Par for the coarse

Is coarse flotation becoming more important for optimisation as ore grades decline? Althee Goodbody investigates

Ore grades in mines are getting lower, as many of the easily accessible high-grade deposits have already been mined. In general, as ore grades dip, a much larger amount of rock and ore must be processed to achieve the same quantity of final product. Many mine sites are getting bigger and are pushing their throughput to maintain the same mineral production and profitability that they previously did.

As a result, mines are asking more from their unit operations and equipment – in existing operations, this means that the flotation process must handle more tonnes within the same amount of time, often leading to crowding of equipment and running beyond design capacity.

Charles Andrews, technical leader at Metso, says: “One often-seen consequence of this is that sites will increase throughput through their milling circuit, resulting in a coarser grind being sent downstream to the flotation circuit.”

Lower-grade ores have not been affected so far by a change in the liberation size or in the retention time compared to ‘standard’ grade ores. Thierry Monerod, director, process equipment – flotation and hydrocyclones at Metso, explains: “As a result, the main impact comes from the increased capacities required to decrease operating costs. Larger volumes for the flotation cells, in the range of 600m³, have been developed by all major flotation suppliers to address this requirement.”

To keep the cost of new plants down, the general trend is to go for larger flotation cells. Ben Murphy, technology director – flotation at Outotec, says: “In the past few years, we have seen a massive increase in our installed base of 300m³ cells. We have had a 500m³ cell operational since 2014 and we expect a number of 630m³ cells to come online later this year.”

The primary drive for the large flotation cells are the copper miners wanting to benefit from the economies of scale. The declining grade trend varies by commodity and this is most evident in the production of copper, gold, nickel and zinc.

“In fields like phosphate, potash and coal we are still seeing grades maintained, but certainly the ore is becoming more complex and new mineral processing plants are also starting to have more complex flowsheets,” notes Andress. “For industries like coal and gold, we are seeing flotation added to improve recoveries, but it is only responsible for part of production so doesn’t get the same level of attention as a mill.”

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where all their production is through flotation.”

More water is also required for the same amount of produced product. Frank Capuzzoletti, president at Flott, says, “Since collector is added for flotation of the valuable minerals, the amount of collector used will not change much with the higher tonnage feed. However, the frother works in the water phase so the amount of frother used will increase based on the water increase in terms of the chemicals used for flotation, the lower grades do not directly change the basic reagent optimization approach: however, lower grades involve complex mineralogy, which requires more selective collectors to treat the ore than the standard chemicals currently being used.

Bill Hancock, technical marketing specialist at FMC Chemicals, explains: “These lower grade ores are often and generally fraught with much mineralogy, surface chemistry and consequent bulk water chemistry impacts as well as liberation issues. Furthermore, gangue entrainment influences reagent scheme frothing properties and circuit design to ensure salvable grade concentrates are produced.”

He adds: “Because the flotation issues typically are more complex with these previously undesired low-grade ores, identifying an optimum combination of reagent, mills, system design and operating strategies is more difficult. Identifying the optimal combination of flotation reagents and process conditions is challenging due to the wide ore variability typically associated with these deposits, which makes defining overall optimum operating conditions for the range of ore conditions that is experienced within an operating shift or day difficult.

“In a flotation reagent supplier perspective, flotation collector blends and matching frothers can be tools for improving hydrophobicity and hydrodynamics to maximize recoveries at target concentrate grades. Due to ore variability, identifying and proving reagent suites optimality requires more effort.”

In developing new deposits that have low grade, the flotation process must be designed to compete economically with existing deposits.

The Outotec TankCell eX30

Benefits of Coarse Flotation

- There are several potential advantages of using coarse flotation in mineral processing that are not currently being taken advantage of in many mines.
- Benigno Ibarra, mining chemicals metallurgical manager at Chevron Phillips Chemical Co., tells Mining Magazine: “Typically, in flotation the recovery curve will show an inverted ‘U’ shape for recovery, with the lowest two points being on either side – namely the finer and coarser particles – with the highest recovery in the middle-sized particles. Coarse particle flotation would enhance recovery, possibly with premium combination of flotation reagents or with a need for regenerating in the cleaner circuit to maintain grade.”

