

MINERAL PROCESSING: FLOTATION

Fresh ideas froth to buoy output

Ailbhe Goodbody looks at the latest trends in flotation, and at some of the new products that have been released in the past year

The major challenges in the mining industry currently include the decline in ore grades, the scarcity of resources such as water and energy, and increasing restrictions to miners' licence to operate. There is also increased awareness of the safety and environmental impact of chemicals. These affect all aspects of the mining cycle, including mineral-processing techniques such as flotation.

A big focus in the mining industry at the moment is on productivity and cost reduction rather than capital expansion. Frank Cappuccitti, president of Flottec, says: "This push to reduce costs has manifested itself by the mills taking more risks than they normally would. We see that there is more interest in different reagent suppliers who can bring lower costs, and there is more interest in looking at innovative ways in which the ores can be processed at lower costs. All expensive processes are being examined for less expensive alternatives."

Danny Canady, North American technical manager at Clariant, agrees: "The industry needs greater value in this down-cycle. All customers are looking to lean-up the operation; the push from the industry is for more cost-effective solutions and more efficient operations."

"This is the perfect time for innovation, and Clariant Mining is investing in new technologies. Once we have returned to an acceptable cycle, the conversation will undoubtedly swing back to degrading orebodies and greater technology in collectors and frothers."

However, the world's dependence on mined goods has led to the depletion of high-grade materials, driving a requirement for higher yields in mineral processing. Lucas Moore, manager of technical services at ArrMaz, notes: "There have been numerous beneficiation techniques that have

been developed to overcome these challenges, but as the grade of these minerals continues to worsen, techniques such as flotation and leaching (metals) become the most viable techniques."

Kevin Shikoluk, global marketing manager for Cytec's mineral-processing business, adds: "Regarding ore-grade declines, operators require more effective and selective reagents that recover not just the primary metal or mineral, but also the other valuable metals contained in the ore."

"Additionally, the current ores are more complicated and difficult to process. Our solutions allow such ores to be processed, resulting in good returns for our customers."

Companies such as Cytec have worked with their customers on solutions such as reagents that reduce energy in the grinding circuit and flotation reagents that can be used with seawater. Shikoluk says: "We also have several solutions that inhibit or eliminate the development of problematic scales that reduce heat transfer, thus reducing energy usage and improving throughput in those operations."

Fine and coarse flotation are also both important trends in flotation. Fine-particle flotation is a topic of high importance, and will remain so due to the lower head grades and the finer dissemination of valuable minerals in ore. Meanwhile, coarse-particle flotation is of interest as it helps to keep costs down for comminution; where coarse flotation is possible, less energy is used within the process chain, resulting in lower total costs of operation.

Eric Bain Wasmund, global managing director, Eriez flotation division, comments: "One major trend in flotation technology is using fluidisation to promote flotation of very coarse particles. Our HydroFloat unit has been doing this in commercial

installations of phosphate and potash since 2002. We are now taking this into base-metal and gold concentrating. There is potential to greatly reduce the grinding requirements in terms of installed capacity and operating costs."

In addition, the mineral-processing industry is under increasing pressure to improve the safety, health and environmental impact of chemicals on the ecosystem and on workers. To some extent this can be improved through the application of mining chemicals with a 'greener' profile.

Shikoluk says: "We have worked with customers to replace some existing hazardous chemistry, and provide the most transparent information to our customers on the profile and the application of the products we sell."

Sven Menger, product manager at Primetals Technologies, concludes: "In our opinion, you cannot just focus on one process step; it is more and more important to always look at the whole beneficiation process."



"The push from the industry is for more cost-effective solutions and more efficient operations"

Products and projects

A range of companies make flotation reagents and flotation equipment for the mineral-processing industry. *Mining Magazine* talked to some of the main players about mining projects that they have supplied, and any recent product releases

Chemicals

ARRMAZ

For the last 50 years ArrMaz has supplied flotation reagents for beneficiation of phosphate and other industrial minerals. Todd Parker, global marketing manager, mining chemicals at ArrMaz, states: "ArrMaz began its operation in Florida Phosphates in the 1960s, and has now grown to supply over 90% of the reagents used for industrial minerals flotation in North America."

