and operations have seen reduced treatment costs and improvement to molybdenum concentrate grades with no significant downstream impacts."

Nitrating conditions in Latin America

Depleting grades and higher consumer demand from electric vehicle manufacturers and the like are not the only challenges copper mines in Latin America face, with solvent extraction operations also battling with the added problem of nitration.

Most copper solvent extraction operations in Latin America are now working with Solvay to overcome this and many other issues, according to the chemical company.

Rodrigo Zambra, Regional Sales Director LATAM at Solvay, explained the challenge: "Ores across Latin America have a higher concentration of nitrates than elsewhere in the world. Nitrates degrade metal extractants. Mines, therefore, need a nitrate-resistant product for their solvent extraction operations but many of the options that have been conventionally employed have failed to adequately address the situation."

Changes in ore feeds, due to mining new ore deposits or toll treating ore, may introduce nitrate salts to solvent extraction operations that previously had not faced this phenomenon, according to Solvay. The presence of nitrate in acid solutions can lead to the formation of nitronium ions, which react with oxime, resulting in nitro-oxime. The nitrated oxime binds with copper to form a highly stable complex, leading to higher viscosity and related physical problems. In addition, this copper complex cannot be stripped under normal plant conditions, generating a recirculation of copper in the organic phase (residual copper) that decreases the recovery and, thereby, the transfer of copper.

To enable mining operations to overcome nitrating conditions, Solvay has introduced ACORGA® NR series copper solvent extractants to help mines protect against degradation of their solvent extractant. This, the company says, reduces extractant replacement costs and improves operational reliability.

Solvay's offer extends beyond nitration-resistant reagents, with the company's Metal Extraction group having developed a proprietary TAP (Tert-Amyl-Phenol) test methodology. This is a unique indicator of nitration aggressiveness, Solvay said.

The company also supports customers through advanced gas chromatography (GC) and liquid chromatography (LC) analysis, both of which are critical to assessing initial nitration conditions across customer sites in Latin America and evaluating the benefits of the ACORGA NR in those conditions.

Last year, a large copper solvent extraction operation in northern Chile faced nitration issues related to its oxime-adopted ACORGA NR at commercial scale. The problem occurred after a year of industrial trials in which the drop of oxime nitration was confirmed through GC and LC analysis. Solvay designed and performed more than 64 TAP tests in the lab, followed by two months of data statistical analysis to generate a 3D diagram, plotting the pregnant leach solution (PLS) nitration potential as a function of nitrate concentration and acid concentration. This tool enabled the operation to predict the nitrate conditions of the PLS entering its solvent extraction plant and adjust parameters to minimise the risk of nitration of the organic phase, it said.

Another plant in the region recently switched to ACORGA NR following two pilot plants run side-by-side at its site and at Solvay. The operation had been experiencing highly aggressive nitration conditions resulting in deficiencies in the solvent extraction process. This included higher residual copper, higher viscosity, lower production and extremely high extractant consumption. Although the operation was using a nitration-resistant extractant formulation, the test work demonstrated an imbalance between the amount of protector present in the organic phase and speed of formation of nitronium ions. This resulted in a fast consumption of the protector and, therefore, an increased extractant consumption to replenish the protector and maintain production targets.

The two pilots also showed that ACORGA NR, which contains a different protector than the incumbent formulation, is more resilient and can significantly reduce the nitration potential.

Switching to ACORGA NR has saved the operation well over $1 million/y in reduced extractant consumption, in addition to maintaining a stable solvent extraction plant and achieving copper transfer targets, Solvay said.

To facilitate the conversion to ACORGA NR by operations running other formulations when they encounter nitration issues, Solvay has developed custom "booster" formulations to ensure a plant reaches the appropriate concentration of protector in its organic phase at a speed much faster than standard make-up replacement.

Such boosters have been successfully used at numerous plants throughout Latin America that, after a few months, were running fully on ACORGA NR, Solvay said.

ACORGA NR series nitration-resistant reagents also have the same tailored metallurgical advantages when compared with unmodified reagents, including a reagent strength matched to the PLS conditions, improved selectivity and enhanced copper transfer, according to the company.

