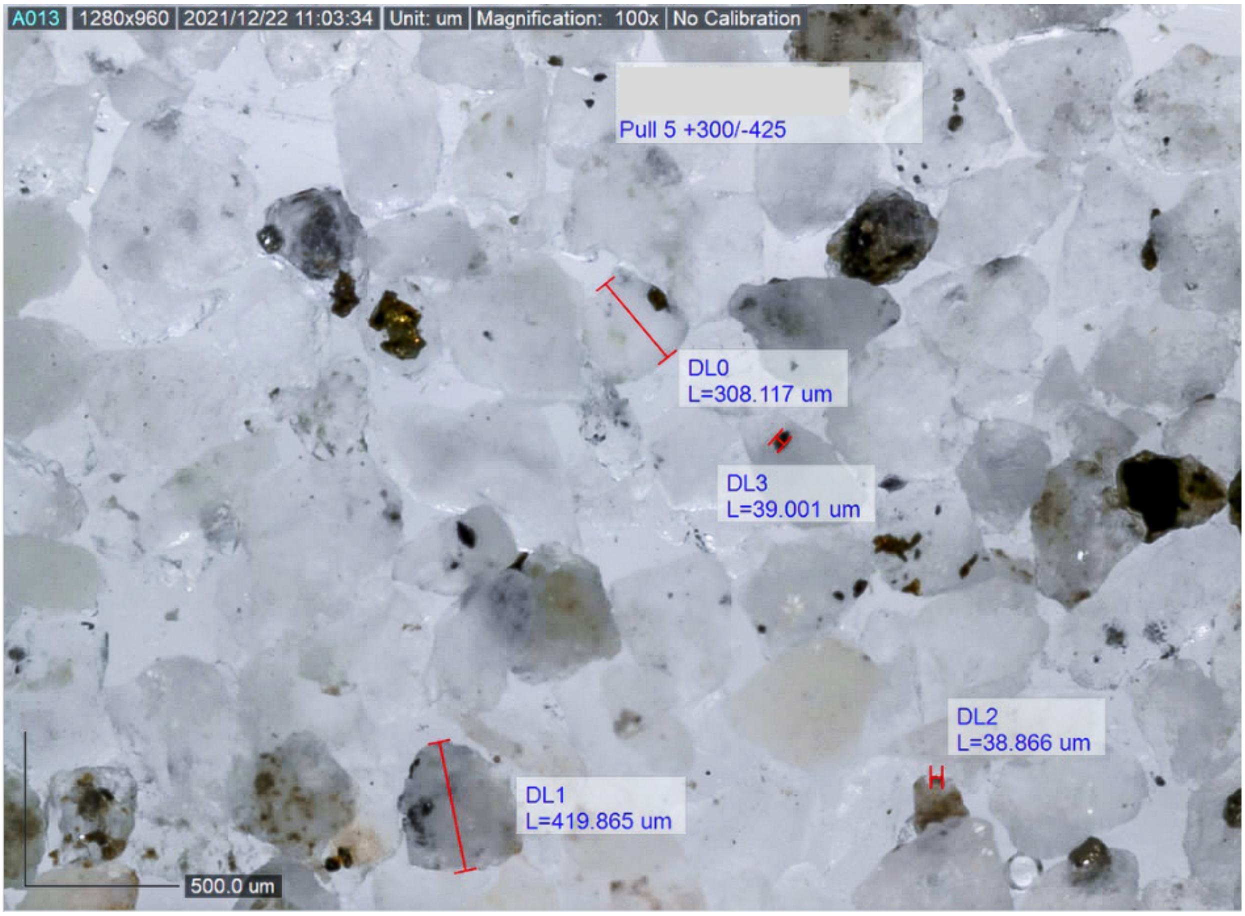

Figure 11 Concentrate in the +300-425µm size fraction, backlighting helps reveal the sulphide surface expression of the particles

ENGINEERED COLLECTION MEDIA

P29 collection media consists of a substrate of reticulated polyurethane foam with a proprietary polymer coating that generates a pliable and highly hydrophobic surface, Figure 12. The properties of the polymer coating can be adjusted to the mineralogy and application duty of the processed ore. The 12.5mm cubed foam media serves as the particle attachment and transport structure, thereby replacing the function of the air/water bubble in froth flotation.

Figure 12 P29 polymer coated collection foam media at 12.5mm x 12.5mm x 12.5mm

The foam substrate can be engineered with different pore sizes measured in pores per inch (PPI) as shown in Figure 13. The PPI of the media can be tailored for the particle size distribution for the specific application. The pore size in the media defines the available surface area for mineral attachment and is analogous to the bubble surface area in froth flotation.

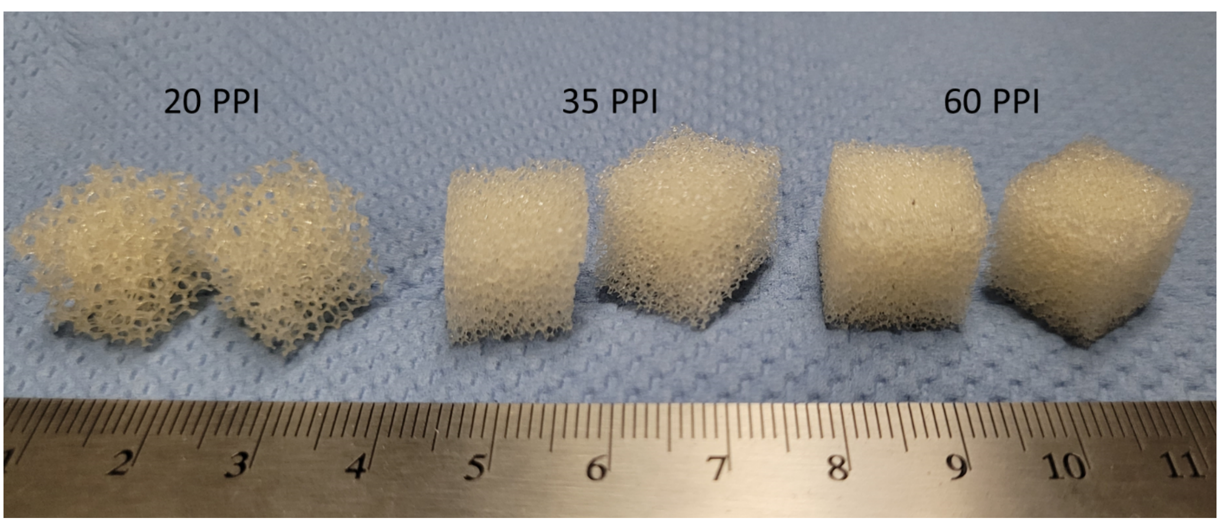

Figure 13 Different pore sizes of P29 collection media allowing for collection of a wide range of particle sizes

The advantage of engineered foam media as a mineral collection mechanism is that it can be optimized for durability, surface energy, compliance, and flexibility, as well as the shape and size of the media. The industrial reticulated foam is coated and cured through industry standard processes, Figure 14, the cured foam sheets are then cut into cubes and vacuum packed for shipping, Figure 15.

Figure 14 111m long foam coating and curing oven

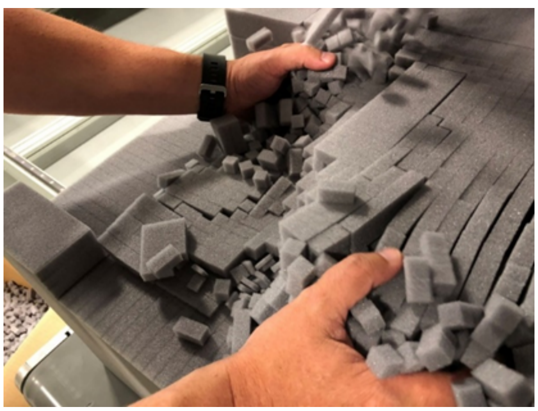

Figure 15 Foam sheet cut into cubes

P29 AND INDUSTRY STANDARD EQUIPMENT

Figure 16 shows a simple flowsheet of the P29 technology process where each of the unit operations are performed with industry standard equipment.

