FLSmidth Minerals and Rio Tinto recently commissioned what FLSmidth Minerals says are the world’s largest flotation cells. Economies of scale continue to drive equipment manufacturers to larger and larger pieces of unit equipment. FLSmidth Minerals has a track record of equipment development and has, it states, “installed the world’s largest crushers, grinding mills, filters and thickeners.” The last flotation cell development undertaken in 2003 was the installation of the 257 m³ WEMCO® SmartCell™, of which 150 have now been sold.

Since 2004, the company has been carrying out a fundamental review of the mechanics of flotation developing proprietary CFD models with the CAST group in order to better understand the mechanisms of flotation before the next phase of cell development. With the results from the CFD modelling, FLSmidth Minerals is now moving the design of flotation cells to a new level – the SuperCell™ – which includes a category of large cells starting at a 300 m³ capacity.

Rio Tinto’s Copperton copper concentrator was facing a bottlenecking problem in the cleaner circuit and needed additional flotation capacity – fast. The modelling and development work carried out by FLSmidth Minerals allowed two SuperCells to be built, installed and commissioned with minimal site testing. Previous cell developments had always involved four to six months of hydrodynamic and metallurgical testing prior to handing the cells over to the production team. The first SuperCell went into production 110 days from receipt of the order and was producing design concentrate at higher than expected recoveries within two days!

FLSmidth SuperCells use a universal tank that can be fitted with any of the three types of mechanisms manufactured by FLSmidth Minerals. The first 300 m³ SuperCell was commissioned with the WEMCO self-aspirated mechanism and the second larger SuperCell will test both of FLSmidth’s forced-air technologies: the Dorr-Oliver® mechanism with a 330 m³ capacity and the XCELL mechanism which will achieve an incredible 350 m³ capacity.

The scale-up design of the SuperCells started with the CFD modelling of existing equipment followed by the company’s conventional scale-up procedure based on dimensionless and hydrodynamic analysis. The results obtained were verified using CFD models of the newly designed machines. After the installation of the SuperCells was completed, the hydrodynamics were first extensively tested on water.

It was this fundamental understanding of equipment design that allowed the project to be fast tracked and completed in 110 days from start to finish. A close working relationship between the Rio Tinto and FLSmidth Minerals teams was maintained throughout. The project was a turnkey installation with engineering and construction
by FLSmidth Minerals’ newly acquired CEntry group in Salt Lake City. The installation includes a wireless control panel, Krebs millMAX® pumps, Technequip™ Valves, and FLSmidth Automation data acquisition systems.

With continued emphasis on flotation research and development, FLSmidth has additionally installed three pilot flotation units alongside the SuperCells to confirm scale-up criteria and verify performance. Testing will also analyse the differences and benefits of each of the WEMCO, XCell and Dorr-Oliver mechanisms to enable continual improvement onsite and for use in recovery evaluations for other installations. Previous testing of these three agitator mechanisms has allowed FLSmidth to offer better optimisation alternatives in rougher and cleaner stage applications and in both fine and coarse particle recovery.

The SuperCells are being proven to reduce operating costs as a result of better recoveries and more energy efficiency. FLSmidth Minerals is currently installing 26 of the WEMCO 300 m³ SuperCells for Antofagasta Mineral’s Esperanza plant in Chile, which will be the largest installation of its kind in the world.

Also at an Antofagasta operation, Siemens has installed a second 16 m³ hybrid flotation cell at Minera Los Pelambres (IM, August 2008, p24). In the molybdenum concentrator, it recovers fines lost by conventional flotation cells. Its benefits include:

- Increased molybdenum recovery by about 2%
- Increased recovery of finest particles fractions
- Reduced gas, energy and water consumption
- Less wear and tear.

Also at Los Pelambres, Maelgwyn Mineral Services (MMS), through its Chilean Partners, Ingenieria de Minerales (IDM) has delivered two Imhoflot G-Cells type IMF-G-22 to the operation. The G-Cells are being used in parallel as second cleaners for producing a final molybdenum concentrate. The nominal throughput of the cells is 200 m³/h each but they can operate in the range of 160 to 280 m³/h. Minera Los Pelambres made the decision to install the G-Cells after running an Imhoflot pilot plant to test their performance. The trial was so successful in increasing grade and recovery that the pilot unit was incorporated directly into production until the full size cells could be installed.

