Pinto Valley Mine, Copper Recovery Study with the NovaCell

S Morgan[1], *P Amelunxen*[2], *B Akerstrom*[3] *and L Cooper*[4]

1. Technology Manager - NovaCell, Jord International Pty Limited, 40 Oxley Street, St Leonards, NSW, 2065, Australia. Email: smorgan@jord.com.au
2. Senior Vice President – Technical Services, Capstone Copper, Suite 2100 – 510 West Georgia Street, Vancouver, BC, Canada. Email: pamelunxen@capstonecopper.com
3. Director – Metallurgy, Capstone Copper, 1138 N Alma School Rd, Mesa, AZ 85201, United States. Email: BAkerstrom@capstonecopper.com
4. Technical Expert – Flotation, Jord International Pty Limited, 40 Oxley Street, St Leonards, NSW, 2065, Australia. Email: lcooper@jord.com.au

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 traditional technologies, such as mechanically agitated flotation cells, can now be recovered by one machine, potentially increasing the plant production. Targeting coarse particle recovery in the flotation circuit also allows for greater flexibility in the comminution circuit, potentially reducing the specific energy consumption, the greenhouse gas (GHG) emissions per tonne of valuable component, and improving the dewatering rates in mineral processing circuits. To investigate these NovaCell benefits, samples from an existing copper operation 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 NovaCell was investigated. The plant throughput is roughly 58 000 t/d, with a copper equivalent production of approximately 59 000 t Cu/y. The existing flotation circuit comprises both mechanical (self-aspirating) and column flotation 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, suggesting a significant increase in production, equivalent to approximately 15 000 t Cu/y in addition to a 15% reduction in equivalent carbon emissions per tonne of copper. Potential water consumption reductions are also discussed.

INTRODUCTION

For countries to reach their net zero emissions targets, critical minerals like copper will be essential for the clean energy transitions. However, current market forecasts indicate that the supply of copper will struggle to keep up with the future demand. For example, it is well documented that electric vehicles use more than double the copper when compared to combustion engine vehicles, and the sales of electric vehicles are steadily increasing. The International Energy Agency (IEA), founded in 1974, predicts that, based on current copper production and lead times for new mines, an accelerated transition could result in a copper supply shortfall by 2025. This would likely drive commodity prices higher and put financial pressure on consumers.

One solution would be to introduce innovative technology and processes that could enable existing copper operations to increase production and/or extend the life of their mines. However, the new technologies must be economically viable and environmentally and socially sustainable. The NovaCell is a novel froth flotation machine, invented by Laureate Professor Graham Jameson, designed to recover valuable particles over a wider particle size range than is typically achievable by conventional forced air or self-aspirating mechanically agitated flotation cells. In base metal flotation, coarse particles typically exhibit low flotation recovery due to poor liberation of the hydrophobic species. If particle attachment to an air bubble is successful, the inherent low buoyancy of the coarse particle-bubble aggregate hinders its ability to penetrate the layer of high buoyancy fine particle-bubble aggregates collected in the froth phase. Fine particles on the other hand, with sufficient liberation, can also suffer low flotation recovery due to lack of momentum and energy resulting in poor collision efficiency with the air bubbles. Furthermore, due to their large surface area, fine particles can suffer detrimental impacts such as insufficient collector adsorption and reduced hydrophobicity from highly reactive surfaces. The NovaCell offers a solution to the mentioned challenges through the design of the particle collection and separation phases of the cell.

Figure 2 presents the process schematic of the NovaCell plant. New feed material entering the plant is combined with recycled tails. The combined stream is pumped and distributed across downcomers where particles and tiny bubbles collide in the high-shear zone ideal for fine and ultrafine particle recovery. The downcomers are designed to receive air from low pressure compressors. The advantage of the pressurised downcomers is that they can operate at higher airflows than previous downcomer designs that are naturally aspirated. The higher air flows provide more bubble surface area for fine particle attachment, thus promoting increased fine particle recovery than earlier downcomer designs.

Material exiting the downcomers enters the fluidised bed (shown as the shaded area in Figure 2). In this region, partially loaded bubbles surround particles in a low-shear environment ideal for coarse particle recovery. After attachment, both fine and coarse valuable minerals rise in the NovaCell and are collected across two product streams. A froth concentrate is collected at the top of the cell, similar to existing froth flotation technologies. A secondary recovery device, an internal cone, captures additional coarse valuable particles unrecoverable through the froth zone. The internal cone also removes the fine waste from the system; thus the stream feeds a classification circuit (represented by the cyclone in Figure 2). Here the coarse size fraction is collected as the second product. The two product streams can be combined or treated separately depending on the process requirements. Figure 2 presents magnified images of the NovaCell product streams for a porphyry copper ore. The froth product recovers particles that are more mineral rich than the screen product. The screen product generally recovers coarse particles with poor liberation of the hydrophobic species.

The NovaCell plant also produces two tails streams. The fine size fraction from the classification plant represents the fine tailings. A portion of this stream can be recycled to increase the available residence time for fines recovery, whilst the remaining material exits the system. At the bottom of the NovaCell, a second waste stream is produced which represents the coarse tailings. This stream would likely be suitable for filtration or other mechanical dewatering applications, followed by dry disposal.