- Murphy agrees. “If you plotted flotation recovery against particle size, recovery is relatively high for particles in the 50-100um range. Outside this range, the recovery falls off rapidly, at the coarse end, it quickly reaches a point in most systems where the particles are not recovered. In producing plants, it is around the 200um mark. Getting particles at this coarse end of the spectrum to float is a balancing act (to get) the right particle properties, chemical conditions and the hydrodynamic conditions created by the flotation equipment.”

- “If we could extend this, improving efficiencies for particles even in the 200-400um range, this would likely have a significant impact on how plants are designed and operated.”

- “The holy-grail of coarse flotation would be a situation where you could do a coarse grind and float off most of the valuable material, then regrind and retreat this smaller stream. This would potentially have big capital and operating cost savings, especially in energy used to grind the ore. What controls this is the liberation characteristics of the ore being treated. Obviously, the coarser the float the more savings would be possible.”

A huge benefit of floating coarser materials is cost savings. One of the most significant ways coarse flotation saves money is by reducing or eliminating the need to grind or reduce particle size to enable flotation. If the mineral is naturally liberated, then the flotation process bears the burden of having to float the mineral at its natural size. A coarser grind produces an ore with lower surface area, and if fines can be minimalised than reagent consumption can be likewise reduced.

- Parker says: “Size plays a critical role in the ability to float coarse particles. The process of grouping size fractions into similar sized bands, and then designing the flowsheet, equipment and reagents to maximize grade and recovery, has enabled the economical utilisation of many deposits around the globe.

Being able to size and float at the coarsest fraction possible enables low-cost mineral processing while meeting grade and recovery requirements.

Floating at coarser particle sizes also has great economic benefits directly related to higher grinding mill throughput and reduced grinding steel and electrical costs. The milling circuit is often the bottleneck in the plant, so increasing throughput increases plant and metal production end profits.

Hancock notes: “There is always a demand to reduce costs while maintaining recoveries. Unfortunately, particle liberation is a limitation in conventional mechanical flotation cells due to the mechanism and hydrodynamics, so as a generality, better liberation provides better metallurgical results.”

Technologies such as the Eriks Flotation Division’s HydroFloat Separator for coarse particle mineral concentration address this – it is designed to effectively float poorly liberated ores at very coarse sizes.

By utilising this separator, the amount of grinding energy and equipment can be dramatically reduced – the technology can recover particles with as little as 5% surface exposure.

Wagner Silva, global iron ore technology manager – Siet, Mining – Client BU OMS, says: “In addition, coarse flotation generates energy consumption savings, which in itself saves costs.”

Grinding is generally the most expensive and energy intensive part of the mineral processing operation, so increasing the grind size can significantly reduce electricity usage and costs.

Eric Wainmund, global managing director for the Eriks Flotation Division, says: “The observation known as Hukka’s conjecture describes that more energy is required to grind particles that are smaller in size. Therefore, grinding down to 400μm for coarse particle flotation will use much less energy and equipment than grinding down to 150μm.”

Eriks Flotation Division designed the HydroFloat Separator for coarse particle mineral concentration. It has the capacity of a density separator and the selectivity of a flotation device.
Meter’s flotation technology at RTB Bor’s Veliki Križevac concentrator plant in Serbia

*Improvements in coarse particle recovery can be achieved by proper flotation equipment selection and equipment design modifications.*

Flotation technology advances have been adapted in several ways to accommodate lower grade or more complex ores, as well as higher throughput. Improvements in coarse particle recovery can be achieved by proper flotation equipment selection and equipment design modifications. The cell volume of the flotation unit can be scaled up using existing technologies to be as large as possible to handle larger flows. This approach has led to the introduction of larger and larger flotation units.

