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NovaCell™—Technology to Meet the World's Future Copper Demands

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ABSTRACT: The NovaCell™ is a novel flotation device that improves recovery efficiencies across all size fractions, whilst also targeting lower energy and water consumption in mining. Invented by Laureate Professor Graeme Jameson, it can recover coarse and fine valuable particles that conventional flotation technologies, like mechanically agitated flotation machines, typically miss. Implemented in coarse particle flotation (CPF) applications, it has the potential to increase revenues at existing copper mines and significantly improve efficiencies across the entire concentrator plant for new copper mines.

Jord International Pty Ltd (Jord) has the global exclusive rights to commercialize the NovaCell™ technology and has investigated the technology benefits across various porphyry copper deposits. The paper discusses three case studies, where the NovaCell™ metallurgical performance has been compared to conventional flotation technology. In case study 1, fresh run-of-mine (ROM) ore from Canada was investigated at the flotation feed grind size (P_{80}) of 350 µm. The NovaCell™ obtained copper and molybdenum recovery improvements of 10% and 17%, respectively. This would enable a 11% higher throughput rate to be targeted consistently, with the potential revenue increase estimated to be ~$97 million USD / year. In case study 2, a plant tailings sample from Chile was investigated at the flotation feed grind size (P_{80}) of 200 µm. The NovaCell™ obtained a copper recovery improvement of 4%, suggesting a potential revenue increase of ~$40 million USD / year. Finally in case study 3 a fresh feed ore from Australia was investigated at a flotation feed grind size (P_{80}) of 550 µm. A new rock breakage system, targeting lower carbon emissions was used for preparation of the flotation feed.

In all three case studies, the NovaCell™ consistently produced higher copper recoveries than conventional flotation technology. This was most evident for the coarser size fractions. This paper highlights the benefits of novel flotation technologies, like the NovaCell™, to satisfy the growing demand for copper, whilst also reducing carbon emissions produced through mining.

INTRODUCTION

It is well documented that by 2030, there will be insufficient copper supply to balance the demand for copper. In May 2022, RFC Ambrian conducted a copper market analysis and concluded that the deficit will be significant. We will need to increase the supply from existing operations, as well as bring new projects online. However, the challenge remains that ore bodies are becoming more difficult to process. Mudd and Jowitt (2018) assessed copper deposits globally and agreed that the average copper grades are declining over time. Northey et. Al (2013) showed as ore grades decrease, both greenhouse gas (GHG) emissions and energy intensity increase. Thus, continuing to apply conventional technologies to meet the copper demand will result in higher carbon emissions. The way forward is to accelerate the adoption of new innovative technologies that deliver both efficient production and reduce energy consumption.

The NovaCell™ is a novel froth flotation machine that delivers high copper recoveries at relatively coarse flotation feed grind sizes. To date, two laboratory studies have demonstrated the NovaCell™ benefits. 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. At a flotation feed grind size (P_{80}) of 300 µm, the NovaCell™ improved copper recovery when compared to the existing plant recovery. The review of Anzoom et al., (2023) on coarse particle flotation (CPF) technologies indicated that the NovaCell™'s ability to recover coarse valuable particles is significant.

The benefit of CPF i.e., coarsening the flotation feed grind size, is that it reduces the energy consumption in the comminution circuit, which allows for higher throughput rates and/or reductions in carbon emissions. Morgan et al., (2023) presented the Pinto Valley mine copper recovery study, which demonstrated the potential impact of NovaCell™ at coarser flotation feed grind sizes. The predicted benefits were a 20% increase in plant production and a 15% reduction in carbon emissions per ton of copper product produced.

Figure 1 presents the process schematic of the NovaCell™ circuit. Feed material entering the NovaCell™ plant is combined with recycled tails. The combined stream is pumped and distributed to downcomers where particles and tiny bubbles collide in the high-shear zone ideal for fine and ultrafine particle recovery. Material exiting the downcomers enters the fluidized bed (shown as the shaded area in Figure 1). In this region, partially loaded bubbles surround