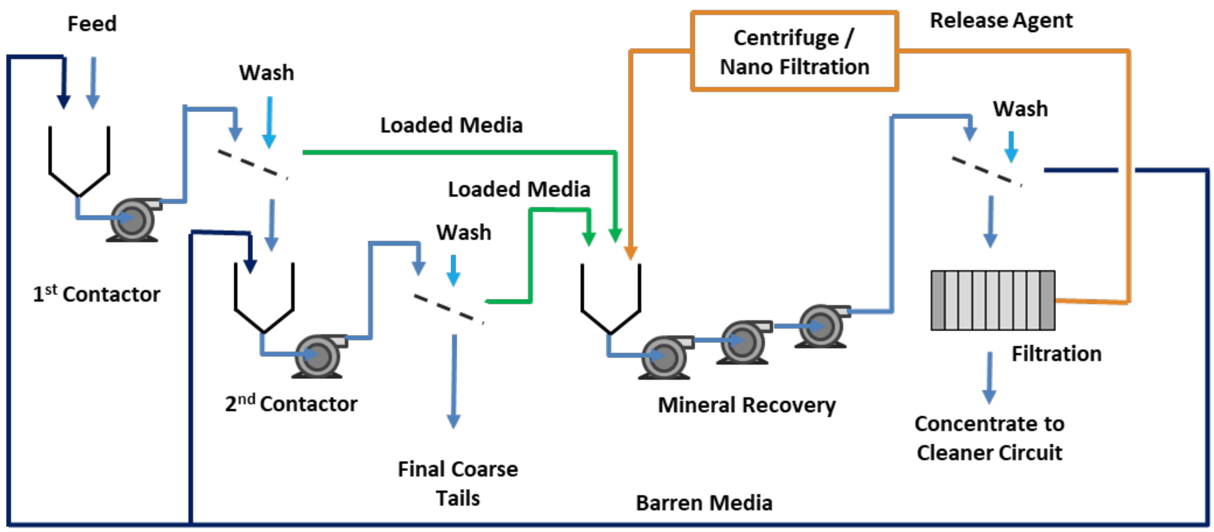

Figure 16 P29 flowsheet

CONTACTOR

The contactor is a simple mixing device designed to contact the mineral slurry with the collection media. Embodiments of the contactor are a sump/pump and pipe or a horizontal rotating drum. The circuit configuration will be a function of the feed slurry mineralogy, rheology and application space.

MEDIA/SLURRY WASH & SEPARATION

The loaded media is separated from the slurry via a screen, either attached to the end of a horizontal drum contactor or as a standalone vibrating screen. A water rinse is used to remove the entrained gangue from the media which results in high upgrade ratios. The media is dewatered prior to the mineral removal stage with either a vibrating screen or a ‘low g’ basket centrifuge.

MINERAL REMOVAL

The mineral is removed from the media by passing the loaded media and release agent through a series of disc pumps.

RELEASE AGENT RECOVERY

The release agent used in the mineral removal stage is reclaimed using a centrifuge or nano filtration stage. The reclaimed release agent is returned to the process.

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DEWATERING

Common minerals processing equipment such as cyclones, settling tanks, thickeners and filter presses are used.

OPERATING WINDOW

The underlying fundamentals of P29 have been tested at multiple mines and commodities since 2012. Over that time numerous approaches and embodiments have been developed, refined, and tested with over 5000 customer bench tests and a successful pilot scale plant campaign. Commodities tested to date include copper, lead, zinc, silver, molybdenum, gold, diamonds, nickel and iron ore. A wide range of process streams have been tested with particle size distributions ranging from a P_{80} of 16µm to 2400µm.

- Drill core
- Grind circuit cyclone underflow
- Rougher feed
- Rougher tails
- Plant tails
- Rougher concentrate
- Cleaner tails
- Old tailings

A summary of the operating window is shown in Figure 17.

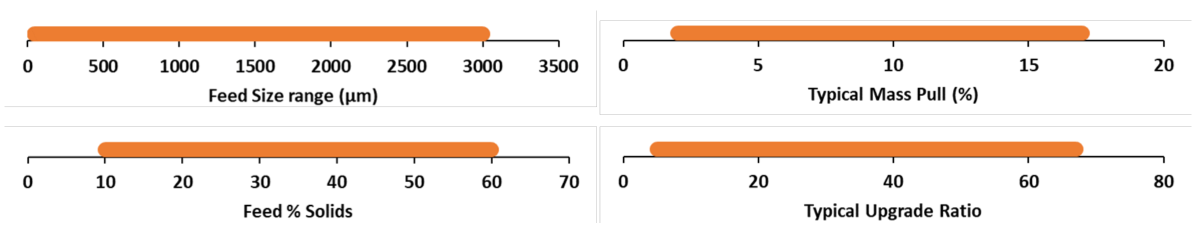

Figure 17 Summary of P29 operating window

Based on the extensive test work, it has been demonstrated that P29 does not require any feed preparation. This is due in part to the fact that the fundamentals of mineral capture, transport, and release have been optimized independently and the collection media has been engineered for application particle size distribution. However, based upon the customer requirements, feed preparation may be selected by the mine site to optimize CAPEX efficiency by leveraging existing capital equipment. This might include unit operations such as fluidized bed flotation or, in the case of old tailings, high intensity conditioning to create fresh mineral surfaces for collection.

A summary of the P29 performance since 2012, encompassing all iterations of the technology, is shown in Figure 18. Figure 19 shows the size by recovery performance of P29 on coarse feed.