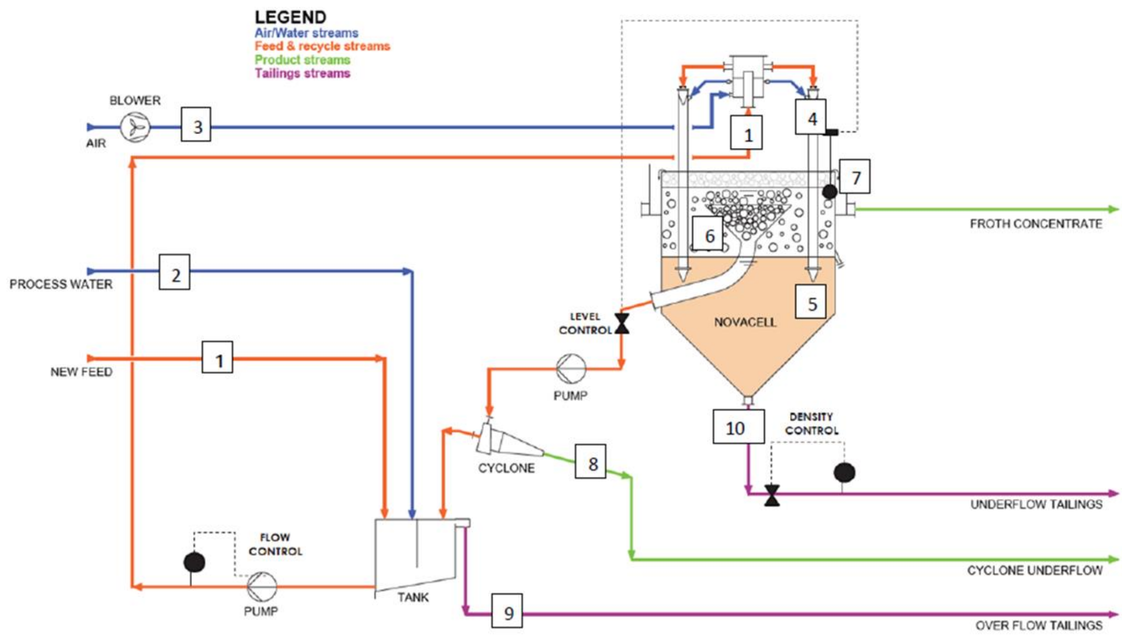


Figure 1: Process Schematic of NovaCell plant

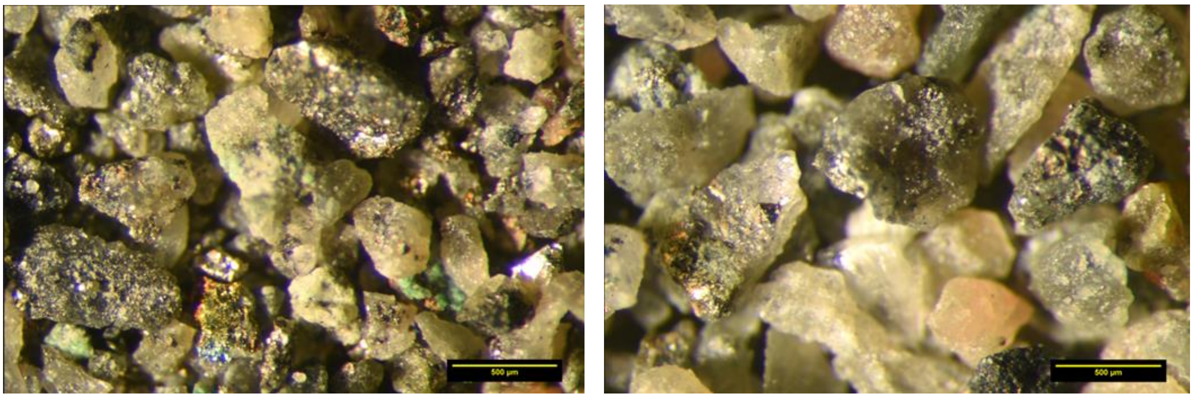


Figure 2: Magnified images of NovaCell float concentrate (left) and screen oversize (right) for porphyry copper ore

For coarse grained porphyry copper deposits, the NovaCell technology targets two principal areas to improve valuable mineral production:

- higher grinding throughput rates - by maintaining mineral recoveries at coarser flotation feed sizes, it allows operators to increase tonnage rates without significant changes to the grinding circuit.
- higher mineral recoveries – by improving the recovery of coarse and fine valuable particles, less metal is lost to the tailings dam improving recoveries and reducing environmental risks.

To date, three laboratory studies have demonstrated the potential benefits of the NovaCell technology. In copper, Jameson and Emer (2019) found that for a porphyry copper ore, the NovaCell obtained 100% recovery at particle sizes up to 300 µm. Morgan and Jameson (2022) observed similar results for a low-grade porphyry copper deposit, where the NovaCell improved copper recoveries at a P80 of 300 µm, when compared to the operating plant. In addition, the NovaCell indicated a product copper upgrade ratio was 8.4, typical of conventional rougher-scavenger circuits. In coal, Jameson *et al*., (2020) demonstrated that the NovaCell successfully recovered high-grade coal particles with a top size of 2 mm.

In this paper, the authors evaluate the potential benefits of the NovaCell technology with samples from the Pinto Valley mine.

CASE STUDY – PINTO VALLEY MINE

Pinto Valley Operations

Capstone Copper Corp.'s Pinto Valley mine (PVM) is an open pit porphyry copper mine in Arizona, USA. Material movement is roughly 56 000 t/d of ore to the mill, 20 000 to 25 000 t/d of dump leach material and 40 000 to 50 000 t/d of waste. The life-of-mine stripping ratio is 1.15 (leach is considered as waste in the calculation). The mine operation consumes approximately 35 000 m^3 of fuel and contributes approximately 38% of PVM's carbon emissions per tonne of copper (1.6 tCO_2e per tonne of copper equivalent). Copper is primarily in the form of coarse-grained chalcopyrite (>95% of the total copper). The ore also contains some molybdenite and lesser gold and silver which contribute a minor proportion of the total revenue stream. The current planned life of mine (LOM) extends to 2039, although the company is progressing a study for a new tailings impoundment facility that will extend the LOM beyond 2039.

Pinto Valley's concentrator process flow sheet is shown in Figure 3. It consists of a crushing plant with primary, secondary, and tertiary crushing. Primary crusher product is screened, coarse material feeds the secondary crushers in open circuit and fines report to the ball mill feed. Secondary crusher product is screened, coarse product feeds the tertiary crushers in closed circuit and fines report to the ball mill feed. The nominal product size of the fine crushing plan is 10 to 12 mm (P80). The six ball mills are equipped with 4000 HP (3000 kW) motors and operated in closed-circuit with hydrocyclones to produce a flotation feed (hydrocyclone overflow) with a P80 of approximately 350 µm. The hydrocyclone overflow is directed to six rows of roughers, rougher concentrate is pumped to two regrind mills with reground product feeding a simple cleaner circuit. The cleaners are comprised of four parallel column flotation cells with concentrate reporting to the molybdenum separation circuit or bypassing to final concentrate where, the product is filtered and trucked offsite. Column tail reports to a single cleaner scavenger bank with its concentrate in closed circuit with the column cells. Final tails comprise both the rougher tail and cleaner scavenger tail, which are thickened and deposited in a wet tailings storage facility.

