

Midas mission

As the discovery rate and grades fall, John Chadwick looks at ideas and technologies to get the most out of the world's gold deposits

The declining rate of new gold discoveries and grades across the global market during the last decade has accelerated over the last four years. Data and analysis from IntierraRMG reveals that the two-year period from 2003 to 2004 was the best in the study range, with over 400 Moz of new gold discovered. This includes Inferred, Indicated and Measured ounces with an average grade of 1.65 g/t. In contrast, 2005 and 2006 had the lowest number, with just over 150 Moz of new gold discovered - albeit with a similar grade. Discoveries then increased significantly during 2007 to 2008 with greater than 390 Moz. The average grade also increased significantly to 2.65 g/t; the highest in the 10 year period.

Over the next two years, slightly more than 250 Moz were discovered with a declining grade of 1.25 g/t. This deterioration continued through 2011 and 2012 as the amount of new gold ounces discovered dipped below 225 Moz with a reduced grade of 1.17 g/t.

In this ten-year study period, Africa led the way with new discoveries of 479 Moz of gold with an average grade of 2.8 g/t. Next was

North America, although with significantly less new ounces of 290 Moz, and with a much lower grade of 1.3 g/t.

Europe had the third most new discoveries with 240 Moz but with a higher grade than North America of 2.0 g/t. South America recorded 188 Moz, whilst Australasia saw 74 Moz of new discoveries with an average grade of 1.4 g/t.

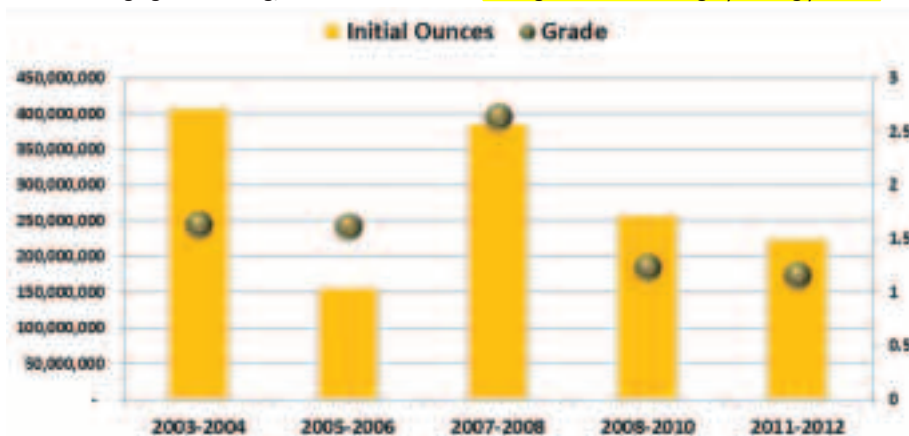
Glen Jones, Western Hemisphere Director for IntierraRMG concluded, "With global drilling activity waning, IntierraRMG forecasts that the next few years will continue the trend with fewer new gold discoveries."

Once a deposit has been discovered, Whittle Consulting has new software that it claims "increases mining NPV by 5% to 35%, or substantially more." It has announced a significant upgrade to its in-house 'Prober' software. After more than three years of development, prototyping and testing, the latest version 'Prober C' enables intricate modelling of multiple steps in the mining value chain, bringing technologies such as mine-to-mill, selective blasting, ore sorting, and complex comminution strategies into the strategic planning process.

MDM Engineering Group has signed an EPC contract for the execution of a 2.4 Mt/y gold plant for African Barrick Gold's (ABG) Bulyanhulu Process Plant Expansion project in Tanzania. ABG is the largest gold producer in Tanzania with a portfolio of four operating mines and is the owner and operator of Bulyanhulu Gold Mine. MDM successfully completed the bankable feasibility study in December 2011 followed by value engineering in March and April 2012. MDM is now executing the project which includes construction of a new 2.4 Mt/y CIL (carbon in leach) facility to process tailings reclaimed from the historical tailings concurrently with current flotation tailings

"New technologies in ore characterisation and extraction processes enable substantial economic and energy saving opportunities. Developments in these areas, led by our alliance partner JKTech, have clear operational benefits, and now we can harness their strategic significance by re-optimising the pits/phases or underground mines, mining methods, life-of-mine schedules, cut-off grade and stockpiling strategies, processing policies, product strategies, logistics and capital scaling decisions to apply these technologies in an integrated fashion. This will compound economic performance and capital efficiency to new levels," explains Whittle Consulting CEO – Gerald Whittle.

For the last decade, Whittle Consulting has helped mining companies substantially improve the cash flow profiles of projects and operations through an integrated approach of 'Enterprise Optimisation'. "Invariably," it claims, "the result is an increase in NPV of 5% to 35%, and sometimes substantially more. In many cases the net cash flow is doubled in the first three to five years, usually with little or no capital expenditure involved. As the trends continue towards lower grade and problematic orebodies,



The world's declining rate of new gold discoveries and grades Source: IntierraRMG

escalating costs, scarce capital and diminishing margins – the Enterprise Optimisation capability will help progressive mining companies lead the way in terms of competitiveness and sustainability.”

Enterprise Optimisation, often nick-named the ‘Money Mining’ approach, is underpinned by Prober software developed by Jeff Whittle, founder of the Whittle business and the developer of the original Whittle Pit Optimisation software that has become the industry standard for mine planning over the last three decades. Jeff, now 83 years old, explains “We have been using the previous version Prober B for over a decade. It allows for three steps in the value chain: mining, processing and production, although with some clever but convoluted modelling more could be accommodated. The new Prober C supports unlimited sequential or parallel procedures, making more detailed yet more intuitive modelling of complex mining and processing technologies possible. This is then simultaneously optimised to maximise the value of the business.”