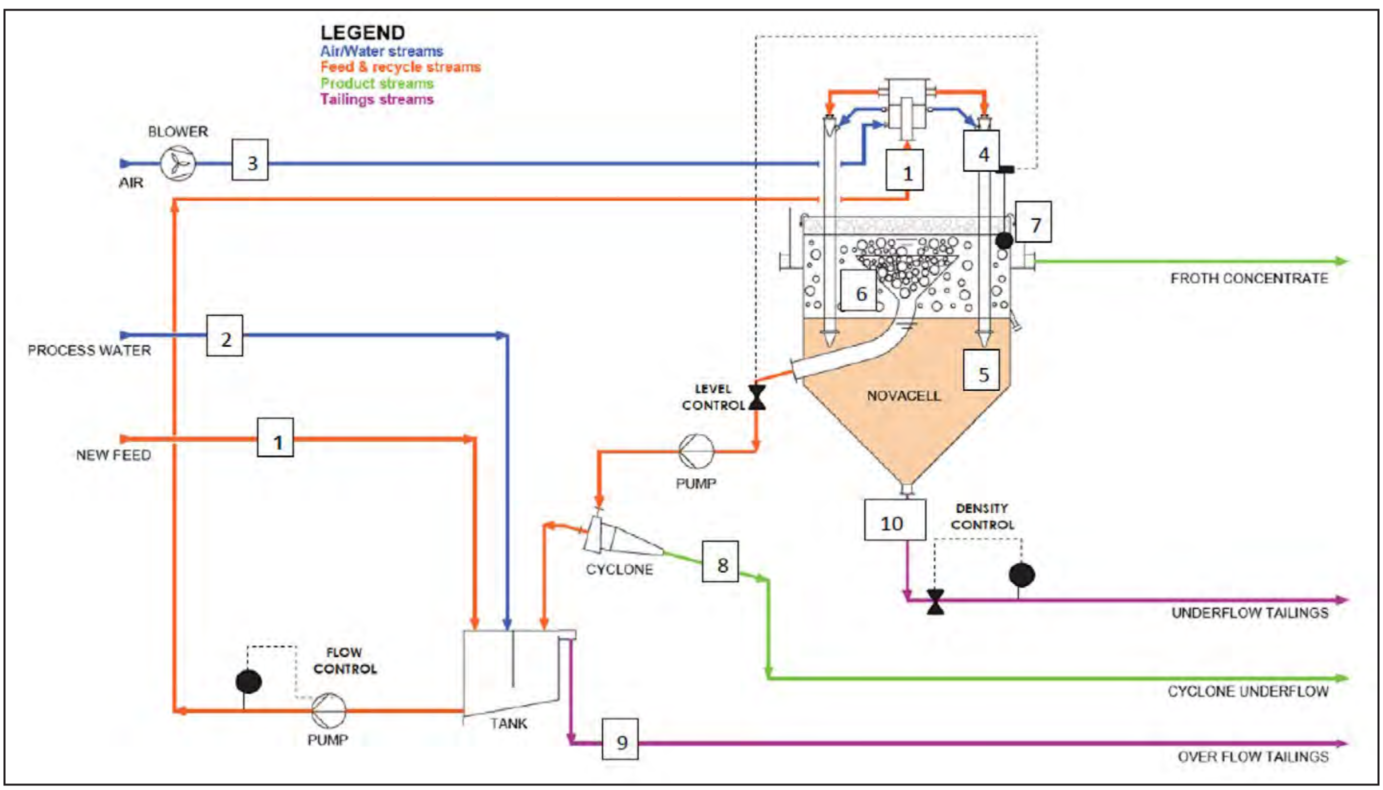

Figure 1. Process schematic of the NovaCell™ circuit

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 in two product streams. A froth concentrate is collected at the top of the cell, as in existing froth flotation technologies. A secondary collection device, an internal cone, captures additional coarse valuable particles unrecoverable through the froth zone. The design of the particle collection and separation phases of the cell enables this innovative technology to achieve high recoveries across a wide particle size range.

For existing and future porphyry copper mines, the NovaCell™ targets the following benefits:

- 10 to 20% increase in metal production – by maintaining mineral recoveries at coarser flotation feed grind sizes, it would allow mines to operate at higher throughput rates and reduce the capital investment required to debottleneck the comminution circuit.
- 5 to 10% increase in copper recoveries – by recovering fine and coarse copper particles typically lost by conventional flotation technologies, the recovery efficiencies could be improved, with less metal content reporting to the tailings storage facility (TSF).
- 15% reduction in carbon emissions – by maintaining mineral recoveries at coarser flotation feed sizes, it would allow mines to reduce the energy consumption in comminution circuits without losing copper recovery.
- Increase in dry tailings disposal – by adopting coarser flotation feed grind sizes, which enables mines to implement mechanical dewatering technologies and adopt dry tailings disposal. This also reduces the amount of waste being sent to TSF, which extends the life of the facility.

In this paper, we discuss three case studies where the NovaCell™ potential benefits are evaluated with samples from mines in Canada, Chile, and Australia. In all cases, the NovaCell™ metallurgical results were compared to conventional flotation technology, i.e., mechanically agitated float cell.

CASE STUDY 1—INCREASED METAL PRODUCTION

In the first case study, fresh ROM ore from an operating mine in Canada was evaluated. The mine is a low-grade porphyry copper deposit, with minor molybdenum. Currently, the flotation feed grind size (P_{80}) varies between 325 and 350 µm, and the final product copper recovery varies between ~82% and ~70%, respectively. At the flotation feed grind size (P80) of 350 µm, the plant throughput rate can be increased by ~11%. However, given the significant reduction in copper recovery (of 12%), the circuit is generally operated at the flotation feed grind size (P_{80}) of 325 µm.

The objective of the test work was to investigate whether at the flotation feed grind size (P_{80}) of 350 µm, the NovaCell™ could significantly improve the final product copper recovery above the current levels. This would provide potential benefits of increased metal production and increase the likelihood of dry tailings disposal.

The material delivered for testing was received as rocks and was crushed and ground to a particle size (P_{80}) of 350 µm. Sub-samples submitted for chemical analysis, indicated head grades of 0.19% Cu and 49 ppm Mo. Note, the copper grade of the feed sample was lower than the typical plant feed grade of 0.25% Cu.

Case Study 1—Sample Characteristics and Flotation Conditions

Table 1 shows the size-by-size copper and molybdenum assays of the feed ore, and the feed distributions of solids, copper and molybdenum. Copper shows the highest distribution in the finer size fractions, with ~83% of the copper in the –212 µm size fractions. Similarly, for molybdenum, ~86% was in the –212 µm size fractions.

Table 1. Case study 1 sample characteristics

Particle Size, µm	Copper Feed Grade, %	Molybdenum Feed Grade, ppm	Feed Distributions		
			Mass	Copper	Molybdenum
–600 +425	0.07	20	14%	5%	5%
–425 +300	0.10	23	11%	6%	5%
–300 +212	0.13	23	8%	6%	4%
–212 +106	0.19	25	13%	13%	7%
–106 +53	0.26	33	10%	14%	7%
–53	0.23	80	44%	56%	72%
Total	0.19	49	100%	100%	100%

The NovaCell™ flotation test work was conducted in a small-scale laboratory rig and the standard test procedure is described below:

- The ground sample is combined with water to the desired pulp density and placed in the NovaCell™ device.
- It is recirculated through the downcomer while reagents are added to condition the particles.
- Air is then introduced to the system, which starts the flotation process.
- The froth and screen concentrate samples are collected for the duration of the test.
- At the end of the test, all the remaining solids in the NovaCell™ are collected as the tailings sample.
- All collected samples are filtered, screened, dried, and submitted for chemical analysis. The dry masses and elemental assays were then used to balance the data using generalized least squares regression.

To benchmark the NovaCell™ metallurgical performance to conventional flotation technology, the sample was also tested in a laboratory-scale Agitair mechanically agitated cell. The Agitair cell generally represents the best hydrodynamic and froth recovery conditions achievable in conventional flotation technology. So, at plant-scale, mechanically agitated cells with the optimum design in pulp mixing, pulp suspension, and froth recovery, will likely get close to the laboratory Agitair recoveries. For this reason, the laboratory Agitair cells (or similar) are routinely used in project studies to predict the metallurgical performance of plant-scale mechanically agitated cells. They are also very useful for optimization work, to identify areas for improvement in plant-scale flotation equipment.

The flotation conditions for both tests are presented in Table 2. The aim was to keep the flotation parameters of particle size, solids density, and chemistry, as consistent as possible. For both tests, the test time represents the time taken for the froth to become barren of valuable minerals. Note, for the NovaCell™, due to the design of the small-scale rig, not all the particles are in the contact/collection zone at the start of the test. Some particles may take up to 6 mins to enter the contact/collection zone. In the Agitair cell test, all the particles are in the contact/collection zone at the start of the test.

Case Study 1—Results

At a flotation feed grind size (P_{80}) of 350 µm, the NovaCell™ obtained copper and molybdenum recoveries of 88% and 76%, respectively. For copper, the recovery split between the froth and screen concentrates were 87% and 1%, respectively. For molybdenum, the recovery split was 75% and 1%, respectively. Thus, the screen concentrate only contributed a minor amount to the product recovery and the classification circuit would likely not be required for this application. Note, for coarser flotation feed grind sizes with P_{80}s above 350 µm, the classification circuit may be required.