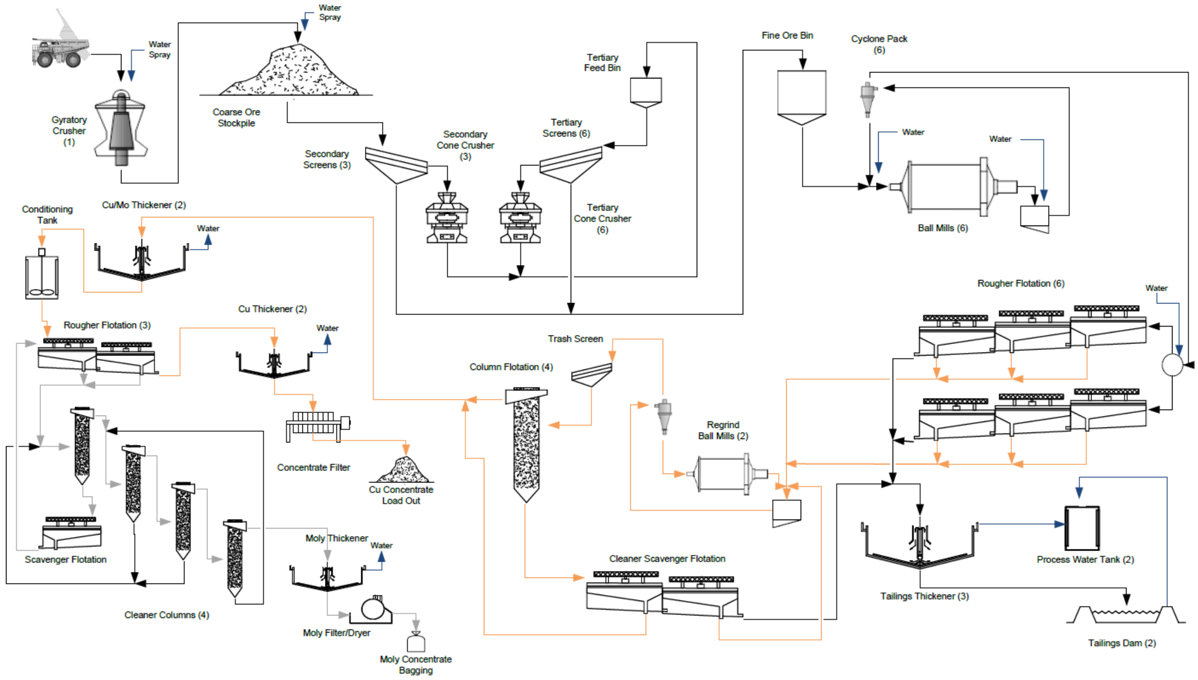


Figure 3: Simplified PVM Process Flow sheet

Samples Tested

Two samples were selected for the NovaCell test work. The first sample was feed ore comprising tertiary crushing circuit product; the second sample was rougher tailings material from the existing concentrator plant.

Feed Ore

Table 1 shows the size-by-size copper assays of the feed ore, including the relative variation of each size fraction from the bulk feed grade. The positive numbers represent increases in the elemental grade and negative numbers represent decreases relative to the bulk feed grade. Also shown are the feed distributions of mass and copper. Note that copper tends to concentrate in the finer size fractions. This is a common observance in mineral processing plants, and is thought to occur due to a combination of factors, including the following:

1. The moduli of elasticity of the copper sulfide minerals are different from those of the host silicate rock, causing fractures to form preferentially at the sulfide-silicate interface when stress is applied during comminution. This leads to lower concentration of sulfides on the surface of coarser silicates, and higher concentration of sulfides in those size classes that are near to the mean grain size of the sulfides.
2. The higher specific gravity of the sulfide minerals results in the preferentially reporting of those minerals to the cyclone underflow, causing them to undergo more comminution (although this factor wouldn’t apply for feed preparation consisting of mechanical screening); and
3. The sulfide mineral grains are often softer than those of the silicates. For example, Mohs scale of mineral hardness for chalcopyrite is 3.5 to 4.0 whilst quartz is 7.0. As a result, the copper minerals are preferentially ground and report to the fines fraction.

Regardless of the causes of the phenomenon, the result is that the coarser size fractions often have less copper bearing minerals and less hydrophobic surface expression; making them more difficult to recover through conventional flotation.

Table 1: Sample characteristics of Feed Ore Sample

Particle Size (µm)	Copper		Feed Distributions	
	Feed Grade (%)	Variation from Bulk Grade	Mass	Copper
-600+500	0.03	-82.8%	13.8%	2.4%
-500+425	0.07	-63.3%	7.9%	2.9%
-425+300	0.09	-55.0%	15.7%	7.1%
-300+212	0.12	-36.9%	11.6%	7.3%
-212+106	0.20	3.9%	16.4%	17.0%
-106	0.35	83.1%	34.6%	63.3%
Total	0.19		100.0%	100.0%

Pinto Valley's copper sulfide mineral texture is considered coarse grained with a typical chalcopyrite liberation profile illustrated in Figure 4.