Recovery challenges

The AMIRA P420 series of Gold Processing Technology projects has delivered industry focussed research outcomes for 25 years. The P420E extension project proposes new initiatives in the area of gold processing set within the context of the complex technical, human resource development and environmental challenges that face the gold industries of the second decade of the 21st century.

The 420E project attempts to address the challenges of the gold mining sector “with a dual approach to low grade ores; investigating physical methods for continuous early gangue rejection, with an emphasis on ore characterisation of the amenability for ores for continuous high mass gravity separation; and novel research into the production of environmentally benign gold lixiviants at site, with an emphasis on organic acids lixiviants through bacterial production. Both these approaches, one physical and the other chemical, seek to reduce 1) fine grinding of the total mined ore; 2) the associated capital and operating processing costs; and 3) environmental aspects of generating large amounts of tailings that have to be treated.”

The project further builds on the existing range of website models (www.goldknowledge.com).

Dr Will Goodall, Principal Consultant/Director of MinAssist notes that “efficient running and optimisation of a gold processing plant requires a deep understanding of the material to be processed, how it changes through the mining



Gold ore by QEMSCAN

cycle and how it behaves. Many operations perform routine metallurgical audits to monitor process behaviour but these rely on chemical assays or basic test work and provide little fundamental understanding of the mineralogy or fundamental associations of gold or gold-bearing grains. Adding a fundamental mineralogical understanding to routine metallurgical test work can provide great insights into the results and lead to more efficient programs that identify and address issues more quickly and at reduced overall cost.”

The last decade has seen rapid advancement in Scanning Electron Microscope (SEM) based automated mineralogy systems, such as QEMSCAN and the Mineral liberation Analyser (MLA). These systems provide a tool for rapid evaluation of mineral composition using standardised sample preparation procedures. Statistically representative populations of particles can be analysed to generate false colour mineral maps and determine important information such as mineral grain size, associations of minerals within particles and mineral locking/liberation characteristics. When applied to analysis of trace phases, such as gold and precious metals, automated mineralogy systems provide the capability to rapidly locate and identify grains with size greater than 1 micron and allow many more particles to be examined than would be possible by manual methods.

“The use of gold deportment characterisation as a tool for routine analysis in gold operations has always been hampered by difficulties in locating representative populations of gold particles,” Goodall continues. “Traditionally, gold deportment characterisation techniques relied on concentration of gold populations through methods such as heavy liquid separation, hydroseparation or superpanning. Optical methods to count gold grains would then be used to determine gold distribution. When invisible or sub-micron gold was present microprobe techniques such as TOF-SIMS might be employed.

“The improved speed and reliability of automated mineralogical systems means that greater numbers of particles may be examined

and the reliance on gold concentration by gravity methods can be reduced. This leads to greater efficiency in the gold deportment characterisation process and much more reliable determination of gold populations. In addition to location of gold grains, information about the ore mineralogy is gathered. This provides much more information about the process behaviour of an ore and means that gold deportment characterisation studies can become detailed process diagnostic tools.

“MinAssist is a leader in applying the information generated through gold deportment characterisation for process troubleshooting and optimisation. Operations can benefit greatly from using the advanced methodologies for gold deportment characterisation. Detailed evaluation of distinct ore types or feed blends can be used to guide process optimisation. Understanding the fundamental gold populations and mineral associations in feed material can be used to highlight areas of inefficiency within the process. Targeted evaluation of process streams can be used to troubleshoot specific problems, identifying the root cause and reducing the need to additional forensic metallurgical testwork. Finally, routine evaluation of tailings streams is used as a ‘health check’ for the process, identifying whether gold losses are occurring and what is causing them.”

Using these tools operations are progressively moving from a reactive approach to process troubleshooting to a diagnostic and manageable approach. This saves time and money, leading to a smoother operation and reduced gold losses.

Gravity still improving

Brenton Fitzgerald of Mineral Engineering Technical Services (METS) explains “gravity recovery of gold is an important method for the removal of free milling, coarse gold from a gold plant feed, resulting in a reduction of gold passing through the leach circuit.

“A gravity gold recovery in excess of 20-30% is generally considered sufficient to warrant the installation of a gravity gold circuit. Historically shaking tables and other low gravity methods have been used, however centrifuge concentrators such as the Falcon and Knelson

concentrators have brought greater efficiencies and recoveries and are now more common.

“The key motivation for the use of gold concentration is to avoid the occurrence of gold short circuiting, where the coarse gold is not leached prior to leaving the leaching circuit due to insufficient residence time.” The removal of coarse free milling gold from the leach feed reduces the short circuiting risk.

Furthermore a high gold grade to the leach circuit can result in higher gold loadings on the activated carbon. If so, this “can result in some gold in solution not being recovered by the carbon and being lost to tailings.

“Another issue that can arise is a higher number of elution cycles, resulting in higher operating costs. With the removal of the gravity recoverable gold the amount of gold passing through the carbon circuit is lower, reducing the risk of gold losses.”

Also, of course, gravity concentration has been a long-term environmentally friendly option for mineral separation. Over the past century its role in the recovery of minerals has declined with the development of other technologies for use in finer grind, higher capacity circuits. Recently, however, gravity concentration has been revisited and, in particular, as a complementary process to flotation. This, Gekko states, reflects, in part, the increasing costs of flotation chemicals.

“The development and application of a continuous gravity concentration unit, such as the InLine Pressure Jig (IPJ), is at the core of this innovative flowsheet. Contrary to other continuous gravity devices, such as spirals and traditional jigs, the IPJ has the capacity to recover mineral at relatively fine particle sizes - down to 100 micron. Batch gravity concentrators are used in free gold recovery and their broader mineral application is limited due to their very low mass yield.”