A comparison of the results for the NovaCell™ and the Agitair cell are presented in Table 3. The results showed that the NovaCell™ achieved a 10% higher copper recovery and 17% higher molybdenum recovery. The NovaCell™ product upgrade ratios were also higher than the Agitair cell. The product upgrade ratio is defined as the concentrate assay divided by the feed assay and is used to indicate the mineral selectivity to the product stream. Thus, the NovaCell™ improved both copper recovery and mineral selectivity to the product streams.

To investigate the copper results further, the NovaCell™ and Agitair results were analyzed on a sized basis. The copper recovery-by-size results for both tests are presented in

Table 2. Case study 1 summary of flotation conditions

		Test Conditions	
Test Parameter	**Unit**	**NovaCell™**	**Agitair Cell**
System Volume	l	22	5
Test time	(min)	30	17
Sample Feed Mass	kg	8.0	2.0
Grind Size (P_{80})	µm	350	350
Feed Solids Density	(% w/w)	31%	31%
Screen Aperture	µm	212	n/a
Collector (17A)	g/t	7	7
Collector (PAX)	g/t	14	14
Frother (MIBC)	ppm (vol)	26	26
pH (Lime)	—	8.1	8.1
Eh (NaHS)	mV (Ag/AgCl)	+199	+154

Table 3. Case study 1 NovaCell™ and Agitair cell results

	NovaCell™		Agitair Cell	
	Product Recovery, %	Product Upgrade Ratio	Product Recovery, %	Product Upgrade Ratio
Mass	5%		5%	
Copper	88%	16.5	78%	16.3
Molybdenum	76%	14.3	59%	12.4

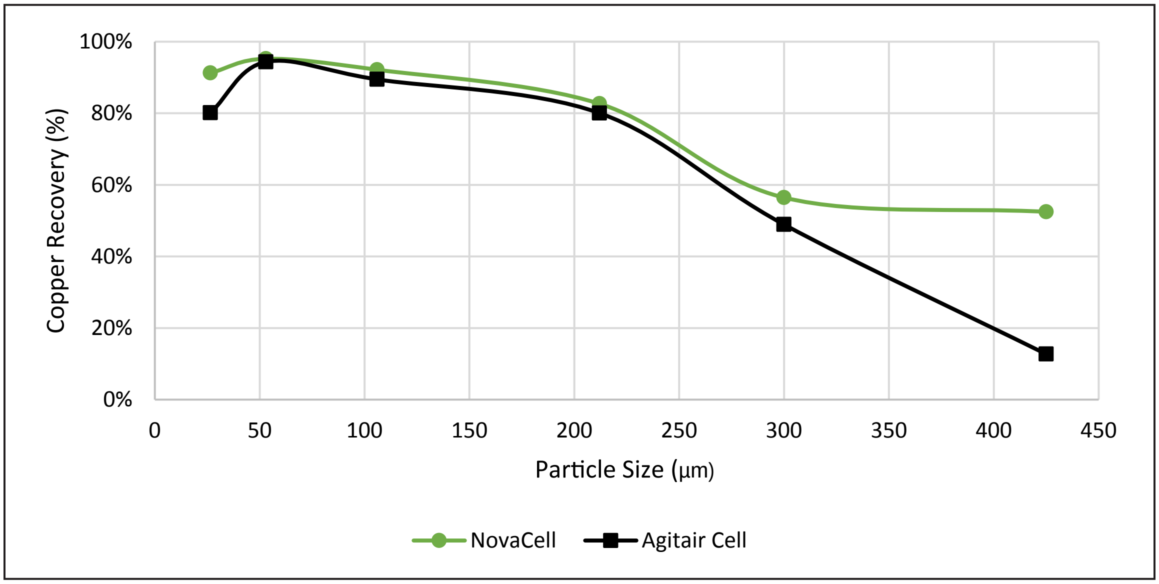

Figure 2. Case study 1, copper recovery-by-size results for the NovaCell™ and Agitair cell

Figure 2. The plot indicates that the NovaCell™ achieved higher recoveries across all size fractions, however the biggest increase was observed in the +300 µm size fractions. Thus, the results suggest that the NovaCell™ with its novel design, recovered the coarse copper particles more efficiently than the conventional flotation technology.

The copper assay-by-size results for both tests are presented in Figure 3. The plot indicates that the NovaCell™ copper grades were higher across most of the size fractions. Only in the –600+425 µm size fraction did the Agitair cell indicate a higher copper grade. However, this was likely due to the NovaCell™ recovering significantly more composite copper particles. Note, the NovaCell™ recovery in the 600+425 µm size fraction was four times higher than that achieved in the Agitair cell.

In summary, the laboratory results suggest that the project objective could be achieved. At the coarser flotation feed grind size (P_{80}) of 350 µm, the NovaCell™ achieved a copper recovery of 88%. When compared to conventional flotation technology, the NovaCell™ copper and molybdenum recoveries were 10% and 17% higher, respectively. The NovaCell™ was better at recovering copper across all size fractions, but this was most evident in the +300 µm size fractions. In addition, the NovaCell™ was better at selectively recovering copper minerals across most size fractions.

Case Study 1—Potential NovaCell™ Impact in Coarse Rougher Duty

The NovaCell™ was evaluated in a coarse rougher duty, using the kinetic rate results from the laboratory testwork.

The potential benefits would be:

- Increase in copper production. The test results suggest that the NovaCell™ can improve copper recoveries at coarser flotation feed grind sizes. Thus, the mine could operate the circuit consistently at higher feed throughput rates.
- Reduction in waste to the TSF. At the bottom of the NovaCell™ a coarse waste stream is produced. This stream would be suitable for mechanical dewatering technologies, followed by dry tailings disposal. The increase in the P_{80} of the feed will flow through to a similar change in the flotation tails, leading to faster dewatering times and better handleability. Thus, the amount of waste being sent to the TSF could be

reduced significantly and the life of the facility could be extended.

Figure 4 presents the proposed circuit configuration with the NovaCell™ in the coarse rougher duty. The NovaCell™ feed stream would be the cyclone overflow. The NovaCell™ product would be pumped to the regrind and cleaner circuits to produce a saleable concentrate. Given the expected NovaCell™ product copper grades and mass pull, it likely that the existing regrind milling and cleaner circuits could be utilized without the need for major modifications. The NovaCell™ fine tails (i.e., the classification circuit fines) will feed the existing rougher circuit for additional copper recovery. The NovaCell™ coarse tails will be sent out of the circuit for mechanical dewatering and dry tailings disposal.