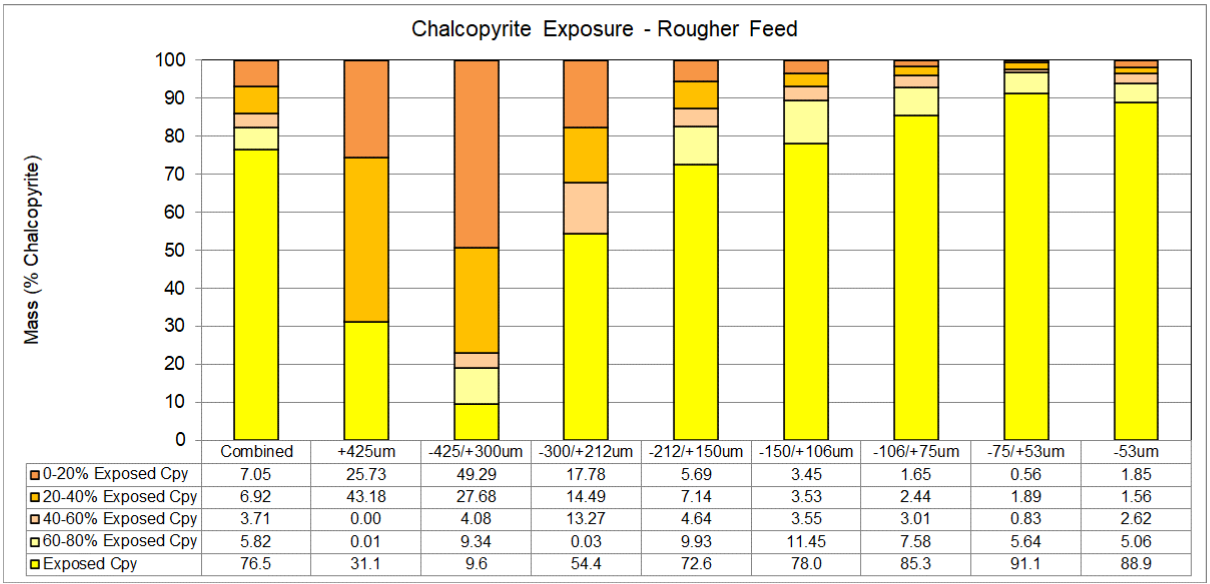


Figure 4: Typical liberation characteristics of the Pinto Valley feed ore.

Plant Rougher Tails

The PVM rougher tails sample delivered for the NovaCell test work was collected ahead of the tailings thickeners. During the sampling period, the plant was operated at reduced throughput, and therefore the P80 was finer than normal, at 212 µm. The chemical analysis of the PVM rougher tails sample contained 0.03% Cu, 34.6 ppm Mo and 0.6% Fe. Table 2 details the size-by-size elemental assays for the PVM rougher tails, including the relative variation of each size fraction from the bulk tails grade.

Table 2: Size-by-size elemental assays of Rougher Tailings Sample

Particle Size (µm)	Copper		Molybdenum		Iron	
	Feed Grade (ppm)	Variation from Bulk Grade	Feed Grade (ppm)	Variation from Bulk Grade	Feed Grade (%)	Variation from Bulk Grade
-425+300	950.4	202.2%	40.7	17.8%	0.3	-49.9%
-300+212	647.3	105.8%	38.7	11.9%	0.3	-53.4%
-212+106	308.6	-1.9%	34.7	0.4%	0.3	-48.3%

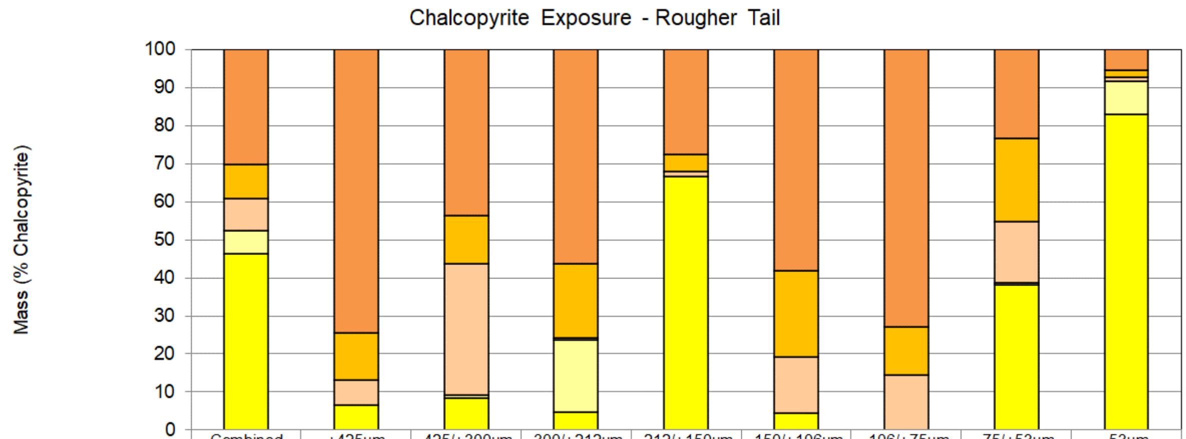
-106+53	128.0	-59.3%	14.3	-58.5%	0.4	-26.0%
-53	209.2	-33.5%	39.0	12.8%	0.9	50.0%
Total	314.5		34.6		0.6	

Table 3 details size-by-size mass and elemental distributions for the PVM rougher tails. Copper shows the highest distribution to the coarse size fractions, with around 40% of the copper in the +212 µm size fractions. In comparison, molybdenum and iron were approximately 20% and 8%, respectively. Iron presents the highest distribution to the fine size fraction, with around 70% of the iron in the -53 µm size fraction. Of interest is the relatively low sulfide content in the +53-106 µm size fraction, where conventional mechanical flotation cells are generally efficient at recovering valuable particles.

Table 3: Size-by-size mass and elemental distributions of Rougher Tailings Sample

Particle Size (µm)	Distributions			
	Mass	Copper	Molybdenum	Iron
-425+300	6.7%	20.3%	7.9%	3.4%
-300+212	10.4%	21.4%	11.6%	4.8%
-212+106	21.9%	21.5%	22.0%	11.3%
-106+53	14.5%	5.9%	6.0%	10.7%
-53	46.5%	30.9%	52.4%	69.7%
Total	100.0%	100.0%	100.0%	100.0%

A typical liberation profile of the Pinto Valley tailings stream is illustrated in Figure 5. This demonstrates that most of the liberated species across the intermediate size fractions are recovered successfully by the conventional flotation technology currently employed by the site.