ArrMaz now has operations in Europe, China, South America, Africa and the Middle East. The company's goal is better grade and recovery in an existing operation with the same or better cost perfor-

mance; developing new technology and better-performing molecules is the way that ArrMaz aims to provide value.

Parker says: "If a mining operation cannot afford to spend the necessary capital to improve the process, often a higher-performing reagent can do the task. ArrMaz's metallurgical labs in the US, China, Brazil and Morocco are exploring new chemistries to bring the next generation of anionic, cationic collectors, frothers, surfactants, pH modifiers, promoters, depressants, flotation oil and polymers."

He adds that mining reagents need to be forgiving of potential surprises in the inevitable variability of the ores needing to be processed. Parker explains: "In short, the pro-

cess design, engineering and construction should be co-ordinated carefully with a deep understanding of the process-mining chemical universe. ArrMaz is the type of company that can advise from the beginning on the best fit for reagents and formulate chemicals to adapt to the changing orebody and process issues."

ArrMaz states that its application expertise and research scientists enable it to deliver superior products for specific mines' needs, allowing:

- Optimised recovery rates;
- Improved grade;
- Increased throughput; and
- Better cost performance.

The company states that it provides excellent responsiveness, expert technical and customer support to meet the mining industry's needs. As ore characteristics differ from mine to mine, resulting in varied impurities, a team of ArrMaz's metallurgists can design a reagent system to solve the specific ore challenge at hand.

ArrMaz provides beneficiation chemistries for oxide minerals around the globe, and develops reagents to improve grade and recovery for phosphate, silica, calcium carbonate, mica, lithium, garnet, kaolin and feldspar.

A recent example of ArrMaz's development in feldspar beneficiation, which is typically a very complicated process with multiple stages of flotation, is a two-stage flotation process that does not require pH modification to achieve the flotation of iron- and titanium-containing minerals.

Moore says: "Unlike the traditional feldspar beneficiation, ArrMaz is able to achieve the two-stage flotation with a single collector that was developed for the specific purpose of achieving the product specification required for feldspar/silica type glass."

Guoxin Wang, global director, mining chemical technologies at ArrMaz, adds: "During the development of the proprietary collector, a Fe+Ti ratio of <0.05% could be ►

"If a mining operation cannot afford to spend the necessary capital to improve the process, often a higher-performing reagent can do the task"

ArrMaz is constantly improving reagent performance by plant testing. In this image, it is setting up to run a tank-wagon full-plant test



► achieved in the final concentrated feldspar product, while maintaining a >90% recovery, based on sodium and aluminium. This is with a two-staged, neutral flotation scheme that is novel to the feldspar industry.”

Along with ArrMaz's Custofloat and Custamine collectors that are ever-changing with differences in mineral feed grade and water, the company has released a series of dolomite collectors with the primary interest focused on achieving a site-specific compositional MgO concentration in a final phosphate product.

In addition, ArrMaz has developed collectors with different reagent chemistry with simple flowsheet modification for use on North African phosphate deposits. Parker suggests: “This will greatly improve recovery on lower-grade feeds and finer-fraction feeds, and will extend the mine life.”

CLARIANT MINING

Clariant has successfully supplied mining reagents to a number of mineral-processing operations globally. The company states that its global footprint for production and supply has made it one of the leading suppliers for industries such as iron ore, phosphates and sulphide flotation.

Canady says: “The regional research and application capabilities of Clariant Mining Solutions have led to a strong local connection with priorities set by the needs of the customers in close proximity to their ore processing.”

Clariant Chile has developed a series of xanthate-replacement products for the copper industry, which can maintain the recovery and grade with better value for the customer.

The company has a focused interest on growing through innovation, with particular emphasis on sustainability. The new HOSTAFLOT series of xanthate-replacement products are delivered in liquid form and are not spontaneously combustible solids.

Canady explains: “The exposure of miners to the dissolution of xanthate pellets could become a problem of the past, with greatly reduced build-up of flammable carbon disulphide fumes in dissolving tanks and sumps. This solution to the use of xanthates has an environmental impact as well by keeping the xanthate packaging out of the local landfills.”