An advantage of Imhoflot is that with its high selectivity in rejecting insolubles a final molybdenum concentrate can be produced without an additional cleaning stage. The G-Cell has other particular advantages when floating molybdenum. The extremely short residence time in the cell reduces the consumption of the reagent NaSH. The self-sucking nature of the aeration unit made it easy to feed low pressure nitrogen as fine bubbles into the system with excellent bubble distribution. The ability to make the cell gas tight means that when floating in such a medium gas losses are dramatically reduced.

The cells and the entire system including the feed tank and discharge collecting boxes are sealed with Perspex and connected via a gas pendulum pipe so that nitrogen losses can be avoided and the gas recycled. Imhoflot offers great flexibility with high availability in an industrial flotation circuit and can quickly remove grade material, especially in the ultra fine size range, to final concentrate. The G-Cells at Los Pelambres are producing concentrate with over 50% Mo content (Cu in the range 2-3%) with improved molybdenum recovery.

**PGM flotation**

Bateman BQR Flotation Cell technology continues to be in demand from an increasing range of international minerals processing projects and clients, with recent orders from the Blue Ridge and Smokey Hills platinum projects in South Africa. In addition, flotation circuits for Hindustan Zinc in India, African Copper’s Mowana Copper mine in Botswana and SOMSY’s Syama gold mine in southeast Mali have been successfully completed.

The contract for the flotation circuit for the Smokey Hills platinum project was awarded to MMS Imhoflot type IMF-G-22 recovering molybdenum at Mineral Los Pelambres in Chile.
Bateman Engineered Technologies by GRD Minproc. The circuit consists of a total of six banks of flotation cells comprising eight Bateman BQR200 flotation cells for primary and secondary roughing, four Bateman BQR100 flotation cells for scavenging and 13 Bateman BQR50 cells for cleaning and re-cleaning. The flotation circuit was supplied complete with all interconnecting piping walkways and blowers.

Smokey Hills in Mpumalanga, owned by Platinum Australia, lies on the eastern limb of the Bushveld Complex, and has a plant design capacity of 97,000 oz/y of three platinum-group metals and gold.

Ridge Mining’s Blue Ridge platinum concentrator in Groblersdal has two circuits of Bateman BQR flotation cells: a primary and secondary circuit. The primary circuit consists of seven Bateman BQR300 cells for roughing and eight BQR100 cells for cleaning and re-cleaning. The secondary circuit is made up of eight BQR500 cells for roughing and 11 Bateman BQR100 cells for cleaning and re-cleaning. Bateman Engineering Projects was also awarded the overall $59 million lump sum turnkey project to construct the concentrator, and conducted the prefeasibility study as well as the full feasibility study for this plant, which is targeting 125,000 oz/y of PGMs.

Ranging in size from 0.5 m³ (BQR5) to 150 m³ (BQR1500), Bateman BQR flotation cells are used in roughing, scavenging, cleaning and re-cleaning, unit and pilot cell applications to process gold, copper, zinc, platinum group metals, phosphates, graphite slag and a range of other minerals and commodities.

The technology’s many advantages include simple process optimisation and start-up under load, together with easy maintenance and minimised downtime due to the ‘hooded’ stator assembly. High shear forces, also due to the rotor/stator assembly, ensure better bubble-particle contact, while the cells also offer a stable froth-slurry interface and formation of a quiescent zone (again due to the hooded stator assembly), maximisation of the aerated volume to meet residence time requirements and purpose designed solids suspension.

With another 300 m³ cell, Outotec and Codelco have finished the testing program of the TankCell®-300, with an active volume of over 160 m³ installed in 2001. Results were obtained during the normal running of the plant, where the feed rate to the cells was 3,600 t/h (dry) on average, with a coarseness (P80) of 300 micron and a Cu content of 0.6%. Sampling of the process was carried out twice a day, averaging four hours per campaign.

In its initial setup, the single TankCell-300 was measured to be 3.7% units higher on recovery compared to the two earlier machines in the parallel bank, while achieving equal copper in concentrate grade (averaging 20%). In this setup, the TankCell-300 consumed 205 kW of energy, when adding the consumption of the cell mechanism and the blower together. Thus the specific energy consumption of the cell was 0.66 kW/m³. The same measurement in the TankCell-160 yielded a result of 0.71 kW/m³.