CiDRA® Minerals Processing

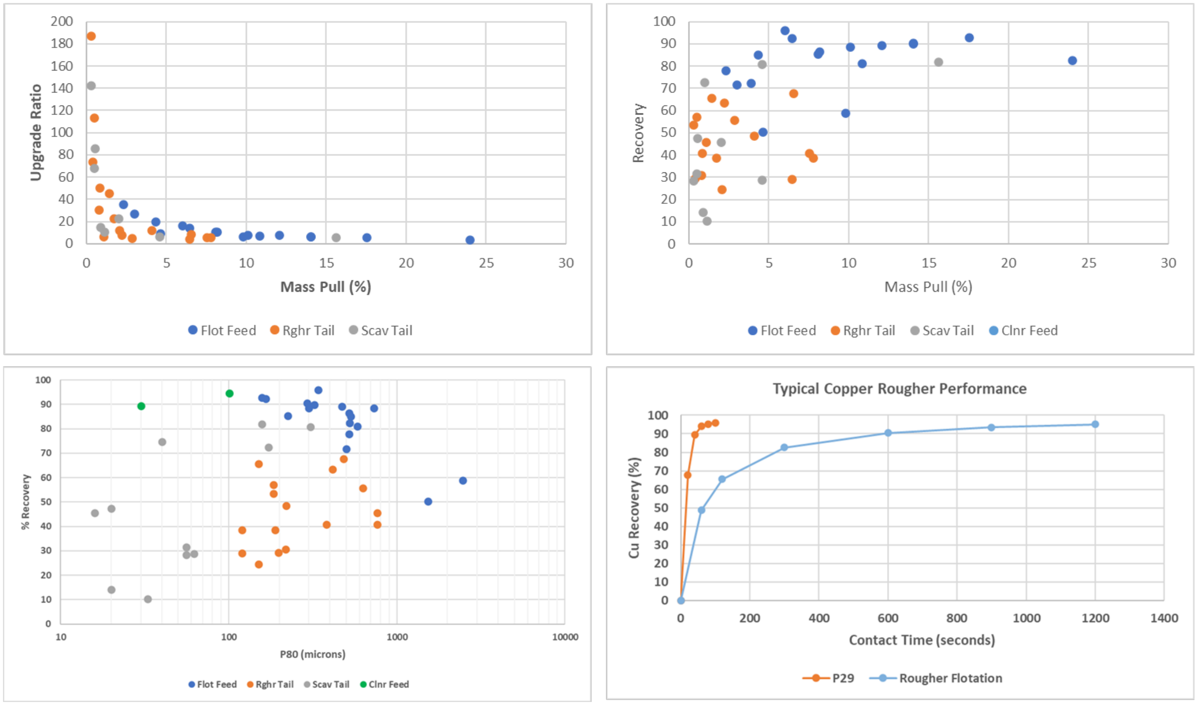

Figure 18 Summary of P29 performance since 2012

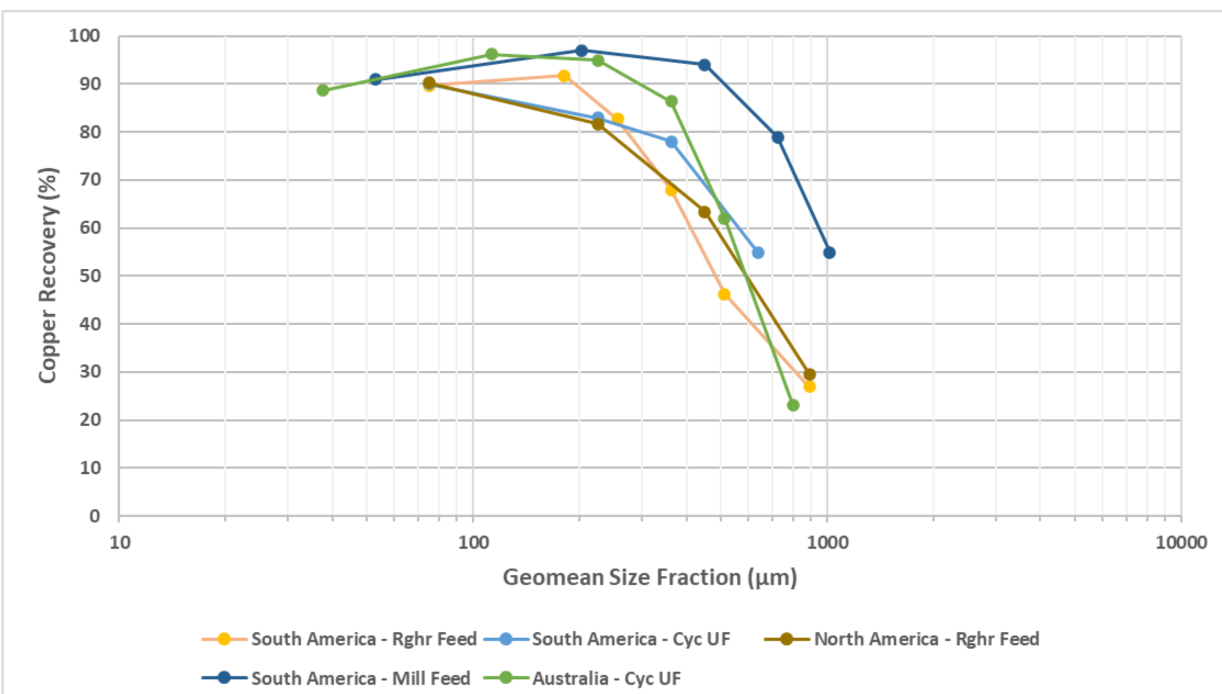

Figure 19 Summary of size by recovery performance of P29 on coarse feed samples from various mines

COMMON APPLICABILITY OF THE P29 TECHNOLOGY PLATFORM

Notwithstanding the improvements to the P29 technology of the past seven years, the results from the test work presented in the 'Operating Window' section are based upon a common collection media and test protocol. This performance shows that for most applications and orebodies a standard P29 collection media can be utilized. The P29 technology does not need to be 'developed' for each mine site. With that said, the engineering levers provided by the fundamental technology platform provide the opportunity to make fine adjustments to the overall metallurgical performance and circuit configuration to meet mine specific requirements and economic goals.

APPLICATION SPACE

P29 can be applied to any current froth flotation application and importantly operates with a wider operating window than froth flotation-based technologies, most noteworthy at a very coarse particle size with no feed preparation requirements. This versatility in operability enables an ESG friendly technology platform with a broad application space;

- Existing operations
  - Brownfield expansion
  - Grind circuit roughing
  - Coarse flotation scavenging
  - Flotation tails scavenging
  - Cleaner scavenging

- Tailings reprocessing (historical tailings)
  - Wide range of particle sizes at high percent solids with minimal feed preparation
- Greenfields
  - Radically decrease the footprint, water usage and power requirements with a coarse tail
  - Marginal deposits become profitable

CASE STUDY – COPPER

MINING INDUSTRY SITUATION: SUPPLY SIDE DEFICIT AND ESG DEMANDS

Industry analysis by Wood Mackenzie [8] and the World Bank [2] highlights that metals will be a linchpin of a zero-carbon economy as the world reduces its dependance on hydrocarbons with an extraordinary build-out of low-carbon electric vehicles and renewable power, Figure 20. Wood Mackenzie looked at an accelerated energy transition scenario (AET-1.5) that assumed the world would decarbonize to limit the rise of global temperature to 1.5°C. Their conclusion was the likelihood of delivering copper to meet the future demand was challenging for the base case and improbable in the accelerated energy transition scenario, and to meet the zero-caron targets the mining industry would have to deliver new projects at a level never previously accomplished. The volume of copper needed means that for the base case 6.5Mt of new mine supply will be required over the next decade from projects that have yet to be sanctioned, a challenge in itself, and 9.7Mt of new mine supply for the accelerated energy transition scenario, Figure 21.

Figure 20 Total copper consumption in 2040 under Wood Mackenzie's AET-1.5 scenario (Mt copper), [8]

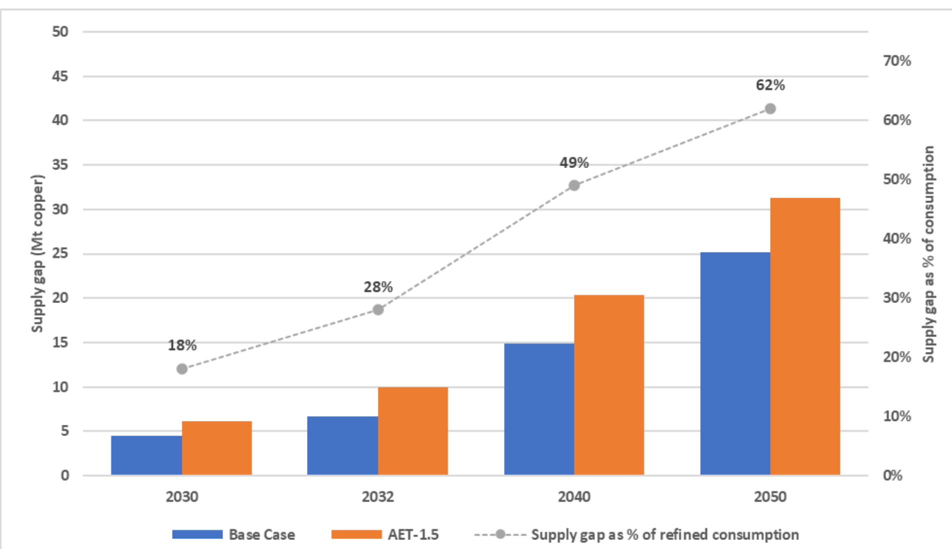

Figure 21 Refined copper consumption that needs to be covered by mine supply to 2050. AET-1.5 is the accelerated energy transition scenario limiting global warming to 1.5°C. Wood Mackenzie Horizons Oct 2022 [8]

In looking to meet the predicted global demand for minerals there are several challenges facing the mining industry. It can take multiple years and billions of US$'s of investment to develop a new resource. An example here is Resolution Copper which was discovered in 1995 and in 2023 is currently in the permitting and engineering phase, with an estimated 10 years of construction to be completed once the mine is fully approved, while the project partners have spent US$2B to date [9].