Selective chemistry, optimised physics

Having perfected its Imhoflot™ pneumatic flotation technology over the past 25 years, Maelgwyn is now looking to match reagents with the specific conditions of high-energy pneumatic cells as part of a research collaboration with South Africa-based chemical solutions provider **Axis House**.

In the quarter century since Imhoflot was introduced to the mining industry, it has evolved with multiple flotation cell designs for different applications, including vertically fed (V-Cell), tangentially fed (G-Cell), hybrid (H-Cell) and VC-Cell as the latest design for coarse particles. This has led to over 180 installations in operations such as coal, potash, kaolin, magnesite, copper, gold, platinum group metals, copper-molybdenum, lead-zinc and reverse flotation of silica.

The unique selling point of the Imhoflot system, the company says, is the superior grade-recovery curve and the increased range of mineral particle sizes that can be recovered (both ultrafine (-20 µm) and coarse (-250+106 um)). This is achieved through high energy dissipation for the bubble-particle attachment and superior froth draining, which reduces gangue entrainment.

Maelgwyn says the research collaboration with Axis House will combine the selective chemistry of Axis House reagents with the optimised physics of Maelgwyn's Imhoflot system. With little industry research carried out into matching reagents with the specific conditions of high-energy pneumatic cells, the two think this area is ripe for further investigation.

The Imhoflot aerator is a fine bubble generator that has secondary benefits when it comes to improving the performance of flotation reagents, Maelgwyn says.

"For example, high turbulence in the aerator cleans the surfaces of minerals of both oxidation layers and adhered slimes," it said. "This increases reagent selectivity and reduces the dosing required."

Maelgwyn's work in the European Union's Horizon 2020 FineFuture project has pushed forward its competitive edge in ultrafine mineral flotation with base metal recoveries down to only a few microns, while maintaining the grade-recovery curve.

Maelgwyn's Imhoflot G-cell is optimised for ultrafine mineral recovery and is widely acknowledged to have several advantages over mechanical and column flotation associated with an increased recovery of fine particles, fast

kinetics, high reliability, smaller plant footprint (capital expense savings) and a lower unit price than competitors.

The Imhoflot system also has a positive effect on the application of flotation reagents.

The concentrate froth from an Imhoflot cell looks different to the froth from a conventional mechanical cell. While this can take some adaption from the plant operations team when considering dosing, it does bring with it additional flotation performance, according to the company.

"The finer air bubbles generated in the pulp provide significantly higher bubble surface area per volume of air, resulting in higher bubble loading capacity with which to carry minerals from the pulp to the froth, thus maximising recovery of the collected particles for a given air volume," Maelgwyn said.

The Imhoflot cell also only requires a very short residence time due to increased bubble-particle attachment kinetics and superior froth draining. This minimises the depth of froth required to achieve the needed grade, meaning the operational froth depth is shallower than a mechanical cell requires.

The "tight froth" reduces the "plateau border" where the froth projects over the launder, which results in lower water recovery and carry-over of entrained gangue, according to Maelgwyn. This entrained water carriage of gangue is a significant factor to consider when floating fine particles.

The quick draining and improved concentrate froth-flowing characteristics mean froth washing and launder water is rarely needed with the Imhoflot. This reduced water content of the fine concentrate cuts capital requirements for downstream solid-liquid separation, while reducing the requirement for de-frothing agents to prevent losses in concentrate thickeners.

Bubble size distribution

Maelgwyn's Imhoflot aerator design is based on the three industry-accepted mechanisms for bubble break-up:

- Rayleigh-Plateau instability of bubbles in shear flow;
- Impact of liquid accelerated flow inertia according to the Kolmogorov-Hinze approach; and
- Richtmyer-Meshkov instability of bubbles under high acceleration.

The patented design generates a spectrum of fine bubble size, resulting in a very high bubble surface area per slurry volume and, thus, high mineral carrying capacities, Maelgwyn said.

The high-intensity environment not only produces very fine bubbles, but, most importantly, creates an intensely turbulent environment to enhance bubble-particle collision frequency and efficiency of the attachment interactions.

"This gives the reagent-conditioned mineral surface more opportunity to attach to the bubble or for surface nucleation to occur, and hence lower reagent dosing may be required for the same flotation effect," Maelgwyn said.