Gravity separation of minerals at coarser sizes, as soon as liberation occurs, can boast significant advantages for downstream flotation treatment stages due to decreased surface area, more efficient dewatering and the absence of chemical coatings that can interfere with further processing. The combination of gravity concentration and flotation of valuable minerals has been successfully incorporated into many mineral processing circuits.

With a combination of gravity concentrators and/or flotation a combined concentrate containing a significant proportion of the total mineral in the feed, can now easily be recovered. Gravity concentration, alone or in conjunction with flotation, can produce a concentrate that is able to be fed directly to more intensive processing units.

Newcrest Mining and Gekko have developed a

three-year research and development program targeting improvements in energy efficiency, reduced operating costs, increased recovery and faster project implementation at existing and future planned projects for Newcrest. The benefits of this program for Newcrest will be achieved through the application of concepts to optimise crushing and grinding utilising technologies and flowsheets that focus on gangue rejection, pre-concentration and liberation at coarse grind size.

Increasingly the alliance with Newcrest is shifting towards supporting brownfield operations. Important studies and work is being undertaken to support the metallurgy teams with a particular focus at Cadia, Telfer, Hidden Valley and Bonikro.

Part of this collaboration is to identify areas for improvement in the recovery of gravity amenable gold at the Cadia Valley Operations. These efforts focus on both primary gravity circuit and secondary treatment. Once enhancements are identified, they are then systematically worked through to resolution.

A further project being reviewed by the collaboration is the introduction of gangue rejection methods at the Telfer mine. The ore is described as having a “bricks and mortar” structure due to the valuable minerals being present within the more friable “mortar” component of the matrix. This gives the potential to separate waste from the valuable mineral by size, density and competency. This matrix has the potential to allow rejection of a significant portion of the ore for very little loss of valuable mineral using gravity methods.

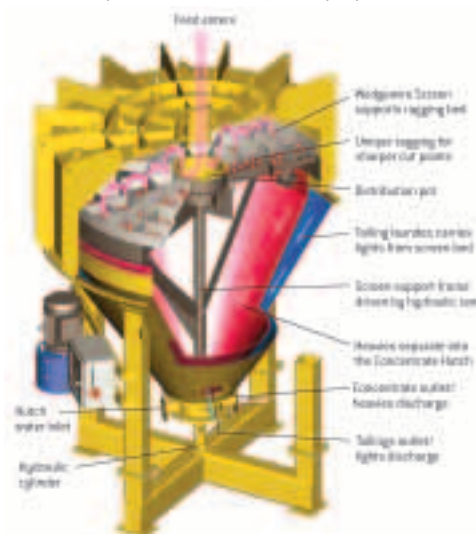
Long term strategic relationships between gold processing specialists such as Gekko and operators such as Newcrest Mining allow for high quality data-based site performance analysis. These studies can not be performed over short periods and require a consistent and critical view to achieve best outcomes. “Using a specialist collaborative resource such as Gekko is providing significant insight into opportunities for improved operation at a number of our sites” says Paul Griffin, Metallurgy Manager, Newcrest Mining.

A structure of this type allows Gekko to allocate senior metallurgical skills on a consistent and systematic basis providing for a long-term investment in quality human resources. Gekko’s senior metallurgy skills are supported by Newcrest-funded graduate metallurgists who provide well directed resources for the undertaking of data collection and plant operation. Gekko’s Newcrest dedicated team is supported on an ad hoc basis by other members of Gekko’s Technical Team. The benefits of such long-term collaboration agreements include the ability to convert

innovative ideas and concepts into more efficient processing.

Continuous gravity recovery

Gekko says the “virtuous cycle” has been conceived as a tool to assist in developing opportunities to reject gangue or recover mineral at optimum crush/grind size. The aim of this model is to maximise throughput and minimise power consumption. Ideally particles are rejected or recovered at liberation size. This process allows for a smaller high-grade concentrate stream to be created which can then be treated intensively for recovery. Mineral or gangue can be rejected based on size (screening), density (gravity separation), surface chemistry (flotation) or magnetic properties.



Gekko's InLine Pressure Jig. Used extensively in continuous gravity circuits installed world-wide recovering a range of minerals

To optimise the application of this cycle using continuous gravity in the separating step, Gekko developed the continuous gravity recovery (CGR) laboratory test work protocol. CGR protocols are an alternative to the standard batch gravity recovery (GRG) test work program offered by many.

Gekko explains: “GRG tests are typically used to determine batch centrifugal concentrator (BCC) recovery in a milling circuit; this produces low mass yield concentrates. BCC units are almost exclusively used in gold applications, whereas the CGR test and continuous concentrators such as the InLine Pressure Jig (IPJ) can be used for a variety of valuable minerals and at coarser size ranges and larger mass pulls.

Determining the recovery of minerals at their liberation size, grade recovery relationships, size recovery relationships, as well as recovery of gold and silver through intensive leach work, have formed part of Gekko’s critical areas of specialty.

CGR test work provides an improved and more accurate understanding of an ore's response to gravity separation devices by plotting the recovery against mass yield. Over the past decade Gekko's Technical Team, led by Technical Director Sandy Gray and Process Engineering Manager Tim Hughes, has researched and developed protocols to replicate the continuous gravity recovery of heavies and lights at their liberation size in mineral processing circuits. This has been an important development in assessing the performance opportunity of Gekko's flowsheet concepts and equipment choices in processing plants.

There are two CGR test work programs that are designed to simulate single pass or recirculating load circuit designs.