Meeting the global demand for minerals is also faced with the increasing demands on energy and water. As the 'easy' orebodies have been discovered and mined, the mineralogy of the remaining resources generally dictates the need for higher energy intensive grinding, which in turn increases the water lost in tailings dams. There is also increasing scrutiny of the mining industry in its energy usage, equivalent to 3.5% of the global energy consumption in 2021 [10] as well as the water consumption, where in 2015 USA based mining consumed 1% of the total withdrawn water or the equivalent water consumed by 22 million people [11].

The mining industry will need to innovate to break the conundrum of substantial increase in mineral demand, stakeholder demands of becoming 'net zero' and mining's impact to its local communities.

P29 ENABLING THE MINING INDUSTRY TO MEET ITS DEMANDS

Application of P29 may allow mines to improve resource efficiencies and unlock value from their existing assets and enables them to deliver against their supply deficit and ESG demands. P29 has the potential to deliver an extra 3Mtpa of copper with the existing grind circuit assets currently installed across the mining industry, or about 50% of the predicted 2030 supply deficit. This is delivered by the ability of P29 to recover coarse particles from the grind circuit circulating load at traditional flotation recoveries unlocking energy in the grind circuit that can be utilized for increased throughput and/or reduced grind size, thus reducing the grind specific energy and carbon footprint of a ton of metal produced.

Coarse particle recovery with a throw away coarse particle tails stream unlocks increased water recovery from the plant tailings, significantly reducing the water requirements for the mine. A coarser tailing also enables new and safer designs in tailings impoundments and in a greenfield application tailings could be dry stacked, eliminating the need of a tailings dam.

The reduction in energy and water requirements per ton of metal produced results in a potentially reduced carbon footprint, and in a greenfield application the indicative energy requirements for the grinding circuit can be up to 50% lower than current design.

Combining the outcomes from the application of P29 will enable miners to re-evaluate ore deposits that until now have been deemed uneconomic, releasing new reserves to the industry, and helping close the supply deficit.

AN EVOLUTION TO GRIND CIRCUIT ROUGHING

Test work on an Australian copper mine ball mill cyclone underflow stream, scalped at -1mm, was undertaken. The performance of P29 was benchmarked against bench flash flotation on the same sample, and the existing rougher at a normal grind size of 75µm, an overview of the results is shown in Figure 22**Error! Reference source not found.** and summarized below;

- 90% Copper recovery
- 96% Gold recovery
- A throw away tail with a p80 of 390µm
- Mass recovery of 14%
- Upgrade ratio of 7

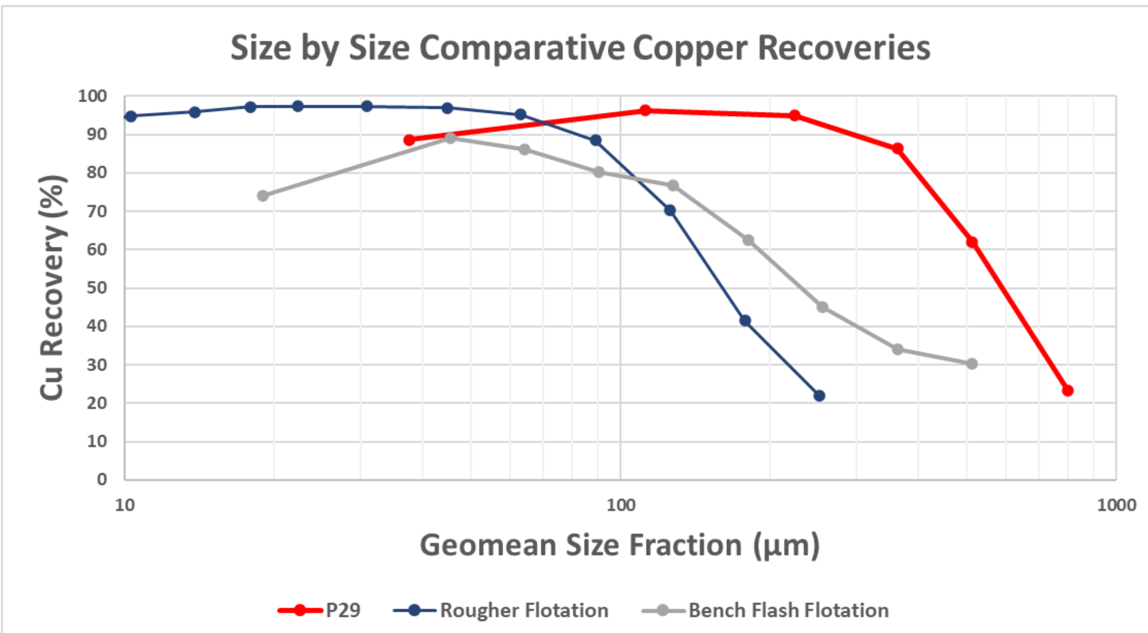

Figure 22 Comparison of P29 performance against flash and rougher flotation

Grind circuit survey and associated modelling looked at the impact of bleeding a portion of the ball mill circulating load to P29 to produce a coarse regrind feed and a throw away tail. The modelling indicated the capability to bleed out equivalent of 16% of the fresh plant feed at -1mm and with appropriate supporting plant modifications resulting in;

- 33% increase in plant throughput with the same SAG / Ball mills
- 40% reduction in grind specific energy (kWh/t)
- 38% increase in Net Metal Production
- 47% increase in total energy efficiency (kWh/t)
- 7% reduction in P_{80} to rougher flotation

Leveraging the case study mine site test work and modeling, a generic baseline plant model was compared with a plant incorporating a P29 Grind Circuit Rougher. The results of that analysis is shown in Figure 23.