He adds that the customers that



There are a range of companies that make flotation reagents for the mineral processing industry

Photo: ArrMaz

ArrMaz has test equipment to run side-by-side comparative reagent testing from tote-bin size to full-plant scale

have replaced xanthate are experiencing better value for money; the operators in the plant have less exposure to hazards, and the packaging for xanthates has been eliminated or greatly reduced.

Pablo Dopico, global technical manager for phosphate, fertiliser additives and industrial minerals at Clariant, says: “In the last 12 months, Clariant has developed new collectors for the beneficiation of phosphates, including silica collectors that are effective at around a quarter of the dosage of the collectors currently used to separate silica from phosphate. In the North American phosphate industry, amine collector dosages of 400-500g/t of feed are often used, and Clariant's FLOTI-GAM amine collectors for silica are able to achieve the required grades using as little as 75-150g/t.”

CYTEC

Cytec recently conducted industrial-scale trials at a mine site in China to address copper-molybdenum separation. Shikoluk explains: “Cytec's business strategy has always been to partner closely with mining operations to solve flotation challenges.”

The site consumed an abnormally large quantity of sodium hydrosulphide (NaSH) in its Cu-Mo circuit. In one trial, Cytec's reagent AERO 8371 PNR was used as a copper depressant to reduce NaSH consumption, increase molybdenum recovery and improve the overall grade of the concentrate.

Shikoluk comments that AERO 8371 PNR was selected based on the improvements to metallurgical, economic and process conditions at the mine. In addition, compared with NaSH, the synthetic reagent AERO ►

“The exposure of miners to the dissolution of xanthate pellets could become a problem of the past”

Flotation of molybdenum
Photo: Clariant



- ▶ 8371 PNR is a non-hazardous, easy-to-handle and cost-effective copper mineral depressant.

The application of AERO 8371 PNR resulted in a 45% reduction in NaSH consumption, and delivered a number of benefits to the mine.

NaSH dust and stench were reduced in the reagent warehouse and reagent-preparation workshop. The reduction in NaSH usage also resulted in a saving of up to 35% in the total cost of reagents. Since the use of AERO 8371, the molybdenum grade has increased by two percentage points, and the copper content in the molybdenum product has decreased to below 1%.

Furthermore, the overall stability of the Cu-Mo circuit was improved, resulting in higher Mo recovery. NaSH consumption reduction also offers a logistics benefit and has solved some operational issues. The risk of a NaSH supply shortage and the transportation burden were greatly eased. In addition, the reduced quantity of NaSH flakes enabled the mine to secure better quality of the raw material, which not only benefits Cu-Mo separation, but also helps eliminate the blockage of the NaSH solution delivery pipes.

Cytec recently commercialised a series of new flotation collectors called AEROFLOAT MX-500. Shikoluk says: "The chemistry of these innovative new collectors was specifically designed to enhance recovery of Cu and Au from porphyry and massive sulphide ores, and to improve coarse-particle recovery of both liberated and composite (midlings) particles."

The AEROFLOAT MX-500 series

of collectors expands the metallurgist's tool box for both primary and secondary collector applications.

Cytec has launched several collector blends built on this technology platform, each targeted for specific operational conditions.

The company is also developing a set of novel collector formulations to help improve the recovery by flotation of oxide copper minerals. Shikoluk explains: "On average, 50-75% of oxide Cu minerals in mixed ores go to tailings due to poor flotation-reagent recovery. As a result, thousands of tonnes of copper oxide ores have been stockpiled awaiting a cost-effective solution. Cytec has recognised this industry challenge and will soon be launching a new product range for this application."

FLOTTEC

Flottec, in conjunction with its affiliate in China called Florrea, provides the latest in its hydroxamate collector technology to rare-earth and other industrial-mineral development projects around the world. The Florrea 7510 collector is a benzoyl hydroxamic acid collector that provides excellent flotation performance in rare-earth flotation applications.