At the flotation feed grind size (P_{80}) of 350 µm, it is predicted that the plant-scale NovaCell™ unit, together with the existing flotation circuit, would increase the final copper product recovery from 70% to ~86%. This is based on a copper feed grade of 0.25% Cu.

A high-level economic analysis was undertaken, based on the following assumptions:

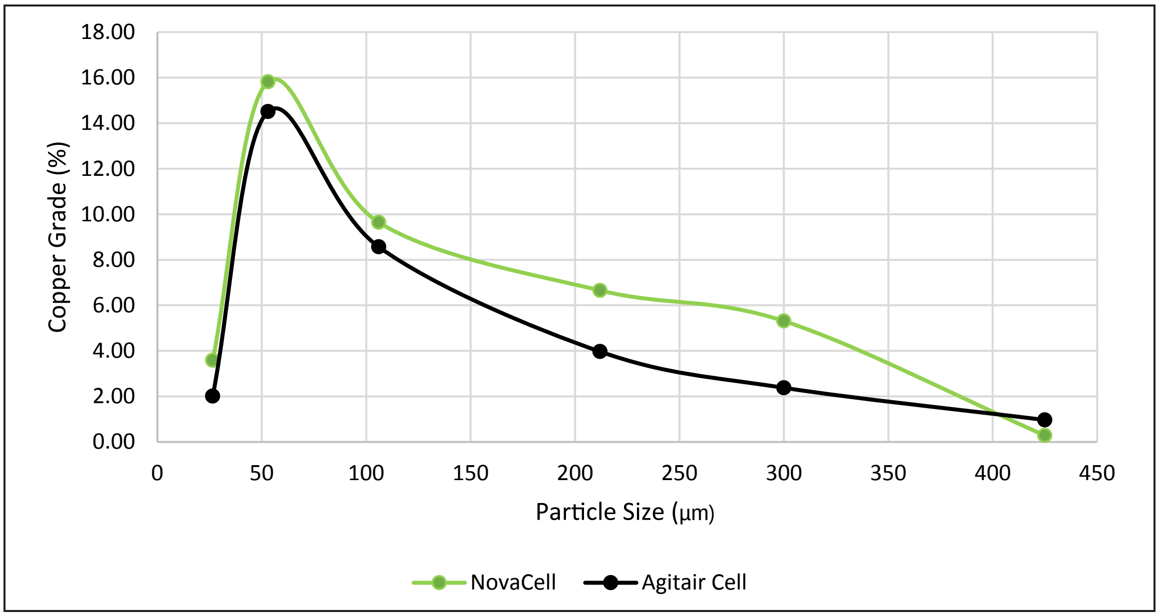

Figure 3. Case study 1, copper assay-by-size results for the NovaCell™ and Agitair cell

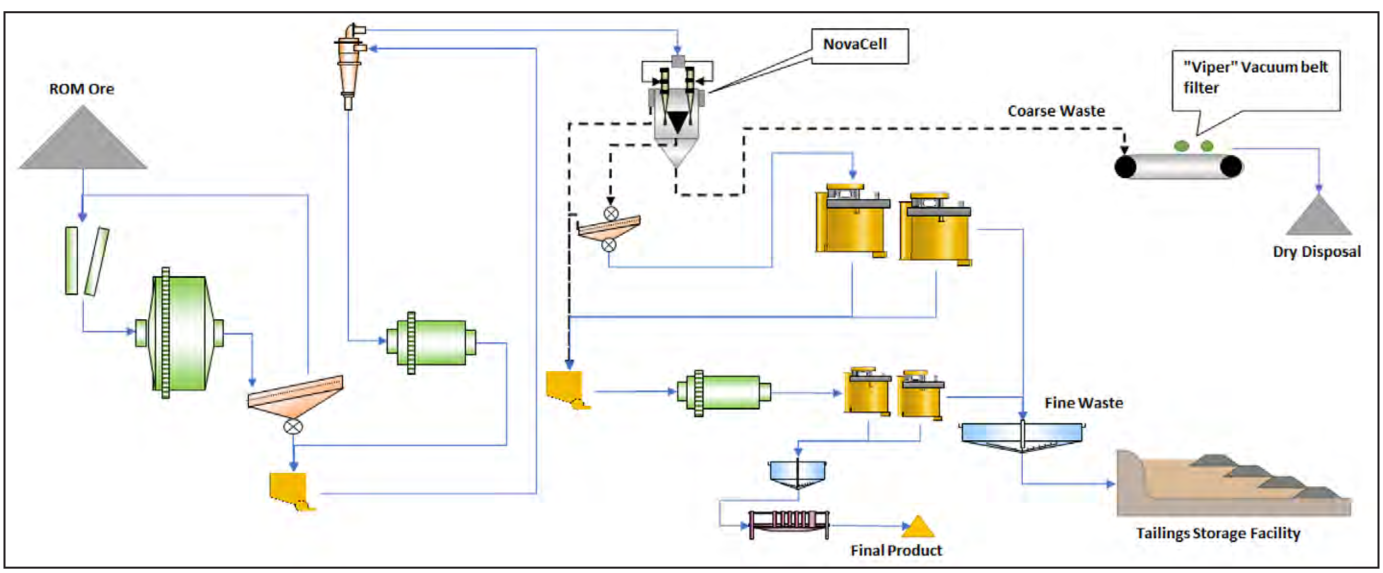

Figure 4. Process schematic of a NovaCell™ in coarse rougher duty

- At a flotation feed grind size (P_{80}) of 350 µm, the feed throughput rate can be increased by 11%.
- The copper recovery loss in the cleaner circuit is similar to the the current circuit.
- Plant utilization is 94%.
- The copper price is $8,300 USD per tonne.
- The plant operating costs are unchanged.

The calculation indicated that with the addition of the NovaCell™, the potential revenue increase for the mine could be ~$97 million USD/year. Jord has proposed an onsite NovaCell™ pilot plant trial to confirm laboratory results and provide additional information for the NovaCell™ plant-scale design. The project is currently under consideration.

CASE STUDY 2—INCREASED METAL RECOVERY

In the second case study, a plant tailings sample from an operating mine in Chile was evaluated. The porphyry copper deposit has a flotation feed grind size (P_{80}) of ~256 µm. The objective of the test work was to determine whether the NovaCell™ could recover additional copper from the final plant tailings stream. If successful, the potential benefits would be increased metal revenue and less metal sulfides reporting to the TSF.

The material delivered for testing was received as dry powder with a (P_{80}) of ~200 µm. This was finer than the typical plant flotation feed grind size. Sub-samples were analysed, showing that the head grade was 0.16% Cu.