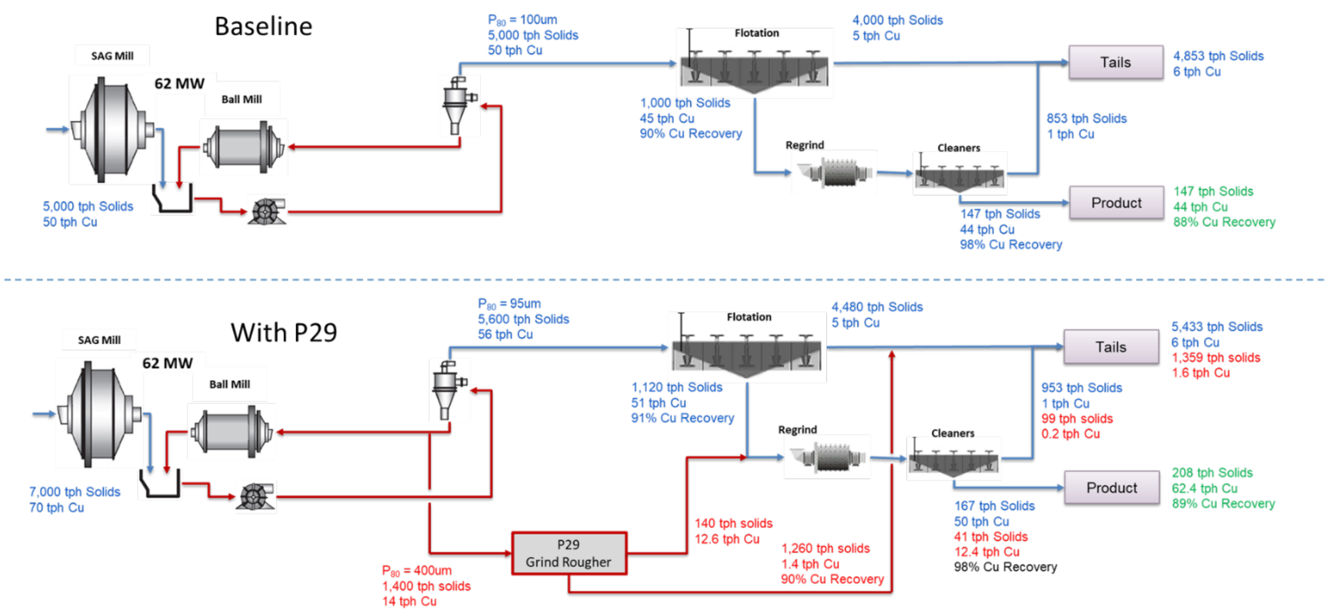

Figure 23 Generic plant model of impact of P29 based upon test work and modeling at a Case Study Mine

The potential significant reduction in grind specific energy from the P29 grind circuit rougher recovering coarse minerals from the ball mill circulating load is highlighted by looking at the Bond equation [3], see Equation 1

$$W = 10 \times Wi\left(\frac{1}{\sqrt{P80}} - \frac{1}{\sqrt{F80}}\right)$$

Equation 1 Bond's Work Index formula.

Where: W is the energy input (kWh/t)

Wi is the work index (Bond work index) (kWh/t

P80 is the 80% passing size of the product (microns)

F80 is the 80% passing size of the feed (microns)

A plot of the Bond Work Index formula using an F80 of 12000 microns and a Wi of 12 kWh/t is shown in Figure 1. If a grinding circuit P80 can be moved from an example of 150 microns to 400 microns by recovering coarse material from the ball mill circulating load, a reduction of grind energy of 44% is potentially achievable (at a P80 150µm Wi = 8.7 kWh/t and at a P80 of 400 µm Wi = 4.9 kWh/t). This reduction of grind energy can then be used to either increase feed to the grind circuit and/or grind the remaining material in the ball mill circulating load finer, assuming the total grind power remains the same.

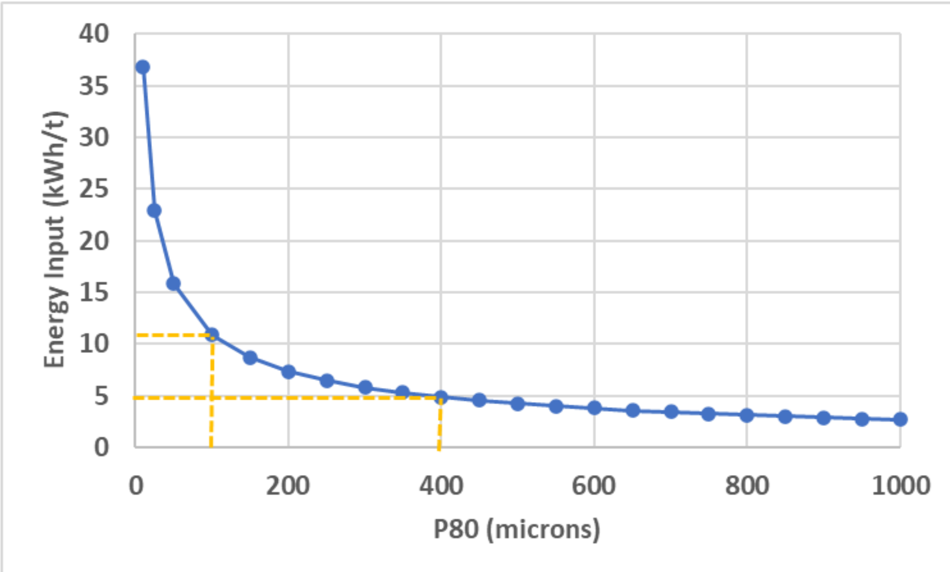

Figure 24 Plot of the Bond Work Index formula using an F80 of 12000 microns and a Wi of 12 kWh/t, highlighting energy input at P80 of 150 microns and 400 microns

COMPARISON OF P29 TO FLUIDIZED BED FLOTATION

The case study mine owns and operates its own fluidized bed flotation equipment. A head-to-head performance test was conducted between the two technologies both processing -1mm cyclone underflow. The mine had to scalp the fluidized bed flotation feed at 650µm to ensure operability while the P29 did not require this feed stream preparation. The size-by-size recovery results are shown in Figure 25.

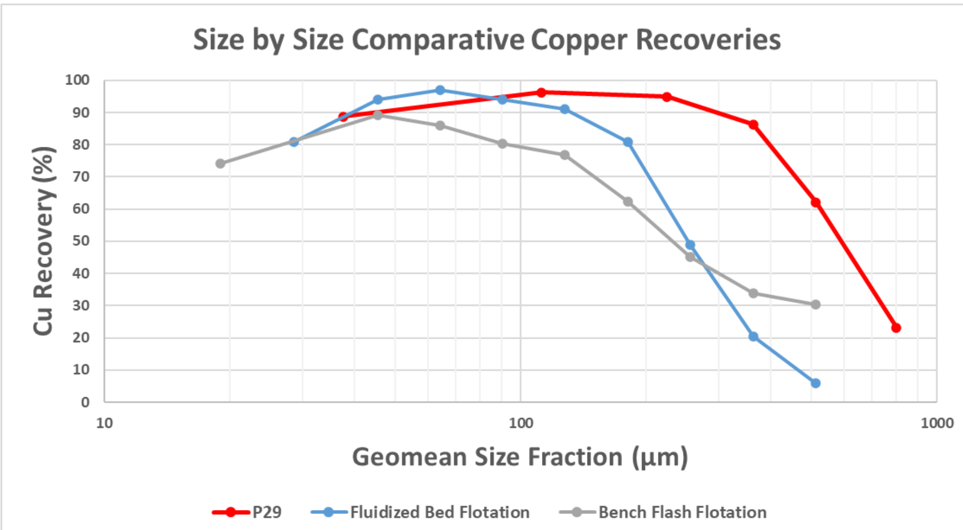

Figure 25 Comparison of size-by-size recoveries for P29 and fluidized bed flotation on -1mm cyclone underflow

MAXIMUM RESOURCE VALUE

Maximizing the resource value is a complex issue, balancing not only the cashflow of the produced mineral(s), but also the stewardship of the natural resource and somewhat trying to predict the future with time value of money. Generally, at the core of understanding the resource value is the combination of two fundamental relationships of throughput versus grind size and grind size versus recovery (and quality), together they give a throughput versus recovery relationship which is known as Net Metal Production (NMP), Figure 26.