The single pass test protocol was developed to simulate the performances of the IPJ in crushing and grinding circuits. Test work of this type is conducted on size fractions from 600 µm to a top crush size of 12 mm. The CGR test uses dense media separation (Gekko's Viking Cone and/or cyclones) for size fractions above 1.2 mm and tabling for size fractions at less than 1.2 mm.

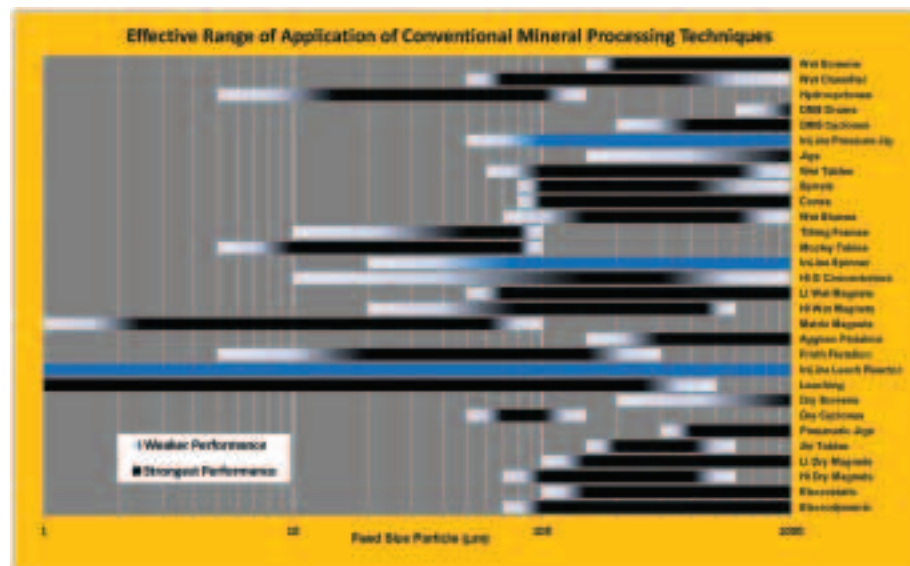
The heavies are collected at different mass yields and the recovery of valuable minerals is determined. From the resulting curve it is possible to determine the optimum mass yield; to recover or reject the heavies or lights.

Where the IPJ is to be installed in a crushing or grinding circulating load, the test is modified so that heavies are removed at the coarser size as it liberates. The lights from the test are then passed over the table again at finer crush or grind sizes to replicate the environment experienced in circulating loads.

Gekko says both these test work programs are becoming increasingly popular at its metallurgical laboratory as clients focus on strategies to reject gangue or pre-concentrate their target mineral in order to reduce capital, energy consumption and operating costs.

Gekko's IPJ and flash flotation are complementary processing methods which remove gold or other minerals from a comminution circuit. In many cases they have been used together to maximise gold recovery in size ranges at which they operate. The combination of flash flotation and continuous gravity recovery covers the full size range from 10 µm up to millimetre sizes.

Using both the IPJ and flotation cells, Gekko has developed a test protocol utilising a Vertical Shaft Impactor (VSI) crushing stage, followed by coarse gravity recovery, then finally the use of flotation to recover fine particles unrecovered by gravity. This technique is expected to recover the minerals between the 100 µm and 250 µm size range where there is a cross over between the



recovery capabilities of both gravity recovery and flotation. Gravity separation can be used to recover the mineral down to the 100 µm size range. Flash flotation can then recover the particles from 150 µm down to 10 µm. This is clearly demonstrated in the chart below, adapted from the original version developed by Napier-Munn and Wills 2006.

This style of flowsheet has been used in Gekko's Python plant and varies from conventional test protocols which recirculate the tails back through the crushing/grinding stages before it reports to the flotation cells. The Python was designed to treat ores that have high amenability to a combination of gravity and flotation. Its capability was based around coarse separations but is now being broadened to accept finer feeds and a wider range of mineral types.

Ish Grewal, President of Met-Solve Laboratories, in a recent paper¹, commented that "the use of fluidised batch concentrators which produce very high ratios of concentration, have become common place for recovering free gold within milling circuits. These units capitalise on the ability of hydrocyclones to act as rougher units and retain gravity recoverable gold (GRG) within the grinding circuit. This allows the low mass yield batch centrifugal gravity units to achieve both high concentration ratios and high recoveries. Considerable research and understanding of gold's behaviour within grinding circuits and recovery using fluidised batch centrifugal concentrators has advanced the knowledge required to predict and scale-up from laboratory results.

"The industry needs similar understanding and advancement of high mass yield centrifugal concentrators since they:

- Have the lowest capital and operating cost of any mineral beneficiation method
- Are environmentally friendly and do not

require addition of any chemicals and reagents making it easier to obtain permits

- Significantly widen the particle size range amenable to gravity concentration.

"Research is also required to understand the interaction of various gravity concentration technologies especially when flow sheets are configured with roughing, scavenging and cleaning stages as is done in froth flotation."

He recently told *IM* that "not a lot has changed significantly however we are working on improved methods for evaluating high mass yield gravity applications." The Met-Solve Analytical Table (MAT) is the primary tool being used for this research. It is designed to determine the response of minerals and other mixed particulate materials to gravity concentration. Applications are diverse, but include quantitative analysis and concentration of such elements as gold, PGMs, mineral sands, chromite, tin, tantalum, tungsten, uranium, iron ore, cobalt, and many other metals and minerals.

There are two decks with the MAT. The flat deck is used to determine the gravity concentration amenability of fine and ultrafine samples from 212 µm to below 37 µm. This is useful for applications such as optimising flotation or gravity concentrates, evaluating de-sliming of heavy mineral deposits, or scavenging fine gold and sulphides from leach of flotation tailings.