	Combined	+425um	-425/+300um	-300/+212um	-212/+150um	-150/+106um	-106/+75um	-75/+53um	-53um
0-20% Exposed Cpy	30.27	74.38	43.64	56.18	27.52	58.17	72.93	23.25	5.39
20-40% Exposed Cpy	8.93	12.52	12.74	19.63	4.66	22.69	12.61	22.08	1.90
40-60% Exposed Cpy	8.43	6.56	34.54	0.46	1.32	14.79	14.45	16.01	1.10
60-80% Exposed Cpy	6.04	0.00	0.62	18.94	0.00	0.00	0.00	0.59	8.63
Exposed Cpy	46.3	6.5	8.5	4.8	66.5	4.3	0.0	38.1	83.0

Figure 5: Typical liberation characteristics of the Pinto Valley tailings stream.

Test Conditions

The NovaCell laboratory test work was conducted in the small-scale rig (Figure 6) at the University of Newcastle. Table 4 details the operating parameters for both samples tested.

Table 4: Summary of NovaCell operating parameters.

Test Parameter	Unit	Value	
		Feed Ore	Rougher Tailing
Grind Size (P80)	µm	480	212
Column Diameter	mm	100	140
Screen Aperture	µm	300	212
Slurry Feed pressure	kPa (gauge)	200	200
Air Pressure	kPa (gauge)	100	100
Collector (PAX)	g/t	95	80
Frother (MIBC)	ppm (vol)	30	40
Feed density	(% w/w)	25%	25%
pH (Lime)	-	9.0	9.0
Eh (NaHS)	mV (Ag/AgCl)	-70	-70
Sample Feed Mass	g	6100	6500

The NovaCell products collected were the froth concentrate and screen oversize material. Both the products and remaining cell contents (defined at tails) were filtered and screened. For the feed ore sample screening was done at 500, 425, 300, 212 and 106 µm, whilst the rougher tailings material, being finer, was screened at 425, 300, 212, 106 and 53 µm.

All size fractions were submitted to an external laboratory for chemical analysis. The feed sample was analysed for copper only, whilst the plant tailings material was analysed for copper, molybdenum and iron.

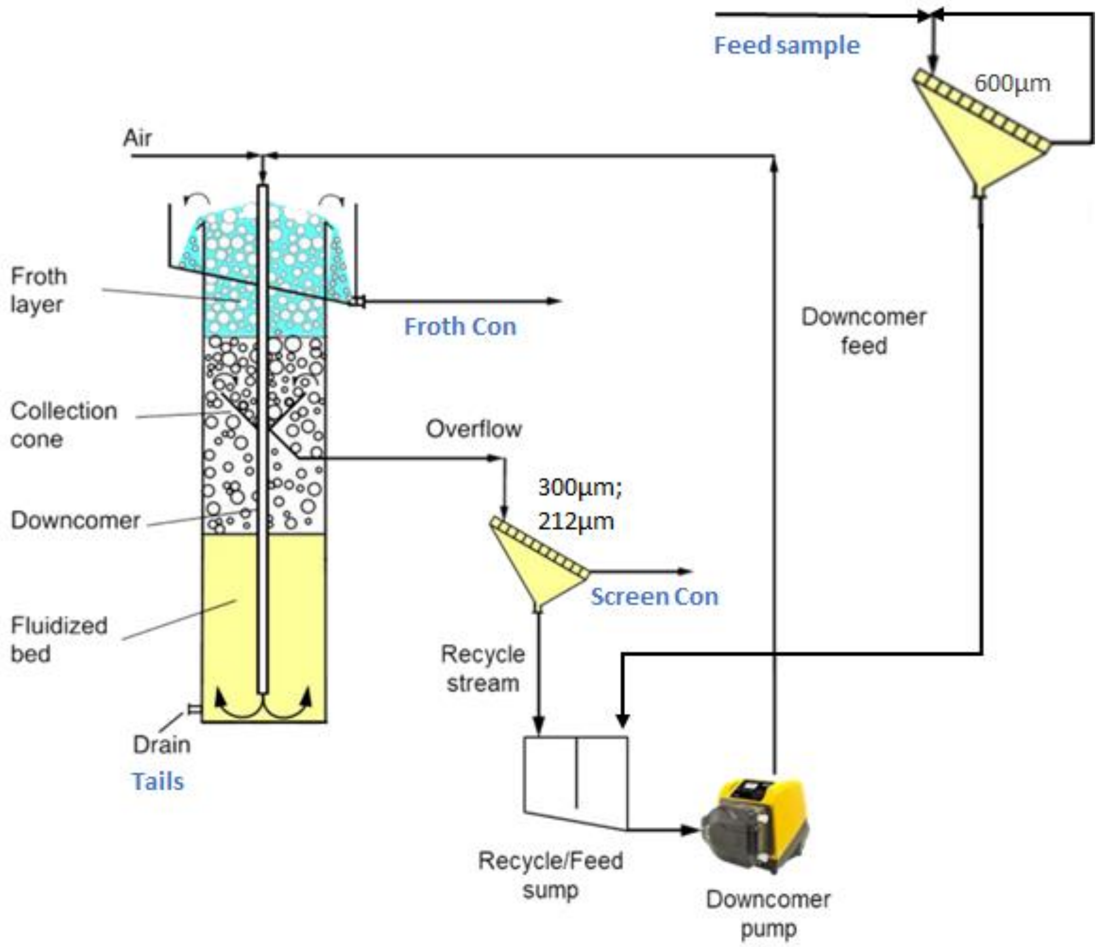


Figure 6: Schematic of NovaCell small-scale rig in batch mode

Test Results

<u>Feed Ore</u>

At a grind size (P80) of 480 µm, the NovaCell achieved a copper recovery of 94% from the PVM feed ore sample (Table 5). Majority of the copper was recovered to the froth concentrate at 90%, with the screen concentrate indicating 4% only. The combined concentrate mass pull was 6.0% and the combined product grade was 3.0% Cu. The product upgrade ratio (i.e. product grade/feed grade) was used to reflect mineral selectivity, and indicated an upgrade ratio of 15.8.

Currently, the Pinto Valley mine produces a flotation feed size (P80) of 343 µm, and the copper recovery in the rougher circuit is 88 – 90% (typical). The mass pull target is 5 – 8% and the product grade is 4 – 6% Cu (typical).