Murphy explains: “One of the challenges facing the industry is that flotation cell sizing and scale-up methodology has not really changed since the 1970s. Engineers are applying the same rules to large cylindrical tank cells that they applied to 8-lpm square cells in the 1970s. This is despite the newer tanks having a different geometry and far more efficient in mixing and air dispersion. There is opportunity to improve here.” For example, FLSmidth has completed research into tank to diameter ratios that concluded that large volume forced air cells can have aspect ratios (the ratio of the width to the height) of 1:3. Aas Weber, product manager of flotation and dewatering at FLSmidth, addresses: “With this height to diameter ratio, the flotation machine can be operated at froth depths equal to a column’s operation. This allows improvements in concentrate grades with the benefits of higher recovery.”

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**TANK DESIGN**

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Measuring hydrodynamic parameters in flotation cells

- Plant design, as well as flowsheet design, which all must work together to effectively process the most troublesome of ores.

As a result, the application of flotation reagents has changed in recent years. "Over the last decade, we have begun to understand the flotation process more extensively," explains Cappuccitti. "Much research has been conducted on the importance of the hydrodynamics of flotation cells and how the hydrodynamics is affected by reagents. We have learned how to measure the hydrodynamic parameters in flotation cells. We have learned that flotation circuits work best at the minimum bubble size for both coarse and fine particles and therefore, circuits should be run at the CCC [critical coherence concentration] of the frother at all times for optimum performance. But, as the new flotation machines for coarse particles are developed, we must challenge this idea and determine if larger bubbles are required as we stretch the upper limit of coarse particle flotation."

To float coarser materials, stronger and stronger frothers are needed to keep the particles suspended. Additionally, some sites can quickly shift between harder and softer seams of ore, which means that the particle size distribution can swing wildly and quickly. Andress says: "As such, Netco have focused on developing frothers with the strength to keep larger particles suspended but to maintain the right level of mobility and persistence so that the circuit keeps running efficiently. As mines are moving to more complex flotation circuits, it's critical that they get a frother that's designed for their circuit rather than a generic reagent."

Cappuccitti notes: "We have also learned that each frother has a distinct relationship between its ability to create froth, water content in the froth and bubble size generation that is dependent on the air rate of the cell. This can be described as a hydrodynamic curve of a frother. Each system requires a specific hydrodynamic curve for optimum performance. If the ore feed is highly variable, each ore may require different hydrodynamic characteristics so therefore, dual frother systems (the addition of a weak and strong frother at different ratios depending on the needs of the system) are now being employed in the reagent scheme."

On the collector side there is also a need to drive towards more selective and specialty reagents. Andress says: "Unselective bulk collectors like xanthates are very effective in floating large volumes, but as we began processing more complicated ores there has been a big shift towards more selective collectors to maintain concentrate grades."

To accommodate high ore response variability, blends of collectors are required to ensure that values are appropriately hydrophobic under the circuit operating conditions to be recovered. As a result, optimum flotation circuits entailing multiple collector components that are able to improve, or at least maintain, the flotation performance in the presence of more complex ores.

CURRENT TRENDS

Various new technologies are being field tested to address the need to float coarser particles and reduce the size of the energy-intensive grinding circuit, including rotorless pneumo-typc flotation processes. Rubble explains: "In theory, the purpose is to have a smaller grinding circuit by grinding coarser, floating the coarse particles at equivalent mineral recovery, followed by regrounding to the required liberation size to produce a valuable concentrate."

He tells MM that topics of FLS meld's interest and research include:

- Alternative flotation technologies that reduce residence time and foaf print through reduced fluid dispersion or the separation of collision and attachment sub-processes;
- One pre-concentration technology deployment to separate waste rock prior to processing;
- Separation techniques that minimise or eliminate water consumption;
- Grinding technologies that may increase throughput at minimised power consumption yet allowing for acceptable maximum mineral recovery;
- Predictive wear and maintenance technologies;
- New froth removal techniques; and,
- Digitalisation of flotation circuits to maximise utilisation and minimise OPEX.