The V-deck is used for coarse samples with particle sizes above 200 µm and up to 2 mm. Typical applications include evaluation of free gold recovery in placer or alluvial deposits, cleaning of concentrates, or scavenging from tailings. In addition to the longitudinal oscillation found on the flat-deck, the V-deck employs a 'knock' mechanism, which pulls materials with a high specific gravity up the table along the 'V' groove.

"We hope to assemble and establish a



Extrac-Tec's HPC-30 is suitable for alluvial/placer mining, tailings reprocessing and as a pre-concentrator to upgrade material after crushing. Here it is seen in operation with belt feeder/conveyor with hopper, which ensures a steady feed rate and efficient operations

simpler and improved methodology and also develop correlational data with full scale operations. This requires a fair bit of co-ordination with mine sites that have such equipment (i.e. Falcon Continuous etc.), Grewal explains. He hopes to provide more information in the near future.

Sepro Mineral Systems Corp specialises in

the design and supply of equipment, systems and plants for gravity concentration, scrubbing, washing, screening, agglomeration, dense media separation, crushing and milling. Last year it was awarded a contract by Hemco Nicaragua, Nicaragua's second largest gold producer, to supply a milling and gravity recovery circuit for its operation in the municipality of Bonanza in northeast Nicaragua.

The order includes a Falcon SB-5200B gravity gold concentrator, a 2.1 x 4.9 m Sepro-Sizetec single deck vibrating screen, a Sepro 2.1 x 6.0 m tyre driven, 330 kW drive, grate discharge primary grinding mill with a feed capacity of 50

t/h and associated pumps, cyclones, control room, MCC and structural steel.

This is a fully engineered package which required the client to provide only the concrete slabs, the feed conveyor, an appropriate building, and integration with the existing process. Sepro has been involved with the client from conceptual design through to detailed engineering and will provide support personnel through the commissioning process which was expected in early 2013.

Hemco's General Manager, Alvaro Peralta, commented that "Sepro's ability to supply all the major equipment as a single engineered package is a tremendous benefit to a relatively small operator such as ourselves with limited in-house engineering resources".

FLSmith Knelson says it has recently made "several significant breakthroughs" in concentrate cone technology including the application-based CONE*Logic concentrate cone selection system. CONE*Logic assesses the specific metallurgical characteristics of the ore and key site conditions to produce a concentrate cone that it best matched to the application. "We began development of the CONE*Logic system in 2003 and over the past nine years we have worked closely with many of our clients to devise a method of cone selection that looks at five fundamental factors of operation including mineralogical test data, target particle size and

BILFINGER



*FLSmidth 5 t fuel oil
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shape, circuit water constraints, water quality and ore abrasivity,” said Doug Corsan; FLSmidth Knelson Global Product Director.

In pursuit of creating the industry’s first fully -customised concentrate cone solution, FLSmidth Knelson has developed an innovative new cone manufacturing platform, the Matrix Cone. During extensive field testing over the past three years, the group says that the Matrix Cone has provided superior metallurgical recovery, enhanced fine particle recovery and has, on average, extended cone cleaning intervals by a factor of five times. “One of the main advantages of this new Matrix Cone technology is the ability to retro-fit these units into existing machines currently in operation around the world,” added Corsan.

Summit Valley gold

FLSmidth is also receiving increasing enquiries from South Africa for its comprehensive and innovative range of precious metal extraction solutions. Its offering in this area was significantly enhanced in 2009, when the company acquired the business of Utah-based Summit Valley, specialists in the design and fabrication of modular plants and equipment for the extraction of gold and silver. This technology includes the industry’s highest capacity EW cell used in precious metals recovery.

“Our part of the FLSmidth group specialises in individual components, but we also have worldclass capabilities in terms of combining these components into customer-specific integrated gold room and plant packages,” Summit Valley equipment specialist, Cameron Barton explained during a recent visit to South Africa. “We lead the world in gold electrolysis and mercury vacuum distillation and are among the top global companies offering indirect fired rotary kilns and packaged carbon strip systems.”

FLSmidth offers a patented new EW cell basketless cathode designed to decrease operator service time and decrease gold inventory in the cells, while providing the continued high cell efficiencies characteristic of Summit Valley cells. Gold sludge servicing is performed in the cell by washing precious metal sludge from the cathodes with a pressure sprayer and sludge is pumped from the cell bottom via the sludge outlet flange to a sludge filter. Since the cathodes are serviced in the cell, less cathode handling is required during servicing and this minimises operator exposure to toxic metals when metals such as mercury, arsenic and cadmium are present in EW solutions. The new electrodes eliminate the need for cathode baskets.

FLSmidth’s patented innovative split Zadra carbon elution process harnesses variable valve timing and an additional strip vessel to boost production levels by as much as 30% on existing plants and reduce the cost of a new plant by the same percentage.



Sandra K part of Colombia Gold's Segovia operations. Historically, grades at Segovia, one of the top ten producing mines by grade in the world, have averaged in the range of 12 to 14 g/t. However, in the third and fourth quarters of 2012, grades averaged approximately 9 g/t due to the temporary depletion of higher grade zones in the levels currently being mined at Providencia and El Silencio and, to a lesser extent, the processing of some lower grade stockpiles. Through mid-March 2013, head grades continue to average approximately 9 g/t as mine development activities progress, it is expected that head grades will begin to show some improvement in the second quarter, increasing to an average of about 10 g/t in the second half of 2013

The company also designs and manufactures indirect heated carbon regeneration kilns and calciners from 0.5 t/d and larger. These kilns and calciners can be gas, oil, or electric fuelled, and are skid mounted, pre-wired and pre-piped.