Case Study 2—Sample Characteristics and Flotation Conditions

Table 4 shows the size-by-size copper assays of the flotation feed (plant tailings), and the distributions of mass and copper in the plant. The results show that the bulk of the copper was in the finer size fractions, with ~63% of the copper in the –212 µm size band. It was also observed that 37% of the copper losses were in the intermediate –212+53 µm size fractions. Typically, conventional flotation technologies perform well in these size fractions, however the appearance of these particles in the tails highlights that there is still significant room for improvement.

Table 4. Case study 2 sample characteristics

Particle Size, µm	Copper Feed Grade, %	Feed Distributions	
		Mass	Copper
–600 +500	0.44	1%	2%
–500 +425	0.46	1%	3%
–425 +300	0.39	5%	13%
–300 +212	0.27	11%	18%
–212 +106	0.16	26%	26%
–106 +53	0.10	17%	11%
–53	0.11	39%	26%
Total	0.16	100%	100%

The NovaCell™ flotation test work was conducted in the small-scale laboratory rig, following the standard test procedure discussed previously. The Agitair cell test was conducted to represent the conventional flotation equipment performance.

The flotation conditions for both tests are presented in Table 5. As in the previous case, the aim was to keep the flotation parameters of particle size, solids density, and chemistry, as consistent as possible.

Case Study 2—Results

The NovaCell™ obtained a copper recovery of 74% from the plant tailings stream. The recovery split between the

Table 5. Case study 2 summary of flotation conditions

Test Parameter	Unit	Test Conditions	
		NovaCell™	Agitair Cell
System Volume	l	26	5
Test time	(min)	45	50
Sample Feed Mass	kg	8.8	1.7
Grind Size (P_{80})	µm	200	200
Feed Solids Density	(% w/w)	28%	28%
Screen Aperture	µm	212	n/a
Collector (PAX)	g/t	95	65
Frother (MIBC)	ppm (vol)	30	30
Frother (Polyfroth W22)	ppm (vol)	8	8
pH (Lime)	—	9.0	9.0
Eh (NaHS)	mV(Ag/AgCl)	–50	–64

froth and screen concentrates were 65% and 9%, respectively. Thus, the screen concentrate contributed significantly to the product recovery and a classification circuit would likely be required to recover the coarse particles for this application. The results suggest that with the current flotation technologies, there is a significant amount of floatable copper being lost to the TSF. With the addition of the NovaCell™, the plant tails grade could be reduced from 0.16% Cu to 0.05% Cu.

The results for the NovaCell™ and the Agitair cell are presented Table 6. The Agitair cell obtained an overall copper recovery of 70%, 4% lower than the NovaCell™. The kinetic rate results also suggest that the NovaCell™ had faster flotation kinetics. Additional work is being undertaken by the mine to investigate this further. Understanding the flotation kinetics will be important for equipment selection. It was noted that the NovaCell™ achieved a lower product upgrade ratio than the Agitair cell, probably because it was more successful in recovering composite low-grade material.

The NovaCell™ and Agitair copper results were analyzed on a sized basis. The copper recovery-by-size results for both tests are presented in Figure 5. The plot indicates that the copper recoveries in the –212 μm size fractions were similar for both technologies, however in the +212 μm size fractions the NovaCell™ indicated significantly higher recoveries. Thus, as observed in case study 1, the NovaCell™ is better at recovering coarse copper particles than conventional flotation technologies. This suggests that at the current flotation feed grind size (P_{80}) of ~256 μm, the NovaCell™ recovery improvement would likely increase even further.

It is important to note that the Agitair cell copper recoveries are not being replicated in the plant. It is hypothesized that the lower recoveries in the plant were caused by inefficiencies in the cell hydrodynamics and froth recoveries, rather than residence time constraints. Further investigation would need to be conducted. However, in some cases, it may be possible to improve plant recoveries through equipment modifications. This may include changes in the process control, instrumentation, mixing mechanism and/or launder/crowder arrangements.

The copper assay-by-size results for both tests are presented in Figure 6. The plot indicates that the NovaCell™ product grades were higher across most of the size fractions, except for the –106 μm size fractions. To improve the product grade in the finer size fractions, the plant-scale NovaCell™ would need to include a froth washing system.

Table 6. Case study 2 NovaCell™ and Agitair cell results

	NovaCell™		Agitair Cell	
	Product Recovery, %	**Product Upgrade Ratio**	**Product Recovery, %**	**Product Upgrade Ratio**
Mass	15%		10%	
Copper	74%	5.1	70%	7.1

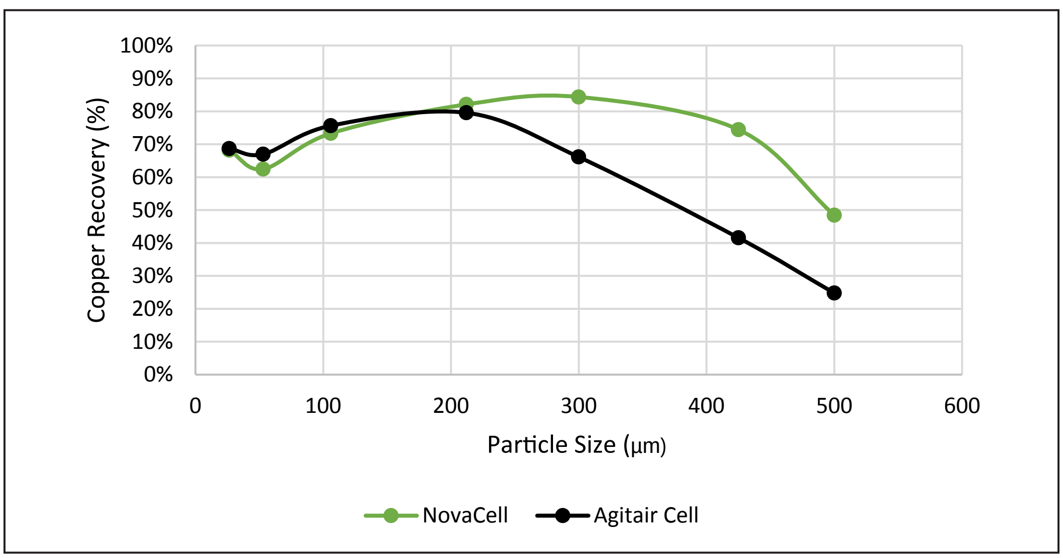

Figure 5. Case study 2, copper recovery-by-size results for the NovaCell™ and Agitair cell