In addition, its new volatile and non-volatile series of frothers are hydrodynamically characterised for strength and bubble-reduction capabilities. The company says these are providing industry with a new system for optimising frother type and usage in a flotation circuit. This optimisation system provides information on the critical coalescence concentration (CCC) of each frother at

the various air rates, and allows the mill to calculate the addition rate that is needed to maintain maximum kinetics.

Cappuccitti explains: "Then, by screening frothers of various strengths at the CCC, the proper frother can be chosen to provide optimum performance. This is a new highly scientific method for frother optimisation."

Flottec has customers in many parts of the world. For example, it has successfully worked with several zinc mines in Mexico to replace xanthate with Flottec 1234 as the main collector. This resulted in dramatic reductions in lime usage and a reduction in copper sulphate usage while improving grade. The company has also introduced sequential flotation into copper, lead and zinc operations using its Flottec 1234 collector.

Recently, a new zinc mine that was under development in Australia was unable to obtain grade and recovery of zinc due to the fine grind. Flottec introduced its Flottec 1344 collector, a modified thionocarbamate, which possesses excellent kinetic properties. Cappuccitti says: "That was the only collector that was able to successfully obtain the desired grade/recovery necessary to move the project forward."

Kemtec, a Flottec/Sinoz company in Australia, has recently introduced Flottec's reagents into several copper and copper-gold mills in eastern Asia that have reduced costs and lowered consumptions.

Flottec frothers have been successfully introduced into the Brazilian market and are having great success in graphite and copper operations. Cappuccitti comments: "Flottec methodologies for optimising frothers in the mines are being used to give the operations the best hydrodynamic conditions in the plants."

Chemiqua, a Flottec/Milman company, is continuing to work with many nickel operations in North America, introducing alternatives to xanthate in order to reduce the carbon disulphide (CS₂) emissions from the flotation cells. Cappuccitti says: "Flottec's X60-01, a dithiocarbamate-type collector, has so far shown the most promise. The testing has shown that the CS₂ can be completely eliminated in the plants, allowing the operators to work without respirators." ▶

"On average, 50-75% of oxide Cu minerals in mixed ores go to tailings due to poor flotation-reagent recovery"

► Equipment

ERIEZ

Eriez is currently commissioning a number of CavTube Sparger columns in Australia, South America and Canada, and has completed promising test work at a number of other locations. This technology is ideal for floating very fine particles that are not easily captured with conventional flotation.

Wasmund tells *MM*: “After studying a number of sites, we have found that adding at least one CavTube Sparger column to a cleaner circuit – consisting of conventional cells only – has a significant impact on overall plant recovery.”

He adds: “Columns have the advantage of delivering high grade because of the counter-current froth washing with water, which is a benefit for the later stages of cleaning.

“Additionally, by sparging with CavTubes, which nucleate micron-sized bubbles onto the ore particles, they are even better for floating fine particles that are usually prevalent in the cleaning circuit. Furthermore, the CavTube’s non-impinging flow design means higher wear-life when compared with other recirculating slurry spargers. This was the conclusion from a large mining company that did a side-by-side comparison in one of their plants.”

One customer in Australia observed an increase in global recovery of 2% when they added a CavTube Sparger column into a cleaner circuit consisting of conventional cells only.

Wasmund says: “The reason for this is that conventional technology is not well suited for floating fines. With the high amount of recycling in a typical cleaner circuit, adding a column almost anywhere provides what may be the only opportunity to float the fines with optimal technology.”

The company has another product called the Feed Air Jet, which is an in-line manifold system for feeding a set of parallel CavTubes. The idea is to pre-aerate feed slurries so that the collection process can begin before entering the flotation cell. It is based on the success of the CavTube and follows a number of plant trials that show feed pre-aeration as an effective way to increase metallurgical performance without increasing the tank volume.

The HydroFloat Separator



Eriez has designed the new Hydro-Float Separator for coarse-particle mineral concentration, delivering the capacity of a density separator while maintaining the selectivity of a flotation device.

Using a novel aeration system to disperse fine bubbles into a fluidised-bed environment, the HydroFloat Separator can significantly increase the selective recovery of coarse particles by applying flotation fundamentals to gravity separation.

