

Golden keys

John Chadwick takes his annual look at the latest gold exploration, analysis and recovery technologies

Nick Holland, CEO Gold Fields, gave a presentation entitled *The Gold Mine of the Future* at Mines and Money in London last year. In it he pointed out that partnering with OEMs will become increasingly critical in the future to harness best-of-class technologies. Gold Fields as well as having relationships with the traditional equipment and technology suppliers has also established relationships with Business Science Corp, Amazon, NewTrax, FTP Solutions, NextGenOpX, IoT.Nxt, Trimble and others to implement technological advances such as rugged sensors and 3D vision and mapping software; used in areas such as mapping and inspection; operator safety in the form of advanced obstacle detection and warning; stockpile monitoring; geological monitoring; enhanced tele-remote operation; and fleet tracking with real time monitoring underground.

The company also gave some case studies of where it has implemented a number of other technology applications at its operations. Aerial and surface drones at its Australian and Ghanaian mines have improved its exploration efforts and aerial mapping. Gold Fields uses different drone technologies to capture high resolution aero-magnetic data, particularly over salt lakes (St Ives and Granny Smith), take aerial photographs of tenements (Australian mines), for early stage geological mapping of tenements (Australian mines), and measuring stockpile volumes in a short space of time (Tarkwa). This is “to improve the way we capture and process data for geology, geo-technical, material movements and reconciliation. Aerial photography of our tenements is now completed in hours – not days or weeks.” Equipment includes Trimble aerial drones. For the salt lake drones a TRAMPE (Tethered Rotary Airborne Platform) and SKIMPI (Sled Kart Instrument for Magnetic Prospectivity Imaging) are used, with scoping drones at Tarkwa.

TRAMPE is a towed bird configuration flying at a MeanTerrain Clearance (MTC) of 5 m for the magnetometer, sampled at 25Hz at an average

speed of 25 km/h along 10 m spaced lines. Flight control is fully autonomous with pilot intervention only during takeoff and landing. Broadcast differential GPS information is collected during acquisition. Final data processing utilises a post-processed DGPS workflow, along with standard, and specialised inhouse potential-fields processing workflows.

Trimble offers precise positioning solutions for drone/UAV use that provide continuous mobile positioning and high-accuracy orientation for applications such as navigation, guidance and control as well as mapping and survey from UAVs. Trimble integrates a wide range of positioning technologies including GPS and inertial technologies with wireless communications and industry specific application software to provide robust solutions.

South Deep has replaced borehole cameras and other observation methods used to determine the effectiveness of preconditioning blasts with ground penetrating radar in the form of a Reutech Sub-Surface Profiler. This means fast and accurate identification of rock structures, including blast induced fracturing. Data can be seen in real-time, reducing the turn-around time for operators to continue mining. A reduction in face bursts has been seen since implementation; and this is expected to continue.

On the processing side, Gold Fields is using Steinert ore sorting equipment at Agnew. Agnew is working with Steinert to improve sorting of underground stope material. This will sort material based on quartz content, helping to remove diluting material with no quartz and retain lower tonnage, and maintain a higher grade mill feed. This has reduced processing costs by not processing diluting material; increased available capacity in the CIL plant; reduced underground cutoff grades through reduced processing costs; and opened up new underground stopping areas due to reduced cutoff grades.

Ore sorting has had an important impact on gold recoveries around the world in recent

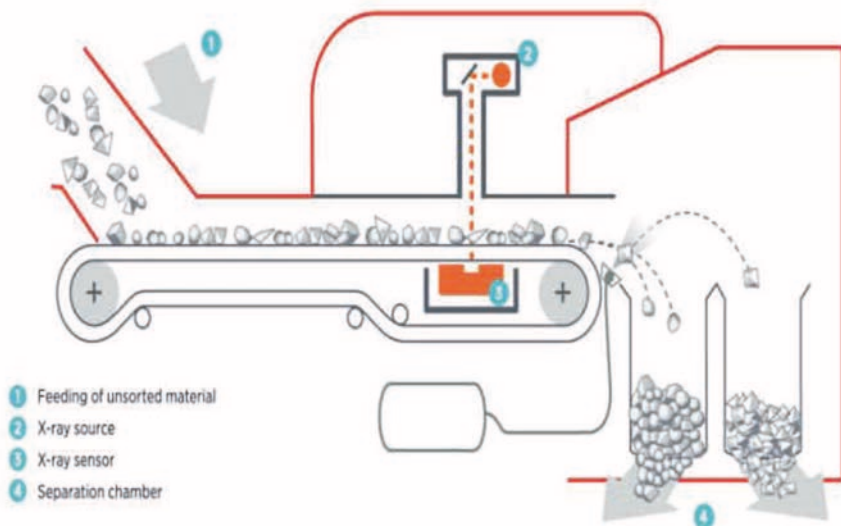
PJSC Polyus's (the largest gold producer in Russia) Natalka mill achieved 80% of its design throughput capacity of 10 Mt/y earlier this year. By end May, Natalka had produced more than 40,000 oz of gold since the beginning of the year. Following the ramp-up, the mill will be producing some 450,000 oz/y