FLS KNELSON

The patented bellows kiln seal has proved effective in eliminating air ingress and process gas egress and can be retrofitted to kilns from other manufacturers. FLSmidth says it “holds the world record for the lowest emissions on a carbon plant.”

The company's Merrill Crowe plant capacities range from skid mounted 3.4 m³/h modular

plants to full-size 2,100 m³/h. The range of supply for plants includes clarification filters, de-aeration towers, vacuum pumps, zinc dust feeders, lead nitrate feeders and zinc cones, precipitate filter feed pumps, filter pre-coat and body feed systems, as well as precipitate filters used by refinery and smelting facilities to produce gold bullion.

These plants incorporate a proprietary zinc dust/lead nitrate feeder and mixing cone system. The company offers individual plant components and partial or complete plant equipment packages, together with total plant design.

Refractory gold treatment

In the Xstrata Process Support (XPS) Winter Bulletin, Arthur Barnes and Rajan Pandher examined the challenges refractory ores pose.

“The first challenge is determining the reason for the poor recovery by direct cyanidation, which can be caused by one or more contributors. The oldest and best understood is gold locked in sulphide, and most frequently pyrite. The second contributor to refractory behaviour is arsenic in the form of arsenopyrite or antimony in the form of stibnite, which causes low recovery even at low concentrations. The presence of carbon in the ore is also a frequent cause of poor recovery, not because it makes the gold unresponsive to cyanidation but because it readily absorbs gold in solution and leads to “preg-robbing”. When

these refractory contributors present themselves in combination, obtaining satisfactory gold recoveries can prove a real headache. Fortunately there are cures.

“A key to success is a proper diagnosis of the cause. First, XPS executes a very systematic sequential leaching technique known as a ‘Diagnostic Leach’ which clearly identifies where the gold is in the ore by systematically destroying key minerals, followed by cyanide leaching of the residue until all of the gold has been recovered. In addition, quantitative mineralogy to establish modal abundance of mineral species and sometimes even identify gold deportment is performed. With the new Qemscan FEG a higher number of gold particles can be found, thus improving deportment statistics.

“Once the cause has been identified, there are a number of alternatives for treating the ore. The gold can be made more amenable to cyanidation by ultra-fine milling, followed by a hot atmospheric leach – the Albion Process. A second solution is complete pressure oxidation (POX), which is effective for all conditions except carbon. The third method is roasting – either the well-established simple dead roasting to convert pyrite to hematite while oxidising any carbon present, or two-stage roasting to firstly remove arsenic by partial roasting followed by dead roasting.

“Since XPS has expertise in fine grinding, pressure hydrometallurgy and pyrometallurgy, these skills have been bundled into a ‘one-stop-shop’.” XPS can perform the diagnostic leach for clients to determine the cause of a particular refractory behaviour with quantitative mineralogy using Qemscan. This is followed by an options review and recommendation as to the best alternatives to suits the client's needs followed by appropriate testing in XPS's fully-equipped laboratories.

Fluid bed roasting can be completed in either 51 mm or 102 mm diameter continuous fluid bed roasters, each equipped with a cyclone, afterburner for combustion of arsenic and/or sulphur vapour, condenser, and scrubber. Typically, 1-5 kg of feed is sufficient for preliminary comparative evaluation using the smaller roaster, while 20-50 kg can be sufficient for longer duration testing in the 102-mm roaster. Both roasters are fully instrumented with thermocouples, pressure measurements, and gas analysers to ensure reliable data capture.

Pressure oxidation tests are carried out in a stirred 2-litre Parr bench-scale autoclave, which typically handles charges of approximately 1 kg. The autoclave is constructed of titanium and can be operated with an optional glass liner. It is fully automated to measure and control the temperature and pressure within the autoclave



and the gas flow into the autoclave. Process measurements are captured continuously to a PI server.

Albion Process setup at XPS comprises an M4 IsaMill to produce the ultrafinely ground ore or concentrate, followed by leaching in an agitated tank at atmospheric pressure. Approximately 15 kg of feed is required for determining the signature plot in the IsaMill, but a single Albion leach test can be carried out on 1 kg of ground material.

Cyanidation: having removed the deleterious elements by one of the above processes, the residue from the pre-treatment stage a cyanide solution is used to leach out and recover the gold. This is accomplished using standard bottle roll tests, which can be run for up to 72 hours. The key data such as slurry pH, dissolved oxygen content and cyanide concentrations are recorded and/or maintained throughout the experiment. Samples are taken at the same time, so that leach kinetics throughout the experiment can be subsequently determined. Multiple bottle roll tests can be run concurrently. Following the cyanidation tests, the samples are assayed to determine the gold in solution and in the residue, from which the gold recovery can be calculated.

REDPATH

Leaching

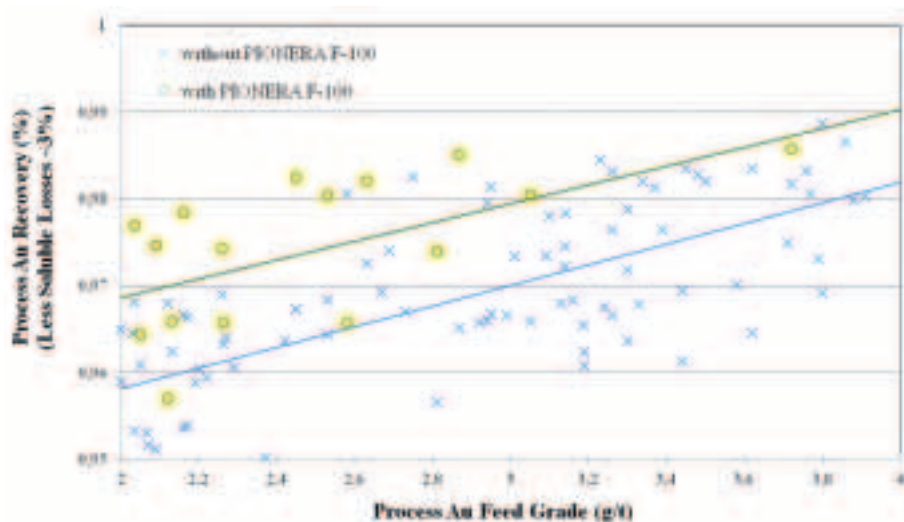
In their paper *Effect of ore particle size on gold dissolution in a cyanide solution* presented at the SME Annual Meeting in Denver this February, J. Egan and C. Bazin propose an experimental procedure to estimate the gold dissolution from the ore within different size intervals using leaching tests carried out with a bulk ore rather than mono-sized ore samples. They report that the “procedure significantly reduces the experimental test work and also eliminates the uncertainties concerning possible interactions between particles of different sizes during leaching. The application of data reconciliation helps in filtering out some of the inherent measurement errors associated to the gold assays.