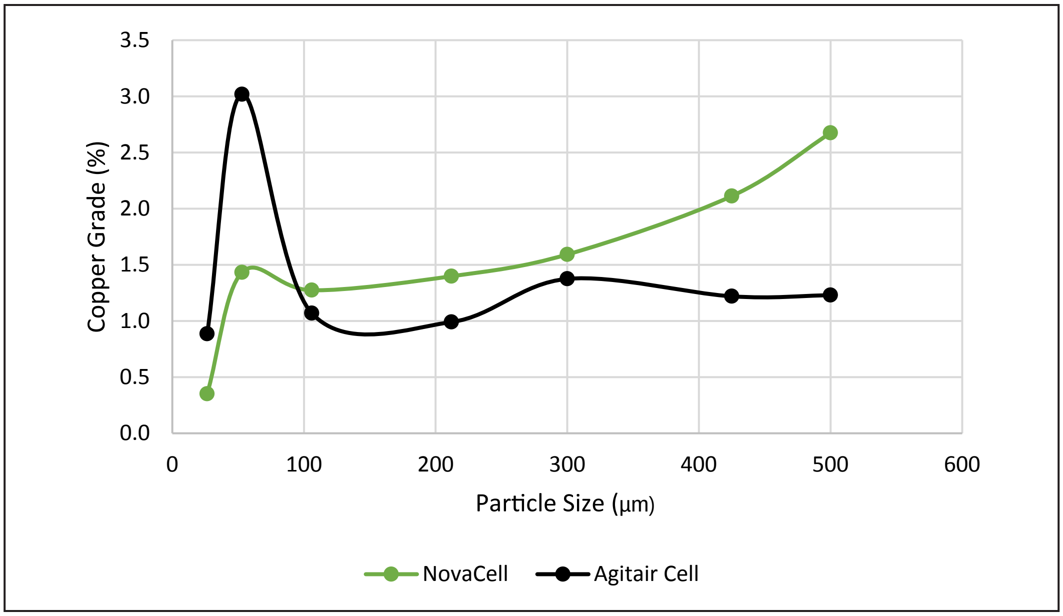

Figure 6. Case study 2, copper assay-by-size results for the NovaCell and Agitair cell

There are multiple examples of froth washing being used in circuits to reduce gangue entrainment in similar technologies. The review of Jera and Bhondayi (2022) on froth washing in flotation showed that froth washing improves the grade of the concentrate and influences the froth stability and mobility.

It should be noted that the higher NovaCell™ product copper grades in the +106 µm size fractions, suggest that the NovaCell™ selectively recovered coarse copper mineral particles better than the Agitair cell.

In summary, laboratory results suggest that the project objective could be achieved. The NovaCell™ recovered 74% additional copper from the plant tailings stream. When compared to conventional flotation technology, the NovaCell™ results showed that the recovery improvement was largest in the +212 µm size fractions. Thus, at the current flotation feed grind size (P_{80}) of ~256 µm, the NovaCell™ copper recovery improvement should increase even further.

Case Study 2—Potential NovaCell™ Impact in Tailings Scavenging Duty

In case 2, the NovaCell™ was evaluated in a tailings scavenging duty, using the kinetic rate results from laboratory testwork.

The potential benefits would be the following:

- Increased metal recovery. The test results suggest that the NovaCell™ technology can recover floatable copper minerals that are typically lost by conventional flotation technology (i.e., mechanically agitated cells).
- Reduced metal minerals to the TSF. Removing more copper and other sulfides from the tailings stream reduces the potential risk of acid mine drainage.

Figure 7 presents the proposed circuit configuration with the NovaCell™ in the tailings scavenging duty. The NovaCell™ feed stream would be the plant rougher tailings. The NovaCell™ product would be pumped to the regrind and cleaner circuits to produce a saleable concentrate. Note, that the cleaner circuits will likely receive additional material in this circuit configuration and should be evaluated to understand whether modifications would be required. The NovaCell™ fine tails (i.e., the classification circuit fines) will feed the TSF, whilst NovaCell™ coarse tails could bypass the TSF and be sent for mechanical dewatering and dry tailings disposal.

At the flotation feed grind size (P_{80}) of ~212 µm, it is predicted that the plant-scale NovaCell™ unit, together with the existing flotation circuit, would increase the final copper product recovery from 78% to ~85%. This is based on a copper feed grade of 0.90% Cu.

A high-level economic evaluation was conducted, with the following assumptions:

- The copper recovery losses in the cleaner circuit were increased by 1%.
- The plant utilization is 94%
- The copper price is $8,300 USD per tonne
- The plant operating costs are unchanged.

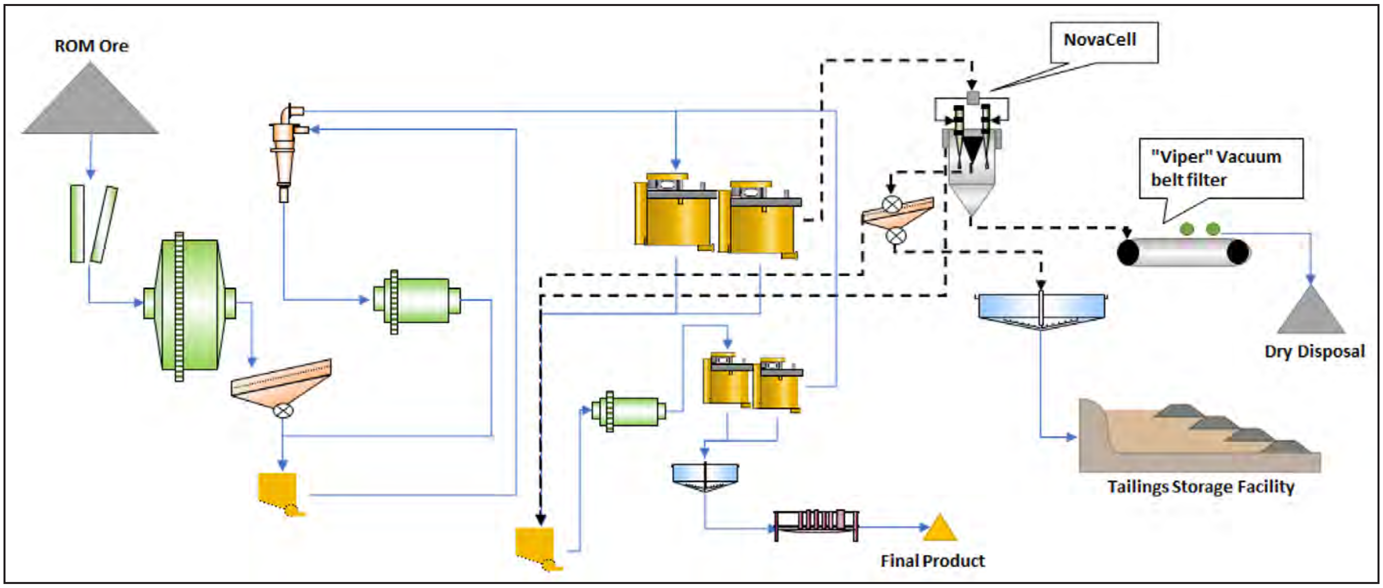

Figure 7. Process schematic of NovaCell™ in tailings scavenging duty

The calculation showed that with the addition of the NovaCell™ circuit, the potential revenue increase for the mine could be ~$40 million USD / year. Jord has completed an engineering study to provide the NovaCell™ circuit and the project is currently being evaluated for funding. An onsite NovaCell™ pilot plant trial is also being undertaken, and the results are expected to be published in future papers.