times. For example, last year EganStreet Resources identified an opportunity to optimise and significantly enhance the financial outcomes of its 100%-owned Rothsay gold project, located 300 km northeast of Perth in Western Australia, through the application of state-of-the-art ore sorting technology. The company received highly favourable initial results from ore sorting test work completed on a low-grade stockpile from the historical underground mine at Rothsay, with the key outcome that the use of a Steinert Multi-Sensor Ore Sorter provides an opportunity to increase underground mine production (being fed to a similar-sized process plant), reduce the impact of dilution from the main ore-hosting structure at Rothsay, reduce life-of-mine processing costs and substantially enhance project economics.

“Ore sorting technology is increasingly being adopted across the gold mining industry in Western Australia, with highly encouraging results. Representative samples collected from the low-grade stockpile located adjacent to the portal of the historical Rothsay gold mine returned an average stockpile grade of 2.5 g/t Au. This compares favourably with previous sampling of this stockpile in 2013, which returned results ranging from 2.7-4.1 g/t Au. More importantly, the results demonstrated that the Steinert Multi-Sensor Ore Sorter was able to successfully reject the barren ultramafic material located in the hanging wall of Woodley's Shear.” The PFS production target of 936,000 t grading 7.0 g/t Au consisted of 43% planned mine dilution (or 400,000 t of the total 936,000 t production target). The ultramafic component of this planned mine dilution represents 59% of the total dilution (or 236,000 t of the total 936,000 t production target).

“The ability to substantially reduce, or potentially virtually eliminate, this hanging wall dilution may allow an increase in mine production, which will have a corresponding positive impact on underground mine productivity, operating costs and economics. Further test work will be conducted to confirm these encouraging initial results. The potential of the multi-sensor ore sorter is that underground mine production rates can be increased by 34% without any increase in process plant size.”

At the time, EganStreet Managing Director Marc Ducler said the application of ore-sorting technology represented a potential game-



Ore sorting mechanism, belt-type XRT sorting machine (TOMRA)

changer for the Rothsay project. “These results, albeit early stage, have shown the ease with which the mine production grade can be selectively upgraded prior to processing. This provides us with significantly greater flexibility in how we develop the mine as well as the ability to optimise our mining and production rates. Given that Rothsay is a relatively narrow but high-grade mine, the ability to significantly reduce the substantial amount of planned mine dilution already built into our mine design and financial model through the use of a Steinert Multi-Sensor Ore Sorter is an exciting and very positive development. We are confident that follow-up testing to be undertaken this quarter will confirm a pathway to significantly enhance and optimise our development plan, adding considerable value to the project and representing an important new input to the definitive feasibility study to be finalised next quarter.”

He added: “Technological advances such as this are increasingly being adopted across the gold mining industry in Western Australia and are a great example of how innovation can contribute to improved productivity and enhanced financial outcomes for new mine developments such as Rothsay.”

The most recent results released in May 2018, demonstrated a successful separation of heavy waste rocks from lighter quartz rocks could be achieved using X-ray Transmission (XRT). The technology works by differentiating the atomic density of the waste rocks (ultramafic and mafic – grey rocks) and the gold bearing quartz (white rocks).

In their paper, *Sensor-based ore sorting to maximise profit in a gold operation*, presented at MetPlant 2017, Perth, September 2017, Bjorn Nielsen, Jorn Rohleder and Harri Lehto of Outotec, and TOMRA Sorting Business

Development Manager, Christopher Robben, conclude that “sensor-based ore particle sorting can be used to significantly upgrade ROM ores prior to feeding to the concentrator. Numerous benefits can be achieved including lower plant capital costs, lower plant operating cost, lower unit mining costs and potential extension to the mine life. Benefits in the plant include a significant reduction in energy, water and reagent consumption.