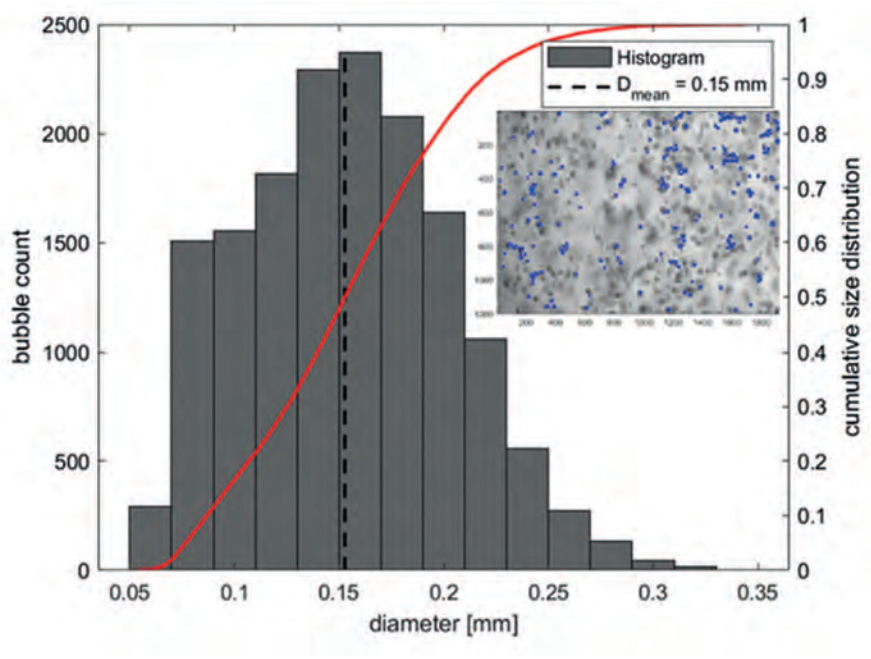
Imhoflot bubble-particle collision occurs within a high-shear zone where the bubbles are still "young" and not yet "contaminated" with adhered fine gangue minerals, the company explained. This improves the selectivity of reagents as the "active mineral surface" is unhindered and reduces the entrainment of fine gangue particles – both of which provide a higher-grade froth concentrate by increasing gangue rejection.

Due to the higher energy conditions used in the Imhoflot compared with other pneumatic cells, there is a high degree of dissolved gas molecules that nucleate to form nano-bubbles in both the gas-saturated pulp and at ultrafine mineral surfaces. This means both historic pathways for bubble-particle attachment are used within the Imhoflot, which benefits the flotation of ultrafine mineral particles.

Particle surface cleaning and reagent optimisation

Mineral flotation is a surface-chemistry reaction where reagents interact with the exposed surface of minerals. Therefore, ensuring a clean mineral surface, thinning the film boundary layers and breaking up any surface-adhered mineral phases are key requirements for the selective adsorption of flotation reagents.

The Imhoflot aerator focuses the energy release from the pulp into high-shear zones to generate high-speed turbulent eddies to polish the surface of the particles, removing the boundary film, oxidised minerals and slime coatings from the surface. This optimised reaction environment means lower doses of more selective reagents can be used to achieve superior flotation performance, according to the company.



A typical bubble size distribution generated by an Imhoflot reactor for the FineFuture project

It is this opportunity to use the higher performance reagents from Axis House at lower

dosages that Maelgwyn hopes will unlock economic and environmental benefits for their respective clients.

The Imhoflot high shear environment disperses reagents into a turbulent zone to aid homogeneous dispersion, decreasing the time and dosing required to condition the entire pulp volume. This leads to operating cost savings and a smaller plant, Maelgwyn says.

"The nucleation of nano-bubbles in the pulp and at the mineral surface enhances the bubble-particle attachment physics by lowering the interfacial free energy," Maelgwyn explained. "In effect, the nucleating bubbles act as a 'secondary collector', reducing the dosage of flotation reagent required."

Maelgwyn says it has found evidence that, in some flotation systems, the small bubbles act as carriers of the collector to the mineral surface from the pulp, which further increases the kinetics of flotation.