Table 5: NovaCell Results on Feed Ore Sample

Element	Recovery			Upgrade Ratio		
	Froth Con	Screen Con	Total	Froth Con	Screen Con	Total
Cu	90%	4%	94%	18.3	3.8	15.8

These results suggest that the NovaCell is effective at achieving a high overall copper recovery at relatively coarse flotation feed grind sizes.

Size-by-size Recovery

The size-by-size copper recoveries for the NovaCell is presented in Table 6.

The results confirm that the NovaCell can recover copper bearing particles across all the size fractions tested. It was highly efficient at recovering copper bearing particles in the -300 µm size fractions, achieving +90% copper recoveries. In the -500+300 µm size fractions, the copper recoveries were closer to 80%, and in the -600+500 µm size fraction the copper recovery dropped to 58%.

The product upgrade ratio for most of the size fractions were relatively consistent. However, the highest value achieved (41.6) was in the coarsest size fraction, suggesting that the coarse particles were very mineral rich. The lowest value achieved (9.5) was in the finest size fraction, which was likely caused by entrainment of fine waste material.

Table 6: NovaCell size-by-size copper recoveries on Feed Sample

Particle Size Range (µm)	Feed Grade (%Cu)	NovaCell Product (Froth + Screen concentrate)			
		Mass Pull (% of Total Feed)	Product Cu Recovery (%)	Product Grade (% Cu)	Product Upgrade Ratio
-600+500	0.03%	0.2%	58%	1.3%	41.6
-500+425	0.07%	0.3%	83%	1.4%	20.8
-425+300	0.09%	0.8%	83%	1.4%	16.4
-300+212	0.12%	0.5%	93%	2.6%	21.6
-212+106	0.20%	0.7%	96%	4.7%	24.2
-106	0.35%	3.5%	96%	3.3%	9.5
Total	**0.19%**	**5.9%**	**94%**	**3.0%**	**15.8**

Plant Rougher Tailings

At a grind size (P80) of 212 µm, the NovaCell yielded a copper recovery of 55% from the PVM rougher tailings (Table 7), with 44% from the froth concentrate and the other 11% from the screen concentrate. The combined product grade was 0.4% Cu, resulting in a calculated copper upgrade ratio of 12.6. The overall molybdenum recovery was 48%, with a product grade of 383 ppm Mo and upgrade ratio of 11.0. The overall iron recovery was 21%, with a product grade of 2.9% Fe and upgrade ratio of 4.7.

Table 7: NovaCell Results on Rougher Tailings Sample

Element	Recovery			Upgrade Ratio		
	Froth Con	Screen Con	Total	Froth Con	Screen Con	Total
Cu	44%	11%	55%	13.0	10.9	12.6
Mo	44%	4%	48%	12.9	4.2	11.0
Fe	20%	1%	21%	5.7	1.2	4.7

The results were achieved at a relatively low concentrate mass recovery of 4.4%. This is important because high mass recoveries can potentially overload regrind circuits, or otherwise require additional regrind equipment. In summary, the results suggest that the NovaCell was able to recover economically significant amounts of copper and molybdenum minerals from the PVM plant rougher tailings while maintaining selectivity and thereby limiting the likelihood of inefficiencies in downstream processing.

Size-by-size Recovery

The size-by-size recovery for copper, molybdenum and iron are presented in Table 8, Table 9 and Table 10, respectively. For copper, the size-by-size recovery results indicate that the NovaCell achieved relatively good recoveries in the fine size fractions, but the major improvement was observed in the intermediate and coarse size fractions. This may be attributed to the higher copper grades in the coarser size fractions compared to the bulk tails grade, likely a result of the reduced efficiency of the existing PVM mechanical cells at coarser size classes.

For molybdenum, the results indicated consistent recoveries in the fine and intermediate size fractions, with a decrease observed in the coarsest size fraction. This may be due to the molybdenum mineral texture and shape in the coarser size fractions.

Table 8: NovaCell size-by-size copper recoveries on Rougher Tails Sample

Particle Size Range (µm)	Feed Grade (%Cu)	NovaCell Product (Froth + Screen concentrate)			
		Mass Pull (% of Total Feed)	Product Cu Recovery (%)	Product Grade (% Cu)	Product Upgrade Ratio
-425+300	0.10%	0.3%	62%	1.22%	12.8
-300+212	0.06%	0.6%	71%	0.83%	12.8
-212+106	0.03%	0.6%	52%	0.62%	20.0
-106+53	0.01%	0.2%	46%	0.50%	38.9
-53	0.02%	2.8%	45%	0.16%	7.5
Total	**0.03%**	**4.4%**	**55%**	**0.39%**	**12.6**

Table 9 : NovaCell size-by-size molybdenum recoveries on Tails Sample

Particle Size Range (µm)	Feed Grade (g/t Mo)	NovaCell Product (Froth + Screen concentrate)			
		Mass Pull (% of Total Feed)	Product Mo Recovery (%)	Product Grade (g/t Mo)	Product Upgrade Ratio
-425+300	40.7	0.3%	31%	259.6	6.4
-300+212	38.7	0.6%	50%	354.5	9.2
-212+106	34.7	0.6%	48%	626.8	18.5
-106+53	14.3	0.2%	44%	695.0	37.7
-53	39.0	2.8%	51%	333.3	8.6
Total	**34.6**	**4.4%**	**48%**	**382.5**	**11.0**

Table 10: NovaCell size-by-size iron recoveries on Tails Sample

Particle Size Range (µm)	Feed Grade (% Fe)	NovaCell Product (Froth + Screen concentrate)			
		Mass Pull (% of Total Feed)	Product Fe Recovery (%)	Product Grade (% Fe)	Product Upgrade Ratio
-425+300	0.30%	0.3%	25%	1.6%	5.2
-300+212	0.28%	0.6%	23%	1.2%	4.2
-212+106	0.31%	0.6%	13%	1.6%	5.2
-106+53	0.45%	0.2%	19%	7.6%	15.8
-53	0.91%	2.8%	22%	3.3%	3.7
Total	**0.60%**	**4.4%**	**21%**	**2.9%**	**4.7**

Potential NovaCell Impact at Pinto Valley Mine

Higher grinding throughput rates

Various studies undertaken internally and externally by Pinto Valley mine have shown that the throughput bottleneck for the plant is the fine crushing plant. With minor capital investment and equipment modifications, an upper limit of 70 000 t/d can be achieved. Beyond this capacity, a larger investment is required, and the capital cost increases significantly. For this reason, the tonnage increase was fixed at 70 000 t/d.