“A sample from a potential gold project in the Northern Hemisphere was tested in industrial scale sensor-based ore particle sorters with excellent results. Recoveries in the range of 98-99.5% and waste rejection in the order of 30-60% of plant feed were achieved. The financial impact on the project was significant, with sorting improving plant NPV by approximately 16% based on current assumptions, including an 8% discount rate. The project was also more robust with the addition of particle sorting as demonstrated by the reduced NPV sensitivity to

gold price downside with sensor-based ore particle sorting.”

In *Evaluating the applicability of gold pre-concentration by sensor-based sorting of quartz ore*, Rohleder et al report on investigating the feasibility of sorting for four gold projects in Northern Europe with similar mineralogy. This included geometallurgical evaluation, amenability testing, small scale ‘mini-bulk’ factory testing in full scale sensor-based sorting.

A “clear sortability” was proven for all projects. The Figure 1 data set follows a clear trend. The upgrade ratio increases measurably when recovery decreases. Figure 2 shows the clear correlation between waste removal and recovery.

“When more mass is removed, recovery decreases. Developing a working sorting circuit concept and choosing the correct sorter setting is a trade-off between retained mass and recovery based on these two findings. Adding a scavenger step for applicable deposits follows the same trend. When treating the laser waste fraction with XRT sorters more mass will be retained decreasing head grade going to the concentrator and increasing recovery. This has been shown clearly in all four tests.

“All test samples come from four different locations and performance indicators follow clear trends. This is a strong indicator for the applicability of laser sorting for orogenic gold deposits with quartz vein association.

“The mini-bulk test results prove the applicability of sorting for all projects. The final decision of incorporating sorting is based on the impact the results have on the mine economics of each project. Further testing is not required after the mini-bulk testing phase due to the industrial sized equipment used.”