Murphy thinks that the next big focus for many operators will be looking to get the correct froth management in their flotation cells. He says: "The focus on efficiency has been largely on the mechanism and in-pulp kinetics, and I think now with the larger cells operators are realising that there are significant gains to be made in better managing the froth on their cells."

If mining companies want to start looking at coarse particle flotation, focusing on the launder and crowding configuration is even more critical because coarser particles are
FMG's more likely to fall out of the froth. As a result, minimising froth retention time and transport distance required for these particles to reach a launder is key.

Morisson suggests: “For ‘standard’ particle sizes – let’s say between 15-200 μm – flotation equipment has become a commodity item and all Western suppliers have already optimised their mechanism design. In order to maximise metallurgical performance, it is now required to expand the use of froth cameras like the Metso VisioFroth with advanced process control since this type of system can typically generate a 1% increase in plant recovery.”

He also adds that for coarse flotation, more research is needed to be applied in pre-concentration, especially for sulphide applications. He comments: “Floation suppliers are adapting their equipment or developing new equipment to handle coarse particles (suspension and wear) and maximise their recovery. In mechanical cells, the use of oversized mechanisms has already proven to benefit.”

From an equipment perspective, Wermund thinks that the biggest trend is the gradual acceptance of the idea that flow sheets can be optimized by using a split-feed approach. This means splitting the feed by size and floating the coarse stream using a different unit than the fine stream.

“Flotation equipment is ready to become specialized,” he says: “This will mean that other flotation technologies will become specialized as well. Eriku Flotation through is already seeing collectors that are specially formulated for coarse particles, for instance. This approach will allow the use of specially adapted technology – such as the HydroFloat – to be used in concentrations in the near future.”

Cappuccitlli suggests that the latest trend in flotation will be the use of new sensors to measure specific hydraulic parameters to control the flotation circuit. “The most promising new control parameter is gas hold-up,” he declares. “As the solids, mineral, air rate and reagents are changed, the gas hold-up in a cell changes. As gas hold-up changes, so does the retention time in a circuit. As gas hold-up increases, flotation becomes more efficient but residence time drops. So, there is an expected optimum gas hold-up where efficiency and retention time are optimum. New sensors are available that can provide this measurement that can help operators keep the circuit performing at its best level.”

In the future, true circuit optimisation will come from a complete understanding of the mineralogy of the ore, the flotation kinetics associated with the various levels of liberation and grind size, the chemistry and hydrometallurgy of the circuit, and a process control (xerpart) system that maintains the circuit at optimum.”

“A holistic approach is necessary for optimisation,” says Cappuccitlli: “We have to increment the approach where one change will fix everything will not work; unless there is some unlikely fundamental mistake in the operation of a mill.”

In the flotation reactors area, dramatically increased hydraulic understanding has enhanced engineering approach to reagent optimisation. Debbie Lanyon, mining chemicals technical manager at Chevron Phillips Chemical Co., states: “Specialty or higher specificity reagents are becoming more in demand.”

Reagent suite optimisation is now more clearly understood as requiring the consideration of both collector and frother chemistry combinations. Hancock says: “In response, FMG Chemnovix has added frothers to our line to improve the response of our collectors. This is because our products often provide unique responses that must be captured and accommodated with frother changes, which have led to improved metallurgical performance versus alternative products and combinations.”

Lower-grade ores have different and complex mineralogy, and can require more advanced flotation collectors than the ones available. She explains: “The research and development of customised collectors for new ores is required in order to optimise ore recovery, reduce the losses of valuable minerals to the tailings, and to allow for the ore flotation process to become more sustainable.”

The creation of finer bubbles in the flotation circuit is also seen as a growing trend. Andress says: “This will be driven by innovation in the equipment side of the industry, but the reagent suppliers will have a major part to play here too.”

He concludes: “The flotation industry is still fragmented. Each of the equipment suppliers, customers and reagent suppliers are working on their own development programmes. Increasing partnerships between customers, equipment and chemical suppliers will be needed to help solve the mining industry’s problems.”