CASE STUDY 3—REDUCED CARBON EMISSIONS

In the final case study, fresh feed ore sample from an operating mine in Australia was evaluated. The mine is a porphyry copper deposit, with minor molybdenum. The circuit has a flotation feed grind size (P_{80}) of ~212 µm and targets a final product copper recovery of 85%.

The objective of the test work was to investigate whether a new rock breakage system could produce a flotation feed product with a final product copper recovery of 85%. This would provide potential benefits of reduced energy consumption, estimated to be up to 80% when compared to traditional milling. Both the NovaCell™ and conventional flotation technology were investigated.

The sample delivered for testing was received as crushed material. No further grinding was undertaken. The material was 100% passing 710 µm, with a flotation feed grind size (P_{80}) of 550 µm. Sub-samples submitted for chemical analysis, gave head grades of 0.45% Cu and 101 ppm Mo.

Case Study 3—Sample Characteristics and Flotation Conditions

Table 7 shows the size-by-size copper and molybdenum assays of the feed ore. Also shown are the feed distributions of solids mass, copper, and molybdenum. The copper was found predominantly in the coarser size fractions, with 59% of the copper in the +150 µm size fractions. For molybdenum, the highest distribution was in the finer size fractions, with 52% in the –150 µm size fractions.

Even though the flotation feed grind size was relatively coarse, it was interesting to note how little copper was present in the finer size fractions. In Semi-Autogenous Ball Mill Pebble Crusher (SABC) circuits, we generally observe more copper being present in the finer size fractions, even at coarse flotation feed grind sizes.

The NovaCell™ flotation test work was conducted in the small-scale laboratory rig, following the standard test procedure discussed previously. The Agitair cell test was conducted to represent the conventional flotation equipment performance.

The flotation conditions for both tests are presented in Table 8. As in the previous cases, the aim was to keep the flotation parameters of particle size, solids density, and chemistry, as consistent as possible.

Case Study 3—Results

At a flotation feed grind size (P_{80}) of 550 µm, the NovaCell™ produced copper and molybdenum recoveries

Table 7. Case study 3 sample characteristics

Particle Size, µm	Copper Feed Grade, %	Molybdenum Feed Grade, ppm	Feed Distributions		
			Mass	Copper	Molybdenum
–710 +600	0.27	39	12%	8%	5%
–600 +425	0.33	54	27%	20%	15%
–425 +300	0.40	71	15%	13%	10%
–300 +212	0.45	96	9%	9%	8%
–212 +150	0.54	144	7%	9%	10%
–150 +106	0.59	157	5%	7%	8%
–106 +75	0.71	193	4%	7%	8%
–75 +53	0.81	206	3%	5%	6%
–53 +38	0.89	222	2%	4%	5%
–38	0.54	162	15%	18%	25%
Total	0.45	101	100%	100%	100%

Table 8. Case study 3 summary of flotation conditions

Test Parameter	Unit	Test Conditions	
		NovaCell™	Agitair Cell
System Volume	liters	22	5
Test time	(min)	40	31
Sample Feed Mass	kg	5.3	1.4
Grind Size (P_{80})	µm	550	550
Feed Solids Density	(% w/w)	22%	24%
Screen Aperture	µm	300	n/a
Diesel	g/t	46	52
Collector (PAX)	g/t	48	50
Frother (MIBC)	ppm (vol)	30	30
pH (Lime)	—	9.0	9.1
Eh (NaHS)	mV (Ag/AgCl)	+12	+8

of 75% and 84%, respectively. For copper, the recovery split between the froth and screen concentrates was 62% and 13%, respectively. For molybdenum, the recovery split was 75% and 9%, respectively. Thus, the screen concentrate contributed significantly to the overall recovery and a classification circuit would be required for this application.

The NovaCell™ comparison to the Agitair cell is presented Table 9. The results indicated that the NovaCell™ achieved a 10% higher copper recovery and 17% higher molybdenum recovery. These results were similar to the NovaCell™ performance in case study 1. However, for the present case the NovaCell™ product upgrade ratios were lower than the Agitair cell.

The NovaCell™ and Agitair copper results were also analyzed on a sized basis. The copper recovery-by-size results for both tests are presented in Figure 8. The plot indicates that both technologies have similar recoveries in the –150 µm size fractions, however the NovaCell™ indicates significantly higher recoveries in the +150 µm size fractions. Thus, the results suggest that the NovaCell™ recovered the coarse copper particles more efficiently than the Agitair cell.

The copper assay-by-size results for both tests are presented in Figure 9. The plot indicates that the NovaCell™ copper grades were lower in most of the size fractions. The lower copper grades in the intermediate and coarse size fractions were likely due to the NovaCell™ recovering more composite copper particles with gangue associations. The NovaCell™ product would likely need regrinding and cleaning to achieve a saleable product grade. Regrinding of product streams ahead of cleaner circuits is a common approach adopted for coarse particle flotation (CPF) circuits. However, care needs to be taken to limit the rougher/scavenger concentrate mass produced from CPF circuits. If the CPF circuit is unselective and a large rougher/scavenger mass is produced, the regrind mill power draw requirements increase significantly, thus reducing the carbon emission

Table 9. Case study 3 NovaCell™ and Agitair cell results

	NovaCell		Agitair Cell	
	Product Recovery, %	Product Upgrade Ratio	Product Recovery, %	Product Upgrade Ratio
Mass	10%		5%	
Copper	75%	7.5	65%	13.5
Molybdenum	84%	8.5	68%	14.2