The Eriez HydroFloat Separator

Eriez has a stage-gate system for developing new products. Wasmund explains: “We understand that continuous innovation is essential. ‘New products’ can be completely new, improvements based on feedback from our customers, or new adaptations to existing products for a new market.”

One product the company has recently released in South America is the Turbo Air Jet. This is an improved air-water SlamJet sparger that produces finer bubbles than the standard air-water SlamJet sparger. Wasmund says: “This is particularly well suited to locations with low electrical power availability.”

Another product Eriez is adapting to a new market is the StackCell. This is a two-stage flotation vessel that was originally introduced into the coal market with great success, but is now showing promise for reducing the residence time requirements in sulphide-flotation processes. The company could not provide further detail at this stage, but will be reporting on some of that work shortly.

FLSMIDTH

FLSmidth’s research-and-development engineers are continually working with its product managers, sales, service and industry specialists to provide customers with new ways of improving efficiency and productivity at their plants.

One such project recently culminated in the successful launch of the nextSTEP rotor/stator for forced-air flotation during the annual Society for Mining, Metallurgy & Exploration (SME) conference in Denver, US, in February this year.

The company states that the nextSTEP rotor/stator provides a ‘step change’ in flotation metallurgical performance and energy efficiency.

After years of flotation research and development, in which over 200 rotor/stator combinations were tested, the FLSmidth team developed a solution that it says delivers significant improvements in the performance of forced-air flotation mechanisms.

The company states that the nextSTEP mechanism’s design gives an even bigger edge over the designs ►

“We understand that continuous innovation is essential”



The first FLSmidth 600 Series SuperCell flotation machine is installed at KGHM's Robinson copper-molybdenum mine in Ely, Nevada, US ▶ currently being used by some of the company's competitors.

Frank Traczyk, global flotation technology director at FLSmidth, comments: "The nextSTEP rotor/stator has the lowest operating power of any forced-air flotation mechanism on the market. Additionally, this new technology demonstrates dramatic improvements in attachment rates, stronger air dispersion and improved pumping efficiency, which leads to increased recovery."

This new flotation solution is being offered globally, as the company states that every forced-air project can benefit from this advanced technology. The solution is not only for new installations, though; the nextSTEP rotor/stator is designed to be interchangeable with FLSmidth's existing Dorr-Oliver forced-air flotation mechanisms.

The technology can also be retrofitted into any existing forced-air flotation cell, allowing all operations to benefit from the improved performance and reduced power.

"It's very exciting to see that the actual operating performance exceeds the aggressive goals we set for this development project over four years ago," says Traczyk.

"We designed the rotor/stator to

not only outperform the competition when it comes to recovery, but to also do it more efficiently, using less power; and that's exactly what we accomplished with the nextSTEP mechanism. This will be very attractive for mineral-processing plant customers who rely on forced-air flotation systems."

FLSmidth has been field-testing the new nextSTEP rotor/stator at several installations, including the FLSmidth Series 600 SuperCell flotation site in Nevada, US.

According to Traczyk, with the need to address declining grades and the pressure to reduce capital costs as well as operational costs, original equipment manufacturers (OEMs) must continue to leverage technology to provide solutions for the mining industry.

He adds that the depth of expertise and experience that resides within the company allowed FLSmidth to progress flotation technology, and this culminated in the development of the new 600 Series SuperCell flotation machine. With an active volume of 660m³, this massive cell is one of the world's largest operating flotation cells and allows customers to take advantage of economies of scale.

The first FLSmidth 600 Series cell was installed at KGHM's Robinson copper-molybdenum mine in Ely, Nevada. Water trials were initially conducted, and when operators were confident with the results, slurry was introduced. The cell was then successfully commissioned in April 2015.

Due to successful functioning of the cell following start-up, the plant's operators were able to take over full operations after only 10 days, with them reporting that the 600 Series cell "runs like it's on autopilot".

One of the primary advantages of the FLSmidth 600 Series SuperCell technology is the reduced flotation-circuit area footprint. Comparing this unit, which offers a significantly higher flotation capacity, with the 300m³ machine, Traczyk explains that it requires between 20% and 30% less area and can reduce CAPEX by up to 25% and OPEX by 15%.