“Results of the analysis show that gold dissolution increases with decreasing ore particle size. The production history of the particles within a size interval may have an effect on the gold dissolution. The effect remains however to be confirmed by other leaching tests. The estimated gold dissolution model parameters can be used to predict the gold recovery following various intensities of grinding. Work is continuing with the objective of developing an integrated gold ore grinding and leaching simulator.”

Also at the SME, in the paper *Estimating the residual inventory of a large gold heap leach pad* J. Winterton of Cripple Creek & Victor Gold Mining Co notes that this estimation “is desirable for many reasons. Several methods have been tried with limited success. Drilling data from the Valley Leach Facility (VLF) at AngloGold Ashanti's Cripple Creek and Victor mine has been used to develop a robust inventory estimation technique.” The technique was presented along with discussion of the particular inventory components and evaluation methodologies.

The conclusions were that “estimating the inventory in an active heap leach operation from drilling samples is a perilous undertaking. The integrity of the estimates depends heavily on how the samples are obtained how the resultant grade estimates are developed and applied. The approach will never supplant strategies based on dedicated sampling and metallurgical testing protocols in terms of reliability or credibility. The estimation methods described were developed using multiple drilling data sets obtained on the VLF over the last decade. The methods substantially improve the ability to gauge the inventory in active heaps and can be extended to any similar unconsolidated structure.”

From the same mine, S. Leichter and D. Larson presented *Geometallurgy for a two recovery process operation – Cripple Creek and Victor gold mine, Colorado*. Here, surface operations are continuing along with an expansion for an on-site mill to take place in the next couple of years. The pit is currently progressing downward from an oxidised zone



Plant-scale PIONERA F-100 trial data from a leach circuit, July 2011

into a transitional, more sulphide/ telluride-rich zone. Gold mineralisation includes native gold, electrum, and tellurides. Cyanide heap leaching is the recovery process for the oxidized ore with the sulphide/telluride-rich ore to be processed at the new mill. The authors state that “ore characterisation prior to mining is vital when there are two possible recovery processes. This characterisation is dependent on geometallurgy. To identify the causes of the variability, multiple parameters are analysed and assayed. These parameters are measured by a variety of analytical test work. The analytical work provides measurements for the desired parameters. Geometallurgical models are developed for the parameters per recovery process, so estimations can be inserted into the resource model to optimise operations and recoveries.”

They conclude that “parameters such as hardness, gravity, and flotability help in constructing robust geometallurgical models. These models are then inserted into the resource block model to help plan and forecast production.”

PIONERA says the recovery of gold, copper, nickel, zinc and other metals can be increased through the use of its BioPolymer. “By modifying the rheology of the concentrate, PIONERA improves the viscosity and kinetics of the system resulting in increased production.” Other reported advantages include:

- Environmental advantages over synthetic reagents (including minimum regulations for storage and handling and minimum harm to environment and toxicity level. Additionally they are exempted from REACH registration)
- By inhibiting scale formation, positive heat transfer is better maintained
- Catalytic properties may deliver faster reaction kinetics for sulphide oxidation

- Does not interfere with the SX/EW process.
- High salt tolerance.

The company says it has devoted considerable research and development efforts towards identifying the most suitable biopolymers for use in pressure leaching applications. Evaluations, both internally and externally with consultants and customers, have demonstrated good performance in various ores. “These efforts have led to the development of superior natural polymers that are optimised for performance under various metal recovery conditions.”

PIONERA says various trials have shown the potential of its BioPolymer to increase metal recovery in leaching circuits. This is especially relevant in CIL/CIP circuits, and benefits are also observed in the Merrill Crowe process. “A recent plant scale trial at gold mine in Canada showed a recovery increase in gold of about 1% over a range of different feed head grades.

Carbon-in-pulp

In the SME paper *Antiscalants for gold processing applications*, W. H. Dickinson of Kemira reported on the evaluation of seven antiscalants spanning a range of chemistries “for control of calcium carbonate (CaCO_3) formation in gold processing applications. Three preferred chemistries were identified which provided up to 100% inhibition in static jar tests when applied at 30 ppm dosage. The three

products were further evaluated using a model carbon extraction circuit developed for this application. The test circuit enabled direct measurement of calcium carbonate formed on the carbon from a supersaturated solution under dynamic conditions. The antiscalants lowered CaCO_3 build-up on the columns by 15–26% compared to untreated controls. Impact of the antiscalants on the rate and extent of gold loading onto a carbon adsorbent was evaluated in laboratory CIP studies. The antiscalants generated a 25 - 35% increase in gold loading at gold extraction efficiencies up to 65%. On-site testing at a gold processing facility demonstrated that 10 ppm of the preferred antiscalant was able to fully suppress CaCO_3 formation in thickener overflow water.