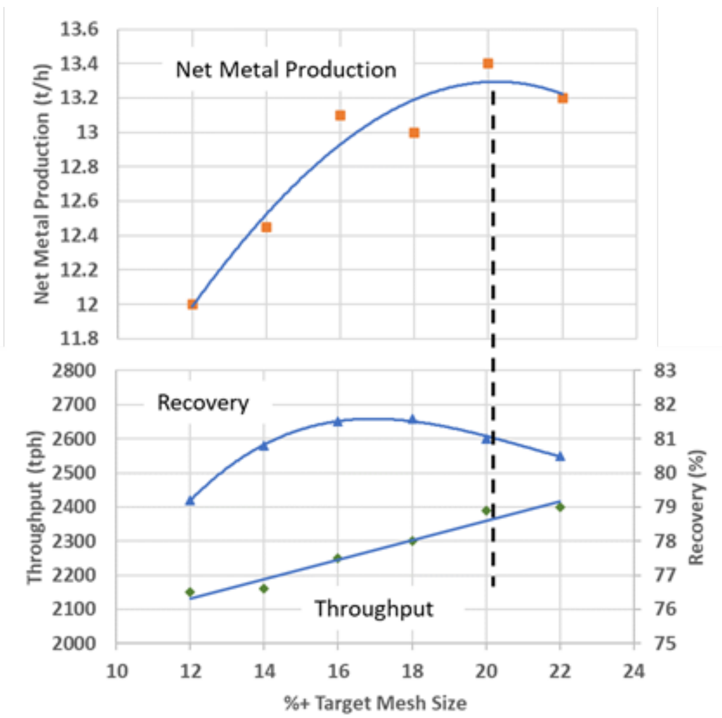

Figure 26 Net Metal Production

However, looking at NMP in isolation does not necessarily equate to maximum value from the resource. It does not account for the value loss associated with increased mining CAPEX and mining value chain OPEX for the increased throughput, or the time value of the incremental drop in recovery that the extra metal units should bear against having a higher potential future recovery. It also does not value the impact to the license to operate, resource stewardship, as well as community and stakeholder sentiment in decreasing the recovery of future metal units. Holistic value analysis of NMP is highly dependent upon the mineralogy of the ore and subsequent throughput-recovery relationships, as well as the impact to C1 costs.

As shown in the case study, the Grind Circuit Rougher trial application of the P29 technology can substantially outperform conventional flotation at coarse particle sizes and performs better than fluidized bed flotation technologies at these particle sizes. This step change in performance may provide a mine operator the value levers to achieve a new higher value operating point. Higher throughput at the same recovery and/or a finer grind with an increase in recovery, all with the existing grind circuit assets, may establish a higher value optimum for the mineral resource.

COARSE PARTICLE ROUGHING VERSUS COARSE PARTICLE SCAVENGING

Various analysis across the mining industry indicates that in more recent years the increase in reserves and resources has come from existing assets rather than bringing on new mines. This increase primarily has come from lowering head grades and increasing throughput while utilizing the existing grinding circuits but at the expense of increasing grind size and therefore decreasing mineral recovery. There are two approaches to recovering the coarse losses. One approach is to split the coarse rougher feed stream into a coarse and fine fraction. Whereby the fine fraction is processed by froth flotation and the coarse fraction is processed by P29. One of the advantages of this circuit configuration is the flotation rougher will be processing a stream that is well within the design specifications for flotation and thereby yielding benchmark mineral recovery as is the coarse stream for P29. The alternate approach would be to feed the flotation circuit with the entire stream while scavenging the coarse losses by either coarse flotation technology or P29. The obvious shortcomings of this approach are that the stream will be processed by two-unit operations in series whereby the coarse material is just passing through the flotation rougher circuit consuming space and hampering mineral recovery. With that said, mines have been turning to coarse particle scavenging to recover the coarse mineral losses that report to plant tails. The intention is to get closer to the peak NMP.

Looking a little deeper into the impacts of increasing throughput using the existing grind circuit assets identifies some negative consequences. Figure 27 shows a generic approach to increasing throughput and grind size while scavenging the coarse tailings. To scavenge the tails stream it generally requires either treating the whole tails stream or using some form of size separation to remove the finer sized particles of the stream and then process 40-70% of the remaining mass flow. It is noted that when scalping out the finer sizes from the tails stream significant volumes of water may be needed. Increasing the grind size, by increasing the throughput, results in poorer performance of the existing rougher flotation and a drop in recovery, resulting in a reduction of CAPEX and OPEX efficiency.

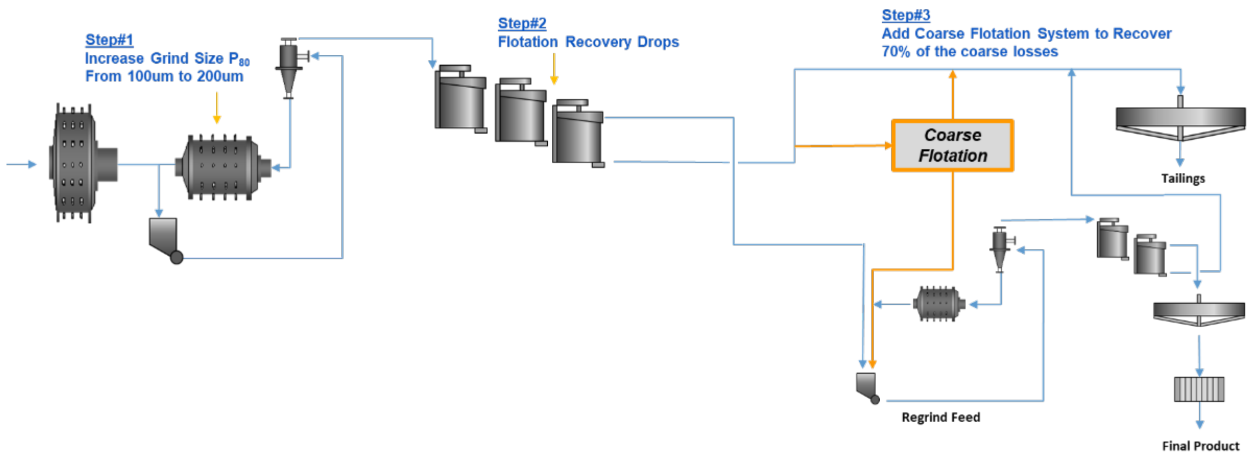

Figure 27 Flowsheet for scavenging tailings from coarse particle flotation

P29 GRIND CIRCUIT ROUGHER

CiDRA Minerals Grind Circuit Rougher™ (GCR) leverages the fundamentals of P29 to recover coarse minerals, <3mm, from within the primary grind circuit and achieve recoveries close to those of traditional flotation at fine grind sizes. A simple flowsheet of the GCR and where it fits in the grind circuit, is shown in Figure 28. As is shown in the case study, for this mine, pulling out the equivalent of 16% of the plant feed from the ball mill circulating load at -1mm increases the throughput of the plant by 33%.

Using the data from the case study P29 was modelled in three coarse particle recovery applications; grind circuit, rougher feed, and rougher tails, Figure 29 shows the resulting NMP from the three different coarse particle recovery applications. The data shows that the grind circuit application has the highest efficiency of NMP increase per ton of feed to the P29 plant as well as the highest ultimate NMP potential of the three applications. This is primarily due to recovering the coarse particles from the grind circuit with a coarse throw away tail, whilst slightly decreasing the primary grind size which in turn protects the performance of the conventional rougher flotation.