To estimate the impact on grind size at the higher tonnage, surveys were collected around the mills and operating efficiency was determined based on the Bond model. Note that at PVM, the Bond work index decreases as the closing screen size aperture increases, i.e. the ores become "softer" when the grind is coarser (Figure 7). This is a secondary benefit of coarse grinding at Pinto Valley; however, this has not been considered in this analysis.

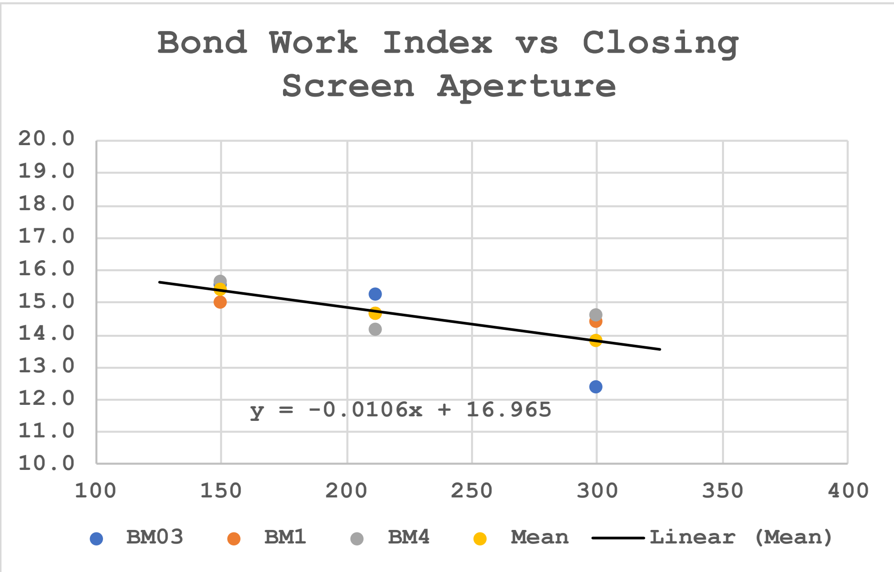


Figure 7: Bond Work Index kWh/t versus Bond test closing screen size for three samples of Pinto Valley ore

Increasing the tonnage from 58 000 t/d to 70 000 t/d at a nominal life-of-mine Bond work index of 16 kWh/t would result in an increase in the mill feed F80 from 12.5 mm to 14.5 mm and an increase the flotation feed P80 from 343 µm to 480 µm. Simulations were performed based on size-by-size kinetics measured on samples of rougher feed collected in the plant. Flotation kinetics for the coarser grind were estimated using AminFloat, a steady-state phenomenological modeling platform configured with size-by-size collection rate (k_c) and maximum recovery (R_{max}) measured with a Full Kinetics Test (FKT), a laboratory flotation test procedure that can provide collection zone kinetics independent of froth zone effects. The results, shown in Figure 8, are compared with the performance of the Pinto Valley plant roughers (six parallel rows of 11 Wemco 164's, with some variations between rougher rows) and the NovaCell. It is expected that the area between the bottom curve ("PVM Mechanical Roughers") and the middle curve ("Laboratory FKT") is total chalcopyrite lost in the plant due to froth recovery effects in the Wemco cells; i.e. coarse particle drop-back from the froth zone. The area between the middle curve ("Laboratory FKT") and the top curve ("NovaCell") is equivalent to the improvement due to the fluidized bed effects in the NovaCell; i.e. the effect of the internal cone mechanism.

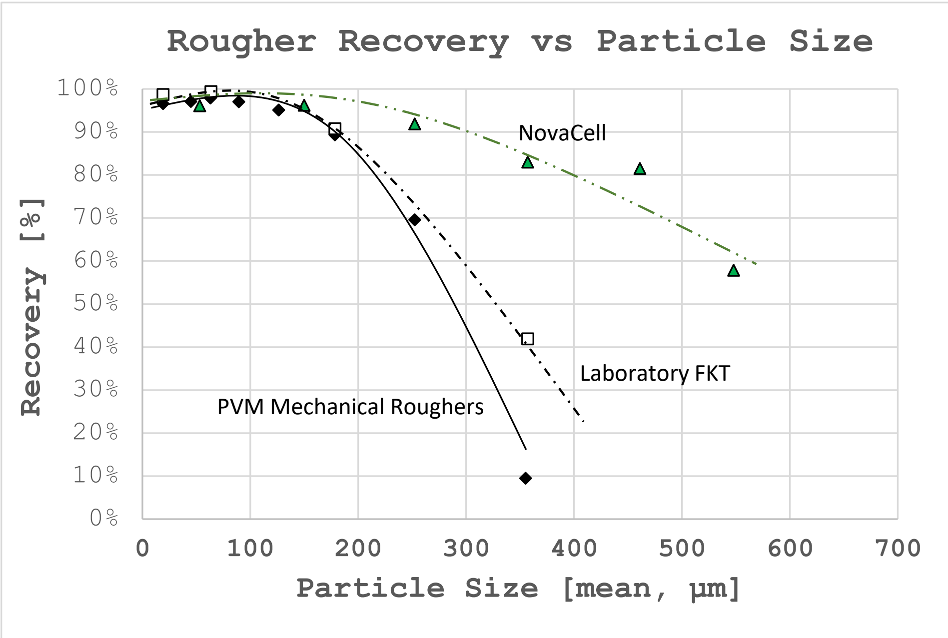


Figure 8: Size-by-size chalcopyrite recovery in the PVM mechanical rougher cells, a laboratory kinetics test in a Denver 5.0L cell, and in the NovaCell.