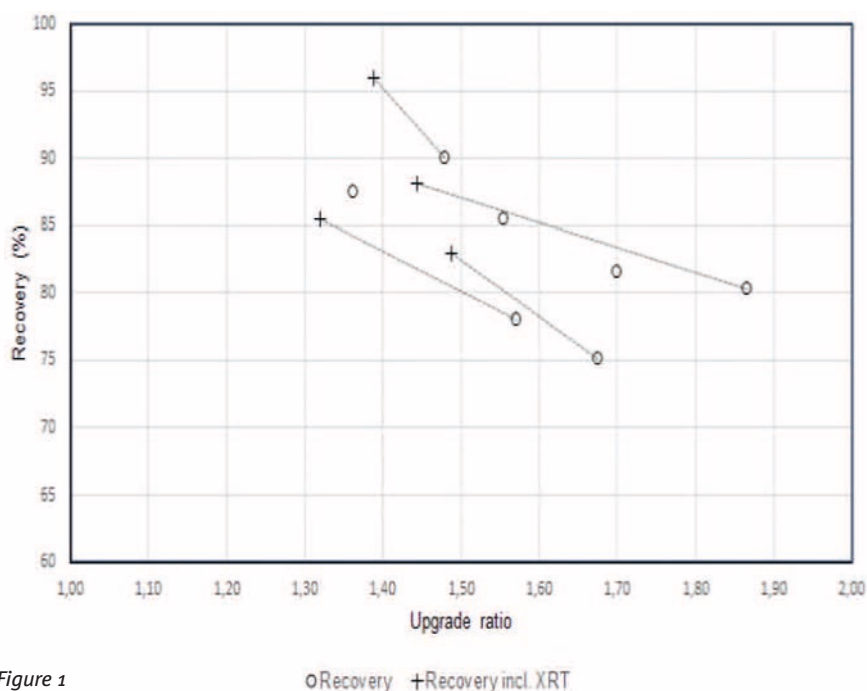


Figure 1

○ Recovery + Recovery incl. XRT

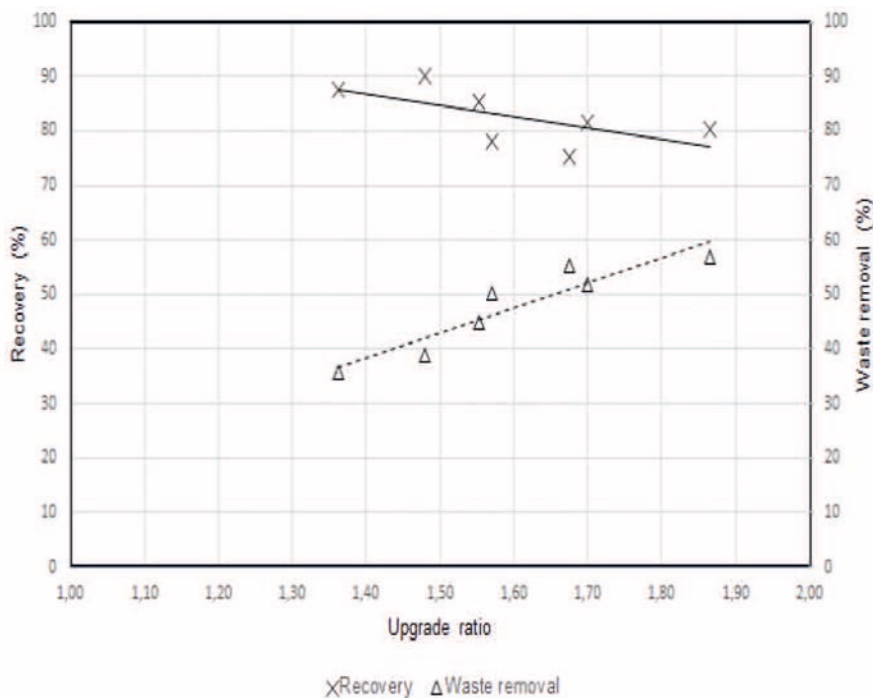


Figure 2

AngloGold Ashanti has applied a new and extensive geological approach based on the correlation of geological information and information collected by different sensor-based ore sorting sensors. Experience of this in several mines proved how critical/important the geological approach is to investigate ore sorting

feasibility in complex ores, particularly gold ores. This is because gold is not detected itself, but correlations between detectable characteristics and gold content need to be present, well understood and reliable to understand the gold deportation to product and waste fractions.

At the 13th International Mineral Processing Congress (2017) J. A. Dumont, and M.G. Lemos of AngloGold Ashanti, Brazil and Robben presented

Sensor-based ore sorting methodology investigation applied to gold ores.

They reported that “the understanding of the relationship between different texture types, grain size and the gold source associations such as quartz or sulphide, and their responses to different types of sensors are the key to project success. The methodology consists to identify the main textures, clustering by the rock description, understanding the response behaviour of each type to the sensors, chemical and mineralogical analysis by textures to identify the gold sources, the machine configuration with the information obtained in the last step and pilot test. In order to achieve the objectives, research has been developed to define the types of calibration and sensors for the different types of gold ore produced by AngloGold Ashanti.

“The methodology showed potential to achieve excellent gold recovery (higher than 95%) in/with a mass pull of 40%, using one or two steps of pre-concentration. This information confirms the importance of a geological approach when investigating ore sorting technology for complex gold ores. In addition, the information acquired supports the stability of other processes such as metallurgy and mine geology.”

Analysing gold levels

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materials is essential for exploration, resource definition, mine planning and process control. Gold has traditionally been analysed using chemical methods, notably fire assay, which are labour-intensive, time-consuming and involve the use of toxic or hazardous reagents.

Chrysos Corp is commercialising an alternative approach, PhotonAssay, which was originally developed by CSIRO. Based on the principles of photon activation analysis, the method uses a high-power, high-energy X-ray source to excite nuclear changes in any gold atoms present in a sample, and then measures a characteristic signature emitted by these atoms. The process is non-destructive, rapid, highly specific and capable of providing a true-bulk analysis of samples weighing 500 g or more.

Samples are packed into barcoded, screw-top plastic jars in which they remain throughout the analysis. Once loaded onto an input conveyor, the analysis process is fully automatic and requires no human intervention. Samples are returned unchanged, and can be safely disposed of or retained for future testing as required.

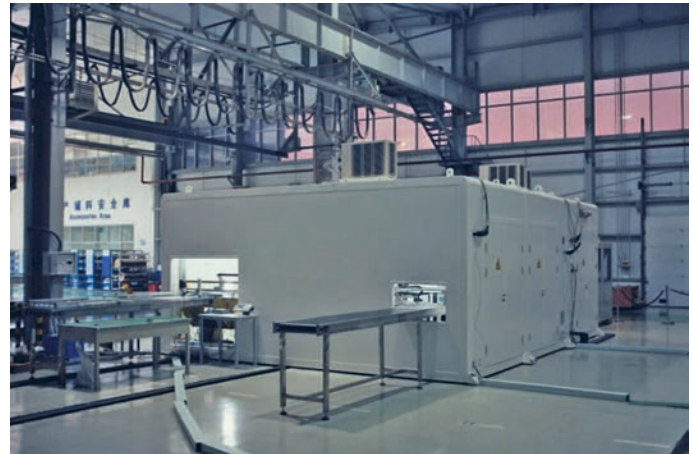
Results from extensive factory testing demonstrate the ability of the technology to measure gold with high accuracy and sensitivity down to concentrations of 0.03 ppm. The system calibration is independent of the chemical or physical form of the sample, allowing different ore types, concentrates, coarse or fine materials,

and powders and slurries to be measured with equal felicity without additional preparation.