Outotec’s TankCell-300 has been incorporated into the flotation circuit of Division Codelco Norte.
An alternate hydrodynamic setup of the TankCell-300 was also trialled in the testing program. During this period, the cells were fed with lower-grade ore (0.49% Cu). This setup of the TankCell-300 improved the metallurgical results further, with over 5% units higher recovery and 1% unit better concentrate grade than in the parallel two TankCell-160 cells. Also the energy consumption was lower: 0.58 kW/m³ (specific) for the TankCell-300. During the entire testing program, the TankCells did not exhibit sanding or mechanical problems.

MaxFlot’s DEC flotation column has been developed over four decades initially in the Florida phosphate industry, and since then in coal and iron ore flotation. It has been used very successfully to float silica and alumina from phosphate rock and three DEC Flotation columns are currently being commissioned to float silica from iron ore.

DEC Flotation columns perform extremely well in recovering phosphate in phosphate beneficiation plants, and can also be used to recover low cost saleable phosphate from tailings dumps and tailings ponds. Typically, concentrates of 60 to 68 BPL are achievable with Florida phosphates.

Coal slurry ponds and waste dumps can also be treated at low cost to recover saleable low ash coal and this is a growing market as coal dumps need to be processed to clean up the environment.

The DEC Flotation column has two cells, each 2.5 m deep stacked one above the other with the top cell operating as a rougher and the lower cell, which is fed from the top cell, acting as a scavenger cell. The column offers exceptional performance and operates with higher capacities and higher efficiencies and lower operating costs than mechanical cells or other flotation columns.

MaxFlot says “a typical deficiency of mechanical and conventional pneumatic flotation cells is the inability to float particles larger than 0.42 mm, due to the weak bubble structure produced by both mechanical impellers and aspirators or sparger systems. The DEC Flotation column can float particles up to 1.5 mm with ease and there is plenty of operating experience on a variety of different feed materials to support this.

DEC - high efficiency flotation has many advantages over mechanical and other column flotation cells:
- Higher capacity throughput
- Lower power consumption
- Enhanced metallurgical performance
- Combines roughing and scavenging in one compact unit
- Cost effective and easy to install
- Easy to control and automate
- Low maintenance costs and low energy and water consumption
- Top of the line bubble generator with anti-choking technology
- Spontaneous restart post power failure.

The bubble generator is a unique patented design which generates very active bubbles and it has an anti choking design which ensures immediate and easy restarts after a power failure.”

Flotation control

After several years of laboratory and field evaluations, Flottec has established that each frother has its own unique relationship among bubble size reduction, gas hold-up increase, froth stabilisation and frother concentration. It has been shown that a frother’s hydrodynamic properties can be characterised using the relationship between the froth zone property froth height and the pulp zone property gas hold-up. The relationship is established in a bubble column run at a given air rate over a range of frother concentration.

In most flotation circuits frother dosage (concentration) can be used to control the kinetics (mass removal rate). Since each frother has a distinct relationship between froth creation (particle loading capability) and kinetics, each frother type will perform differently in a circuit. This implies that there is a specific frother (providing a specific hydrodynamic characteristic) that will balance the need for mass pull and froth loading.

If a frother is too weak for a circuit this is seen in a collapsing froth due to too heavy a mineral load. The operator increases the frother addition rate. This in turn increases kinetics and more mass is pulled into the froth. The froth stability is not increased significantly and the collapsing of the froth is exacerbated. Therefore, if the frother is too weak, adding more in this circumstance simply makes the problem worse.

If the frother is too strong, the tail in a flotation circuit is high. The operator wants to increase the mass pull and increases the frother dosage to increase kinetics. The froth persistency
is increased significantly but the mass pull is not. The more persistent, voluminous froth causes grade to drop and there are operational problems with frothing downstream. The frother may be too strong for this circuit.

It is important to find the frother with the appropriate strength that will provide the optimum control in each flotation circuit across a range of dosages and ore conditions. Also, understanding flotation cell hydrodynamics, how they can be affected by frothers and other operating parameters, and what hydrodynamic conditions exist in your circuit can assist greatly in making adjustments to improve metallurgical performance.