The simulator and NovaCell test results were used to estimate the metallurgical recovery for the 70 000 t/d throughput scenario. The circuit configuration consists of a single NovaCell treating the tailings of each of the six rougher banks. The concentrate from the NovaCell is returned to the ball mill circuit for further grinding. The fine and coarse tailings streams are combined and report to the existing thickeners.

The results indicate that for Pinto Valley's coarse-grained, fast-floating ores, the overall recovery would increase because the beneficial impact of the NovaCell is sufficient to offset the loss due to reduced liberation at the coarser grind. The coarser grind would result in a reduction of 3.7% copper recovery and 7.5% molybdenite in the existing rougher flotation circuit, but this would be offset by the coarse particle recovery achieved in the NovaCell. Overall, it is predicted that an increase in metal recovery would be achieved, of approximately 5% (absolute) for copper and 17.8% for molybdenum. Table 11 summarizes the predicted economics of the NovaCell operation at Pinto Valley mine and were calculated for a simple ten-year period and based on US$3.50/lb Cu and US$11.79/lb Mo.

The capital costs were determined based on simple assumptions, summarised as follows:

- US$40M for mine fleet increase, based on the net present cost of a leased fleet sized for the current stripping ratio.
- US$60M direct installed cost for six NovaCell circuits treating each of the rougher tails
- 1.42 installed cost multiplier for owners costs, indirect costs and contingency .

This capital cost allowance also includes minor costs incurred in debottlenecking the fine crushing plant. Downstream major equipment have already been assessed and can handle the higher throughput, but minor equipment (pumps, etc.) have not been assessed yet and these potential upgrades are not included in the above cost estimate. Lastly, the Novacell concentrate is assumed to be recycled back to the ball mills for further grinding; a separate study will be to evaluate the installation of a dedicated regrind mill for this material.

The operating costs were estimated based on current Pinto Valley milling costs. Mine operating costs were assumed to be constant per tonne of material moved. No change in the cutoff grade or mine plan was considered.

Table 11: Conceptual level economics of NovaCell operation at Pinto Valley mine

Parameter	Units	Base Case	NovaCell
Tonnage	t/d	58 000	70 000
Grind Size (P80)	µm	343	480
Copper Recovery	%	85%	90%
Water Consumption	m3/t	0.43	0.43
Capital Cost	US$	$0	-$126,200,000
Capital Intensity	US$/t/d		$10,517
Total Copper Production	t/y	57 802	73 149
Total Molybdenum Production	t/y	394	630
Copper Equivalent Production	t/y	59 130	75 269
Incremental Revenue	US$	$0	$124,528,000
	US$/t	$0	$4.87
Operating Cost	US$/t	-11.92	-10.76
After-tax Earnings (21%)	US$	$161,013,000	$241,691,000
NPV (10 Yr, 8%)	US$		$335,938,000
IRR	%		63%
GHG	TCO2e/tCuEq	4.27	3.62

The economics suggest that the NovaCell technology presents a compelling opportunity to significantly increase the metal production, by approximately 15 000 t/y of equivalent copper[2], with a payback period of less than two years. Furthermore, because the increased production is achieved at higher throughput and coarser grind, it does not require a commensurate increase in the energy consumption of the Pinto Valley concentrator. For this reason, the CO_2e per tonne of equivalent copper production is estimated to drop from 4.27 t to 3.62 t, amounting to a 15% reduction in equivalent carbon emissions per tonne of copper equivalent.

[2] Equivalent copper production is calculated based on $3.50/lb Cu and $11.79/lb Mo.

CONCLUSIONS

The technology benefits of the NovaCell have been investigated on feed ore and rougher tailings samples from Pinto Valley Mine. On the feed ore sample, the NovaCell demonstrated high overall copper recoveries at relatively coarse flotation feed grind sizes (P80) of 480 µm. In addition, the NovaCell recovered a significant proportion of the coarse valuable particles to the froth concentrate. On the rougher tailings sample, the NovaCell was able to recover economically significant amounts of copper and molybdenum minerals while maintaining selectivity and thereby limiting the likelihood of inefficiencies in downstream processing.

The potential impact of the NovaCell technology at Pinto Valley Mine suggested a significant increase in metal production, by approximately 15 000 t/y of equivalent copper and a 15% reduction carbon emissions per tonne of copper equivalent.

Based on the NovaCell test work results and predicted economic benefits, Pinto Valley mine has decided to investigate the technology further at site. A NovaCell pilot plant trial is planned for Q1 2024, and the results are expected to be published in future technical papers.

Other planned future work includes:

- Evaluation of a dedicated regrind and cleaner circuit for the Novacell concentrate, instead of returning the concentrates to the ball mills.
- Detailed liberation studies on Novacell product streams, and analysis of Novacell flotation kinetics with the aim of developing a scale-up model that does not require piloting.
- Evaluation of filtration or other dewatering technology on the coarse Novacell tailings.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Professor Graeme Jameson, Joshua Sovechles and Kitty Tang from Hunter Process Technologies (HPT) for their assistance in conducting the NovaCell test work. We would also like to thank the Pinto Valley metallurgical teams for providing the samples for the NovaCell test work.

The authors acknowledge the funding support from the Australian Research Council for the ARC Centre of Excellence for Enabling Eco-Efficient Beneficiation of Minerals, grant number CE200100009.

REFERENCES

Capstone Mining Corp., "2021 Sustainability Report." www.capstonecoper.com

https://capstonecopper.com/wp-content/uploads/2022/12/Capstone_2021_SustainabilityReport.pdf

Jameson, G.J., and Emer, C., 2019. Coarse chalcopyrite recovery in a universal froth flotation machine, *Minerals Engineering* 134, pp 118-133

Jameson, G.J., Cooper, L., Tang, K.K., and Emer, C., 2020. Flotation of coarse coal particles in a fluidized bed: The effect of clusters, *Minerals Engineering* 146, pp 2-13

Morgan, S., and Jameson, G.J., 2022. Improving mill throughputs, with coarse and fine particle flotation in the NovaCell™ in *Proceedings IMPC Asia-Pacific 2022*, pp 1101-1117