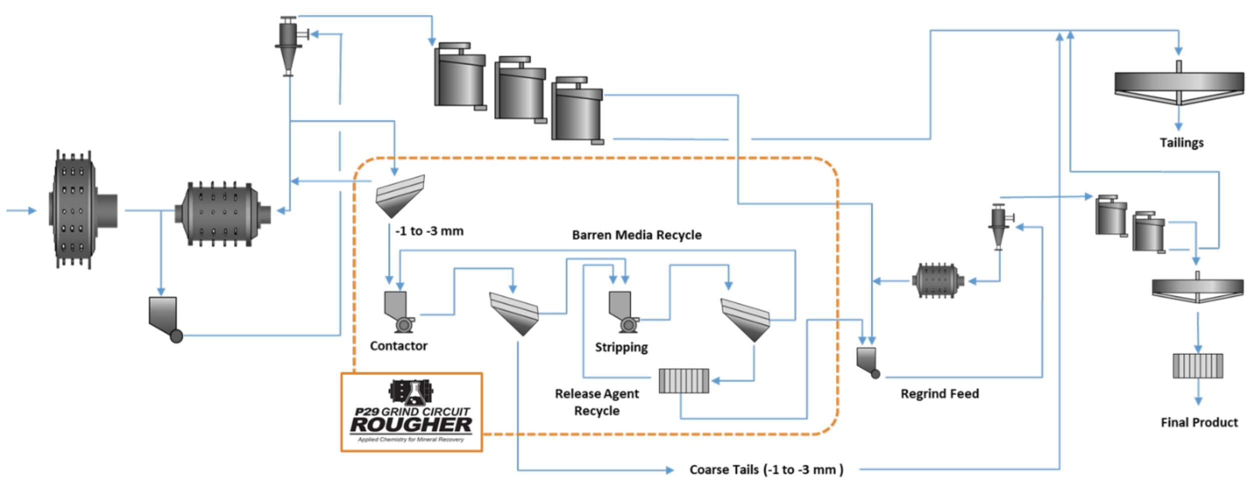

Figure 28 P29 Grind Circuit Rougher flowsheet

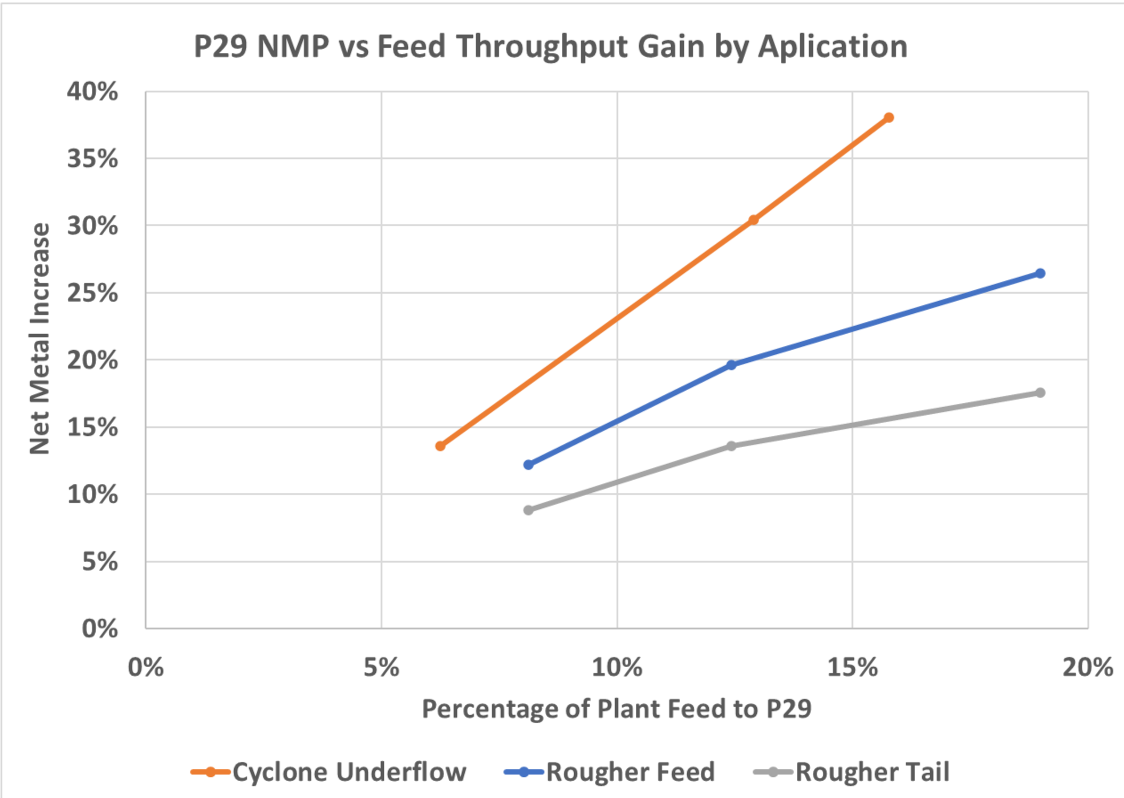

Figure 29 Comparison of NMP of various applications of coarse particle recovery by P29

CiDRA Minerals Processing

SUPPORTING THE ESG GOALS OF THE MINING INDUSTRY

ENERGY

In 2021 the mining industry consumed 12EJ/a of energy or some 3.5% of the global energy consumption [10], of which the grinding circuit typically consumes 40-44% of the total energy consumption of a mine and processing facility, see Figure 30, [12], [13]. It is estimated that 85% of ores mined annually are recovered by the froth flotation process [4], therefore the energy consumed by grinding circuits of froth flotation-based concentrators equates to 1.3% of the global energy consumption, or an equivalent 1.1% of the 2021 global CO_2e emissions [14], [15], [16] (scope 1 and scope 2) .

Referencing the grind circuit modelling at a mine site (page 17), it can be seen P29 in a grind circuit rougher application with an equivalent of 16% of the plant feed going to P29 reduces the grind specific energy of by nearly 50%. In a greenfield application where rougher flotation is replaced by P29 the grind energy demand is half of the energy that would be needed for a plant running at the same throughput at a conventional grind size of 100µm. The P29 Grind Circuit Rougher has potential to have a significant impact on improving the energy efficiency or kWh/t of metal produced on 1.3% of the global energy consumption.

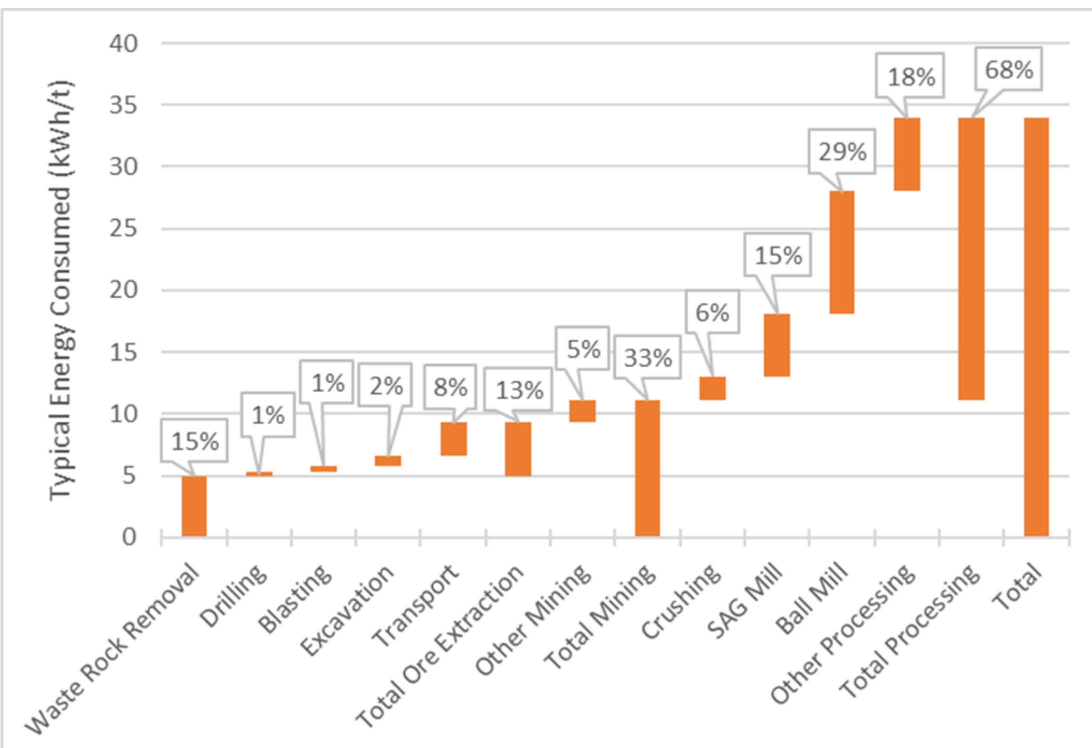

Figure 30 Typical energy consumption within a mining value chain [12]

WATER

A case study of a copper mine shows that increasing the P_{80} of the tailings from 111μm to 548μm increased the total water recovery from tailings from 17% to 79% [17], Figure 31. With the P29 Grind Circuit Rougher demonstrating the ability to recover minerals at P_{80}'s up to 2000μm (Figure 18) the impact on water savings to the mining industry is significant. This applies to brownfield implementation but more significantly with a greenfield implementation where traditional rougher froth flotation is replaced by the P29 Grind Circuit Rougher.