A method of characterising the hydrodynamic properties of frothers using froth height (as a measure of froth stability) versus gas hold-up (as a surrogate for bubble size in the pulp) has been introduced. Frothers exhibit different relationships and this helps distinguish frothers considered ‘weak’ from those considered ‘strong’. Use of the relationship is illustrated in the authors’ SME paper through a series of case histories, ranging from replacing a discontinued frother to recommendations for operating practice.

In another SME paper, Lotter and Fragomeni of Xstrata Process Support (XPS) note “the reliability of a set of flotation results is key to minimising project risk either at concentrator commissioning, or at the point of implementing an improvement to an existing concentrator operation. High-Confidence Flotation Testing (HCFT) was developed for this purpose, and is part of the list of technologies of various scales used by XPS in addressing these projects. The methodology is based on two principles: one, to ensure that the ore sample is representative and has been well-blended and subsampled; two, to perform the flotation tests in sufficient numbers of replicates with appropriate quality controls, so as to improve the reproducibility of the test data. Across ten years of practice and continuous improvement with this methodology at XPS, several improvements to this method and complementary connections into sampling and quantitative mineralogy have been developed.”

Two case studies are reviewed in the paper and show the capability of this system in both optimising an existing concentrator operation and in serving a new mine scenario. The HCFT model has shown accurate diagnosis in two different cases that successfully scaled up into operations. These were:

1. Finding the correct dose for a CMC talc depressant at Raglan
2. Scoping out the metallurgical performance of a new operation from drill-core.

One modification has been made, to redefine the rule on first rougher concentrate, which has now been more appropriately defined as a point where cumulatively some 60-70% metal recovery has been attained.

The authors conclude that the “connection between modern mineralogical measurements, such as X-Ray Diffraction and QEMSCAN, and this model, has been shown to be very strong, and focuses the flotation work to good effect.” At the Pogo mine in Alaska (a 2,500 t/d gold operation employing processes including grinding, gravity, rougher flotation, leach, CIP, and E/W), an OCS (Optimising Control System) expert control system was implemented on rougher flotation in early 2008. The OCS system communicates with the plant’s DCS (Distributed Control System) through OPC (OLE for Process Control) communication. Initially this was to control the flotation cell froth level set points to achieve target froth velocities. This strategy was enhanced by controlling both level and air flow set points. The flotation cell air and level are adjusted to reach cell pulling rates (froth velocities). The pulling rate set points for each cell are determined based on downstream capacity (concentrate surge tank level). The effect of pH and upstream disturbances is also taken into account in adjusting the air and level set points. Feed forward compensation is employed down the flotation row to minimise disturbances.

Throughout the lifetime of a mine - typically 15 years - the competitiveness and profitability are strongly dependent on costs of operation and sustainability. One would expect the issues on energy and environment to increase in importance. That is why Outotec technologies are developed to minimize the operating costs and energy consumption. For example Outotec TankCell®, the largest operational flotation cell in the world, is far below its competition in energy consumption, even up to 45%. With today’s energy prices and large installations, this will translate to millions of dollars of savings per annum and similarly, depending on method to produce energy, remarkable reduction on CO₂ emissions.

Outotec TankCell® - proven metallurgy, lowest operating costs - the choice for today and for the future.
was recommended to enhance the flotation recovery and stability based on its successful applications in other operations. The Metso Cisa VisioFroth Expert Control system is a combination of vision hardware including cameras, lights, mounts, Ethernet switches and computer and the OCS Expert control system software. OCS is a piled advanced control system that is composed of modules. The modules being used at Pogo are:

- **HMI** – Operator interface
- **Stats** – data filtering, trending and historical control troubleshooting
- **Expert** – Full fuzzy and crisp logic Expert system. This is where the control actually takes place
- **Vision** – A vision module that processes the streaming video signal from the Ethernet cameras and analyses each frame for critical information such as: froth velocity, texture, bubble size, collapse rate, stability, colour vectors in RGB, Lab, and HSV formats, camera status, etc.

By using these four modules, OCS can interpret camera data, match it with plant data communicated via OPC, filter it and perform control functions on the plant (like an operator) within limits set on the HMI screen and send control action back to the DCS.