Harley Schreiber, flotation product manager at FLSmidth, explains: "Needing a smaller installation area makes it much easier and more cost-effective to retrofit these flota-

tion machines into existing plants, and also allows the footprint of new flotation circuits to be reduced, resulting in infrastructure and construction savings of up to 25% for the customer."

Schreiber says that process control in a flotation plant can be onerous, with controlling slurry level and froth proving inherently difficult in a row of flotation cells. He adds: "The slurry level in any cell affects the driving head in adjacent cells, and this can easily create unstable control conditions. This situation is exacerbated as larger concentrators with increased flotation cells are forced to use more cells per row."

The FLSmidth 600 Series SuperCell, with half the number of flotation cells of smaller machines, can offer a major advantage in terms of process control, which facilitates more manageable control conditions on the plant. The improved control can then result in improved metallurgical performance, according to Dariusz Lelinski, flotation-development manager at FLSmidth.

In addition to improved process control, maintenance requirements with their associated labour and time costs are reduced. Schreiber explains: "The maintenance crew can be mobilised to focus on only the single larger cell in some cases and economies of scale can also be applied to parts inventories, again resulting in decreasing operational costs for the plant."

With the growing need to optimise plants, this technology will allow additional rougher or cleaning capacity to be added to an existing circuit using a single a 660m³ cell. In this way, the customer could easily increase the capacity or retention time of that particular row.

FLSmidth says the technology allows greater flexibility in terms of providing flotation solutions, and allows various options to be considered to increase throughput or increase retention times.

Specifically, where a plant is able to reduce two streams into one, there are additional savings to be realised in terms of the entire installation as fewer blowers, samplers and pumps, for example, would be required. Lelinski notes: "These savings would be both from a capital expenditure and operational cost perspective."

The massive FLSmidth 600 Series SuperCell installed in Nevada has

been integrated as a rougher-scavenger in the copper-flotation circuit without the need to add another line of flotation cells.

The large flotation machine, which has a tank approximately 8.5m high and nearly 11m in diameter, offers significantly reduced specific power consumption. By providing the necessary power in the critical contact region near the rotor, excellent metallurgical performance is ensured, with less energy used overall.

Lelinski notes: "Importantly, the FLSmidth 600 Series SuperCell uses the same well-respected FLSmidth flotation technologies and operators who are familiar with other flotation equipment will not have to change their operational approach. This means there is no learning curve, and it is possible to realise the inherent advantages of the massive machine almost immediately following installation and commissioning."

PRIMETALS TECHNOLOGIES

In January 2015, Mitsubishi-Hitachi Metals Machinery and Siemens VAI Metals Technologies joined forces

to form a new company: Primetals Technologies.

The hybrid flotation technology, formerly owned by Siemens, is now part of Primetals Technologies' technological portfolio. Menger says that the hybrid flotation technology will extend Primetals' portfolio in terms of ore beneficiation; it is part of the company's ironmaking activities, but it is not limited to iron ore.

One of the biggest advantages of the hybrid flotation technology is that it can be used in a variety of applications; both fine and coarse particles can be addressed directly with the technology. Menger tells *MM*: "The relevant adjustment is done by parameter modification, but the machine parts on all the equipment still remain the same."

Primetals processed the coarse fraction of final tailings at a scheelite operation. Its pilot tests obtained a recovery of around 35% of tungsten trioxide (WO_3) from this stream; this mineral content would have been lost in the final tailings. Menger says: "The remaining mineral content could not be further processed economically."



The company has increased its laboratory facilities, and can offer laboratory studies including the whole beneficiation chain at its facilities in Leoben, Austria. The laboratory not only includes flotation equipment, but also has the ability to simulate different steps within the mineral-beneficiation chain such as magnetic separation, classifying and so on.

Primetals Technologies will soon release some new designs with increased capacity to the market, but could not give any further details at this time. ♥

FLSmidth has been field-testing its nextSTEP rotor/stator technology at several installations

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