“All the antiscalants were able to significantly reduce CaCO_3 formation and CaCO_3 control improved with increasing product dosage over the range 5–30 ppm. A sulphonated polycarboxylate chemistry afforded 100% inhibition when applied at 30 ppm under static test conditions.

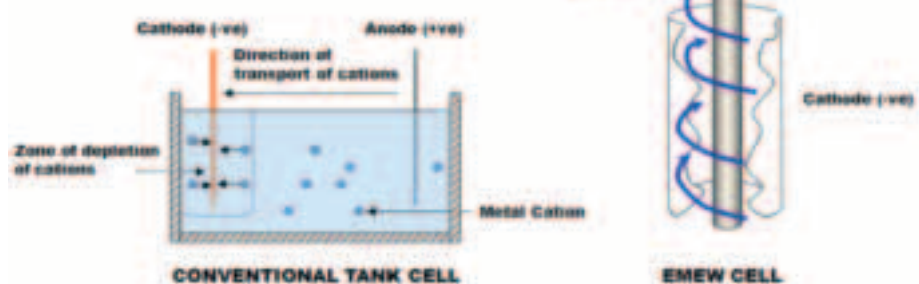
“Polyacrylate chemistry was able to achieve greater than 95% inhibition at 15 ppm but scaling was aggravated when the antiscalant was underfed.”

Electrowinning

At the February SME Annual Meeting in Denver, Michael Mooiman, Franklin Pierce University, NH & Argo Advisors International and Ian Ewart and Jeremy Robinson of Electrometals presented *Electrowinning precious metals from cyanide solution using EMEW technology*. The paper reviews the recovery of gold and silver from cyanide bearing solutions using EW technology designed by Electrometals Technologies. They say “the technology can be considered as a complete or partial replacement for Merrill Crowe technology and offers several advantages in the processing of high grade solutions.”

They conclude that the cylindrical EMEW EW cell, designed, developed and implemented by Electrometals, “has been successfully implemented for the electrolytic recovery of a variety of base and precious metals. Notably the electrowinning of silver and gold from cyanide solution has been successfully implemented on

Conventional versus EMEW cell design





IAMGOLD's processing plant at the Westwood mine in Quebec started up in March. Initially processing stockpiled ore from the adjacent Mouska mine, in 2013 the plant is expected to produce approximately 140,000 oz of gold, 60,000 oz from the 30-year old Mouska mine and approximately 80,000 oz from the new Westwood mine. The first gold pour was expected at the end of March. President and CEO, Steve Letwin, said: "The same in-house engineering team, who constructed Essakane, has now completed the development of the Westwood mine and refurbishment of the old Doyon plant to process Westwood ore"

a plant scale and as a result millions of troy ounces of silver (along with some gold) are recovered every year using EMEW technology.

"The EMEW operation results in substantial reductions in operating costs, it produces a cleaner precious metals doré, and it permits automatic harvesting of the silver product.

"In some cases, the EMEW process can be viewed a replacement for the Merrill Crowe zinc cementation process but plant experience has demonstrated that some circumstances might require both the implementation of the electrowinning and Merrill Crowe process to operate in a complimentary manner. The bulk of the precious metals recovery is done electrolytically to produce a low cost, higher precious metals content doré and the Merrill Crowe process is used to recover the residual amounts of precious metals in solution and to act, when necessary, as a second process to increase overall precious metals throughput.

"Even though implementation has been successful there remain many opportunities for process improvement and optimisation. These include voltage monitoring of individual cells, increases in current densities and the determination of first order circuit constants that can be used to monitor the performance of an EMEW circuit.

In their paper, *Ion exchange as a primary production technique in hydrometallurgy*, presented to the SME Annual Meeting in Denver this February, D. R. Shaw, S. Arnold and J. D. Illescas of Fenix Hydromet, noted that "increasing pressures on the environmental acceptability of cyanide leaching pushes gold

mining companies to look at alternative, more environmentally friendly leaching reagents. The development of thiosulphate leaching and recovery using strong base anion exchange resins in an RIL [resin-in-leach] process has

been tested at Barrick Gold's Homestake project in Nevada, USA and is progressing to full scale plant conversion. This change in approach has the potential to lead to a change in industry approach with an increased usage of ion exchange over carbon in the western world.

"The use of carbon as a sorbent for gold recovery has predominated over the use of resins especially in western countries. Resins exhibit a number of characteristics which offer advantages over carbon;

- Resins can have their chemical functionality modified to achieve optimal selectivity
- Resins are less susceptible to poisoning by organics or calcium
- Resins have faster kinetics and superior loading capacities

- Resin elution can be achieved at ambient temperature and require no thermal regeneration
- Resins can be efficiently operated at high percentages in RIP circuits, as high as 20-25% compared with more typical carbon concentrations of 3-5%
- Resins also offer the potential for the recovery of cyanide and other metal cyanide complexes.

"These advantages of resins offer the potential for improved recoveries, smaller plant footprints, reduced capital costs and enhanced environmental outcomes. Resins do nonetheless have some disadvantages, the main one being that resins have a maximum physical bead size above which the mechanical integrity of the bead is compromised. Resin beads are therefore typically smaller than carbon which requires smaller aperture screens in the RIP circuit, conversion from carbon to resins requires modifications to existing plant equipment. The cost of resin is significantly higher than carbon, however resins are more mechanically robust with no angular corners to be lost and as such last longer." **IM**

References

1. Grewal, I, *Advances in centrifugal gravity concentration – beyond low mass yield*, 41st Annual Meeting of the Canadian Mineral Processors, January 2009, Ottawa.

TOMRA