Moving forward, the VisioFroth camera system also has the capability of analysing bubble size distribution and colour properties. And with the laser option, VisioFroth can detect the elevation of froth surface. The mine has been considering further development of the control system by using these unused capabilities to control reagent dose rate and optimise operational parameters in order to improve flotation performance.

**Froth research**

A year ago, Rio Tinto established the £6 million Centre for Advanced Mineral Recovery in the Royal School of Mines, Imperial College London. Of the first four five-year projects, two are looking at rock fracture and seismic methods, and two are focussing on mineral processes; flotation and leaching.

The flotation project is led by Professor Jan Cilliers, who also directs the Centre. The flotation team now has more than 10 researchers.

In the last year, the Centre has made great progress in flotation development. In particular, the research into the froth and how it affects the separation achieved has been extremely positive. Two developments will be reported on in detail at three upcoming international conferences; the Conference of Metallurgists in Sudbury in August, the Mill Operators Conference in Adelaide in October and Flotation ’09, in Cape Town in November.

The first development is the use of Positron Emission Particle Tracking (PEPT) for observing particle behaviour in flotation vessels. Using PEPT, a single particle in a flotation tank is radioactively tagged to emit a steady stream of back-to-back gamma rays. The signals from these gamma rays are detected and used to triangulate the particle’s position in milliseconds. For the first time, the complete particle behaviour in a flotation tank has been observed - mixing in the pulp, attachment to a bubble, movement into the froth, detachment and re-attachment, and finally the slow upward motion until it overflows into the concentrate. PEPT opens new avenues for verifying CFD flotation froth models, and for testing new cell designs in a real flotation environment.
Currently, the only PEPT facility is at the University of Birmingham, where these tests were performed. In the last month, however, the most sensitive medical PET scanner was donated by Imperial College to the University of Cape Town where a new collaborative PEPT facility is being established at the iThemba nuclear facility. This is being commissioned and will be operational in August. It will allow much smaller particles to be radiated and tracked with greater accuracy. The results from that facility will be of great value to flotation research in the Rio Tinto Centre.

The second exciting industrial development is a new method to determine the optimal volume of air to be added to a bank of flotation cells, and simultaneously its correct distribution to each cell. Previous plant-based studies have indicated that different total air volumes and different distributions affect the separation, but never have the two been successfully combined. The methodology for setting up the flotation cells correctly has been extensively tested and statistically verified. The methodology has been patented and implementation is ongoing.

The research projects are validating custom dynamic flotation models currently so that the effects of process disturbances can be evaluated. These models, combined with the PEPT facility and the air profiling methods are providing Rio Tinto with a suite of new technologies to enhance both existing operations and allow future operations to be designed and operated more efficiently.

Pumping froth
The froth flotation process previously required conventional pumps to be oversized or specially designed ‘froth’ pumps with large suction inlets to be used. The Shearpeller option on standard Goulds SRL-C pumps handles slurries with froth factors up to 2.5, reducing downtime and saving customers an average of 20 to 35% on capital investment by not having to purchase larger pumps.

“Because the ‘froth factor’ is an issue in many applications, a lot of mine managers consider it a special pump requirement to select and buy oversize pumps and accept this as a cost of doing business,” said ITT Goulds Pumps Slurry Pump Product Manager Haminder Ahluwalia. “When customers realise that our Shearpeller handles froth efficiently with a simple upgrade to the Goulds’ most proven SRL-C pumps, they are eager to try it. Once they see the effectiveness and benefits, many immediately order more.”

For example, Ahluwalia described one copper mine in South America that tried Shearpellers on two pumps in frothy applications, and rapidly converted 12 other pumps. “With a simple parts replacement, this customer saw an immediate improvement in process efficiency and uptime,” he said. “That is why they’re converting the pumps that handle frothy slurries to the Shearpeller.”

Shearpeller is a special open design impeller made out of durable urethane (or any elastomer) that can process the froth without changing pump size or other pump components. It can be retrofitted to all Model SRL-C pump sizes, and is made to be interchangeable with original standard closed impellers. It has radial vanes and wide-open water passages that allow the froth-laden slurry to pass easily, and the elimination of the front shroud further extends the pumping capacity. It provides a positive pumping action and develops higher heads than fully recessed impeller pumps, the company reports.

References