Fine recoveries

The Imhoflot G-cell is applicable for a range of particle sizes from ultra-fine (-20 µm) to intermediate-sized particles (50 µm).

The G-cell uses a "unique" dynamic centrifugal motion to promote gangue disengagement from mineral-bubble agglomerates within the pulp before gently spinning the concentrate froth to reduce gangue entrainment by both keeping the pulp-froth interface turbulence low and allowing gangue entrained in froth bubble interface water to drain away from the central concentrate launder by centrifugal force.

"It is this combination of factors which, when combined with a selective reagent scheme from a team such as Axis House, allow the G-cell to achieve superior concentrate grades," Maelgwyn claimed. "The G-cell often finds application in challenging cleaning duties or recovery of ultra-fine particles (down to 5 µm) where columns are struggling to achieve the recovery required."

Imhoflot cells can be supplied in modular forms to achieve specific test work tasks before installation of a full-sized cell or combined to provide a cost-efficient retrofit to existing plants.

For instance, the application of a three-stage G-Cell at a nickel plant in Europe demonstrated Imhoflot's ability to recover an additional 30% of nickel from the final tailings, predominantly in the -11 µm size fraction.

At another operation – this time zinc – a two-stage Imhoflot G-Cell plant was used to avoid losing metal in the -7 µm mineral particle category. In this operation, the G-cell recovered an additional 20% of the zinc from the final cleaner tailings.

Imhoflot is currently being trailed at one of the biggest gold concentrators in the CIS region where the existing conventional cells were not achieving the desired grade-recovery profile with the main gold losses reported to be in the fine (-38 µm) and ultra-fine (-20 µm) size fractions.

The application of two pilot G-14 cells in open circuit demonstrated the ability to recover the fine and ultra-fine gold loss to the tailings, with the G-cell achieving an average concentrate grade of 19.94 g/t with an addition of plus-40% gold recovery from the tailings. Size-by-size analyses from the same gold operation showed it was possible to achieve an additional recovery of 65% and 68% in the size fractions of 0-20 µm and 20-38 µm, respectively.

Tailings treatment

Reacting to the critical need to reduce waste in tailing ponds and maximise recovery of valuable minerals, **Clariant**, in 2020, launched a suite of new tailing flotation products for the treatment of slimes.

The solutions, which included those from the FLOTIGAM™ and FLOTINOR ™ range, are geared towards improving iron ore recovery.

FLOTIGAM 7500 is a sustainable flotation collector for the removal of quartz and other silicate minerals from iron ore. Based on its new technology, a more selective adsorption at these gangue minerals' surface is achieved, providing improved flotation performance in terms of iron recovery and concentrate grades, according to Clariant. It is a robust product that can sustain plant variations and keep operational targets under control, also allowing the production of iron concentrate within market specification with a better cost-benefit outcome than other industry solutions.

FLOTINOR 5530, meanwhile, is a collector developed for iron ore slimes flotation.

Typically, the iron ore concentration process requires the step of desliming to remove ultrafine particles that damage conventional flotation performance. However, at this fraction, there are still high contents of valuable iron minerals that, in most processes, are sent to the tailings dam as waste material, Clariant says.

This slimes fraction, instead of being disposed at the tailings dam, can pass through a flotation step. Gangue minerals, mainly quartz and kaolinite, are floated and the iron mineral, mainly hematite and goethite, are kept in the concentrate, thus presenting as a commercial product, Clariant explained.

FLOTINOR 5530 presents not only economical benefits that come with increasing the overall iron recovery at the processing plant; it also has environmental benefits by reducing the amount of tailings generated by an iron ore processing plant, the company said.

Alongside these iron-related innovations, two HOSTAFLOT™ products were advanced by Clariant in 2020.

These xanthate replacement technologies provide mining operators with a safer and more sustainable alternative to xanthate collectors, allowing mining operators to discontinue the use of xanthates, which can come with fire and explosion hazard risks.

These alternatives, which Clariant developed through collaboration, offer a high copper flotation performance, safer handling and disposal, reduced capital expenditure and a longer shelf life than xanthates, according to the company.