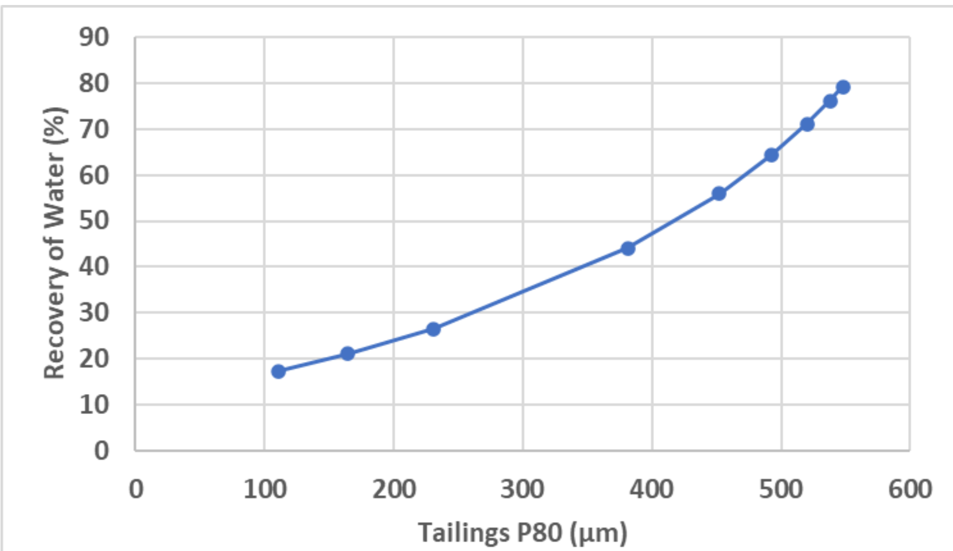

Figure 31 Total recovery of water from tailings versus P80 particle size of the tailings at selected Chilean mines [17]

HISTORICAL TAILINGS AS A RESOURCE

A potential low energy intensity resource for the industry is historical tailings, either as tailings are relocated for stability / environmental opportunities or just to recover minerals. Apart from high intensity conditioning to create fresh mineral surfaces, P29 does not require any other pre-treatment or size reduction of the feed stream and can process a wide range of particle sizes. Test work shows an improved recovery performance of P29 over traditional froth flotation used to process historical tailings, see Table 1.

	Mass (%)	Grade (%Cu)	Recovery (%)	Upgrade Ratio
Feed	100	0.22		
Flotation Concentrate	3.3	2.92	42.8	13
P29 Concentrate	2.4	4.55	53.2	22

Table 1 Comparison of flotation versus P29 technologies on recovery of copper from old tailings at a South American mine (CiDRA Minerals Inc testwork 2019)

ENVIRONMENTAL FOOTPRINT OF THE COLLECTION MEDIA

Currently the common approach to handle end of life polyurethane foams (rigid and flexible) is via landfill or waste combustion combined with energy recovery, and there are also some commercial steelworks using polyurethanes (PU) as a fuel source for the steel blast furnace [18]. With the global growth in the use of PU foams (compound annual growth rate of 75%, [19]) numerous research activities continue into the re-use and recycling of PU foams, with the most promising at scale solutions being [18], [20] - [21];

- Glycolysis to recycle PU back to polyol which can be used as feedstock to manufacture new PU
- Gasification to produce syngas as a source of energy and base hydrocarbons to be used as feedstock for the synthesis of methanol, ammonia, carbohydrates etc
- Green Chem-Biotech approaches to recover building blocks to be used in the synthesis of new PU

Other research [22], [23] shows industrial pathways for producing renewable carbon sources for the production of PU through carbon capture in the form of CO_2 from industry coupled with producing ethanol from biomass in the form of Miscanthus grass, three times more productive than producing ethanol from corn. The impact of this approach to decarbonize the production of PU sees a potential 50% reduction in the total carbon footprint, not including any benefits of recycling or reusing PU.

Assuming virgin PU in the manufacturing of the P29 collection media then the carbon footprint [24] (kgCO2e/t of plant feed) of the virgin PU at current performance and lifetime is equivalent to the carbon footprint of a low-pressure blower that supply forced air to a froth flotation tank cell at an equivalent mineral recovery basis. If the PU is manufactured from feedstock recovered from end-of-life PU or from renewable carbon sources for the feedstock, then the carbon footprint of the P29 collection media will be 50% lower than the supplied forced air to flotation that it replaces (the air bubble).

The R&D in this space will be closely followed and P29 will leverage successful at scale solutions for the recycling of the collection media and will work with suppliers to source renewable carbon sourced PU for the collection media.

NEXT GENERATION P29, FUTURE NOVEL DEVELOPMENTS

P29 is a two-phase solid/liquid system that currently leverages traditional aqueous soluble flotation reagents, which have been developed over centuries. These solutions have a significant limitation in needing to be at best soluble and, at a minimum, miscible in water. CiDRA Minerals continues to develop new and exciting collection media chemistries and these developments will further enhance the ability to economically recover minerals that with today's technologies are deemed uneconomic. The development pathways for innovative polymer coatings fall into three major categories;

- Mineral release mechanism
- Novel collectors
- Media lifecycle

MINERAL RELEASE INNOVATIONS

Leveraging the developments from the ink printing industry where the ability to adjust the degree of hydrophobicity can be controlled via an external catalyst such as pulp chemistry, light or sound waves, could enable a reduction in operating costs.

NOVEL MINERAL COLLECTORS

The engineered P29 collection media enables the innovation of novel non-aqueous based collectors that are currently unknown to the mining industry, the ability to engineer the collector mechanism into the collection media without having a reagent be soluble in water, opens us a completely new frontier in mineral collection. The possibility to recover minerals at low cost that today are un-recoverable by froth flotation is large, the collection media could also be fine-tuned for specific minerals enabling selectivity that is currently not available to the industry.

COLLECTION MEDIA LIFECYCLE

The development of the collection media to balance its strength and the properties that enhance mineral attachment continues and the developments within this pathway will enhance the efficiency and serviceable life of the collection media, further reducing operating costs and its carbon footprint.

DISCUSSION

CiDRA Minerals has developed a step change in minerals separation technology that fundamentally impacts the mining and minerals industry.

The P29 technology replaces the air bubble in froth flotation with an engineered collection media enabling the independent optimization of mineral collection, transport, and release, and is highly selective demonstrating the capability of recovering partially liberated minerals with very low mineral exposure of less than 1%.

The nature of the novel engineered media and P29 technology platform allows for a wider operating window than current froth flotation-based technologies. Very short retention time, low mass yield and high upgrade ratio, and the ability to selectively recover very coarse particles up to 3mm enables the P29 technology to be applied to traditional grinding circuits and deliver significant reduction in grind specific energy. The reduction in specific grind energy can then be utilized to increase plant throughput and/or reduce the P_{80} feeding traditional rougher flotation, generating an extremely high value proposition to mine sites.

The P29 technology platform will continue to be developed with a view to unlock innovative ways to recover minerals that are currently unable to be recovered economically by current froth flotation technologies.

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