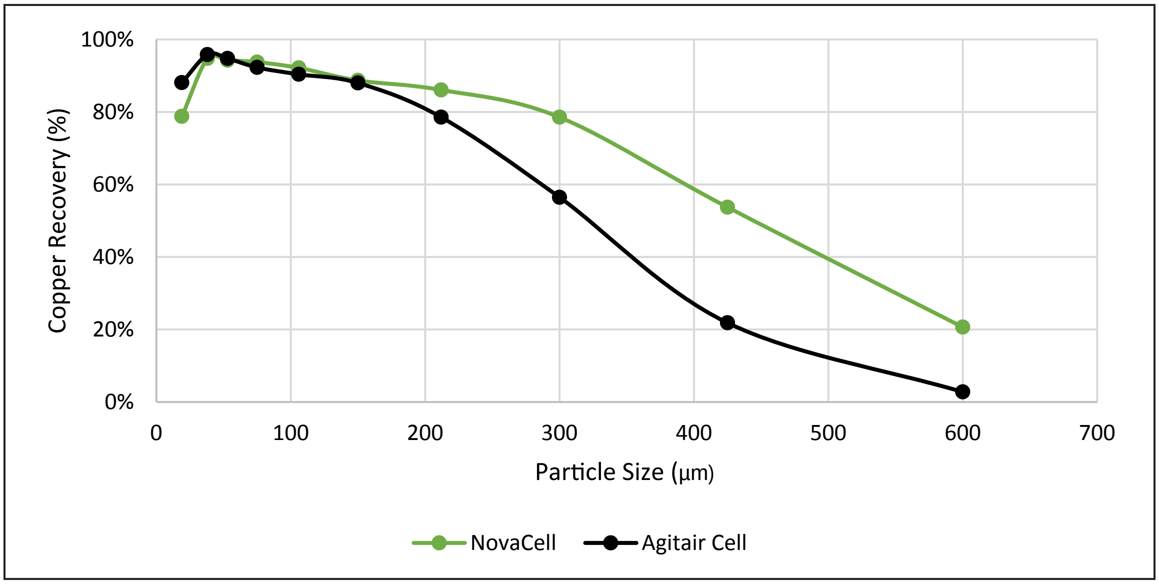

Figure 8. Case study 3, copper recovery-by-size results for the NovaCell™ and Agitair cell

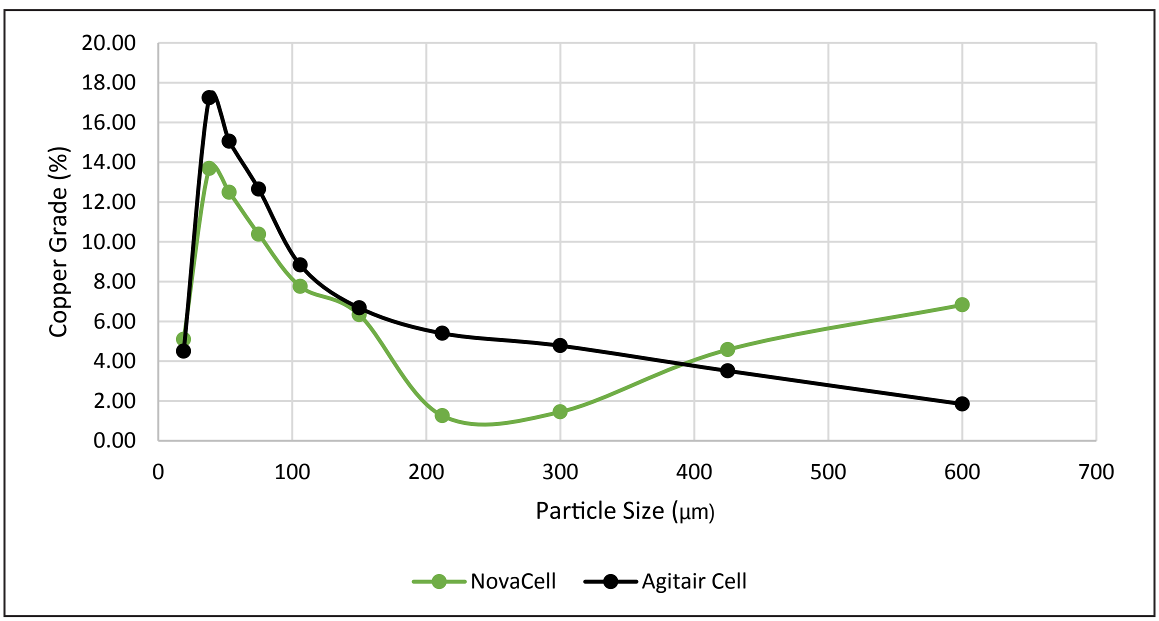

Figure 9. Case study 3, copper (left) and molybdenum (right) assay-by-size results for the NovaCell™ and Agitair cell

benefits. In some cases, it can also lead to increased valuable mineral losses in the cleaner circuit.

The lower copper grades in the finer size fractions were likely due to gangue entrainment to the froth concentrate. As mentioned previously, the copper grades in the finer size fractions can be improved with a froth washing system.

It is interesting to note that the NovaCell™ copper grades in –710+425 µm size fraction were significantly higher than the Agitair cell. Thus, the NovaCell™ improved both the copper recovery and grade in the coarsest size fraction.

In summary, laboratory results suggest that the project objective could not be achieved. At the flotation feed grind size (P_{80}) of 550 µm, the NovaCell™ achieved a copper recovery of 75%. Although, this was 10% higher than conventional flotation technology, it was still below the desired final product recovery target of ~85%, probably due to liberation constraints. It is well-known that as the particle size increases, there is a decline in particle surface liberation, which can cause a reduction in flotation recovery. Collection of ore particles can occur, even if the grade of the individual grain is small, provided some of the hydrophobic mineral is exposed on the grain's surface. However, if the floatable particle is completely encapsulated within the grain, it cannot be found by a colliding bubble and will be lost to tailings. It is likely that the reduction in recovery observed, is entirely caused by encapsulation.

It is recommended that further work be conducted to investigate finer flotation feed grind sizes with P_{80}s lower than 550 µm. It may be possible to achieve the desired final product recovery at a finer grind size and still achieve significant energy reductions. Secondly, the products produced from the new rock breakage system should be submitted for mineral liberation analysis (MLA). It would be useful to understand the particle surface liberation characteristics and degree of mineral locking, to determine the theoretical grade and recovery curve.

CONCLUSIONS

The NovaCell™ produced higher copper (and in some cases molybdenum) recoveries than conventional flotation technology i.e., mechanical agitated float cells. This improvement was observed for all the samples investigated, representing porphyry copper mines in Canada, Chile, and Australia. It was also evident that the largest recovery improvements were observed in the coarse +300, +212 and +150 µm size fractions.

The results suggest that the NovaCell™ is a viable option for CPF circuits at existing and future porphyry copper mines. The potential benefits of higher feed throughput rates, improved valuable mineral recoveries and lower carbon emissions, can all be achieved. With the adoption of the NovaCell™, there is a real likelihood that the mining sector will be able to satisfy the growing demand for copper, whilst also reducing the carbon emissions produced through mining.

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