By adjusting the operating conditions of the X-ray source, and identifying different emitted radiation signatures, the PhotonAssay process can be extended to measure a range of elements beyond gold. Preliminary results have demonstrated potential performance for other commercially important elements, including silver and copper.

The first PhotonAssay unit has recently been installed and commissioned at MinAnalytical's assay laboratory operating in Perth, Australia.

Gekko and CSIRO are partnering to commercialise a new technology that provides real-time analysis for gold content in a slurry or solution stream. Delivering an updated sub-ppm Au measurement every 10 minutes, the OnLine Gold Analyser (OLGA) provides insights into process performance that are unobtainable with assayed sample sets. While traditionally assayed samples consist of homogenised samples that are collected once per shift and then delayed up



Full design capacity for Chrysos Corp's PhotonAssay PA1408X system is 72 samples per hour

to 12 hours by lengthy processing, OLGA provides live data. This enables real time monitoring and adjustment of process systems and empowers mining operators to minimise gold losses from process excursions.

Complementing Gekko's existing Carbon Scout measurement system, OLGA will enhance Gekko's metallurgical accounting system which is currently under development in collaboration with Rockwell Automation.

CSIRO Research Director – Nick Cutmore: "OLGA is a breakthrough in on-line analysis for the gold industry and we are excited to be able



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Gekko's Carbon Scout technology helps optimise process plant efficiency and reduce soluble gold losses. The self-contained device collects slurry samples from CIP and CIL tanks to determine the distribution of the activated carbon in the pulp for each tank, to an accuracy of ±0.5 g of carbon per litre of pulp. The machine improves the accuracy, regularity and consistency of carbon density measurements in CIL and CIP circuits. It also improves safety by reducing operator exposure to cyanide and other hazards

to work with Gekko in its implementation.”

Gekko's OnLine Gold Analyser is specifically designed to enable direct measurement of gold in tailings, feed and concentrate slurry streams down to sub-ppm levels, unlike conventional X-ray fluorescence (XRF) systems that have detection limits in the tens to hundreds of ppm range.

The system is delivered to site fully pre-calibrated using a range of samples representative of the plant stream allowing fast installation and commissioning into the existing process plant. As the system measures a sample slurry stream, it can be taken offline without interruption to production.

Following successful in-house testing at CSIRO, OLGA is now ready for field testing. Plans for field trials at a number of Australian gold mining companies are well advanced and should see OLGA undergo full product release early in 2019.

Reducing grinding power needs

Santral Madencilik chose a Loesche dry vertical roller mill to grind gold ore at its project in Turkey. Loesche reports that the project is attracting a lot of attention because the ore's gold content is relatively low and therefore the profitability of the grinding and subsequent flotation is of particular importance. In grinding and flotation tests, it was proven that Loesche grinding technology not only works in a more energy-efficient and wear-resistant way than the conventional wet ball milling, but it also makes a significantly higher yield of the dry ground

product possible.

The energy demand for vertical roller mills depends on the pressure and, in particular, the speed when grinding hard rock. Loesche also notes that it is “developing vertical roller mills with drive-power capabilities of up to 18 MW for use in mining applications. Wet grinding systems (SAG and ball mills) have drive systems with power capabilities of up to 25 MW. The Loesche mill requires substantially less power for comparable grinding capacities of up to 2,000 t/h. The cost benefits of using large grinding plants with vertical roller mills will encourage the more widespread use of this technology, which is a relatively new concept for the mining industry.”

The Tropicana mine of AngloGold Ashanti Australia (70% owned and managed) and Independence Group (30%) is located 330 km east-northeast of Kalgoorlie, Australia. Following extensive feasibility studies, an HPGR-ball milling circuit was selected based on the reduced power requirements and thus reduced operating expenses. The HPGR-ball mill circuit was estimated to require 75% of the energy of a standard SAG mill circuit. Even with an anticipated greater capital cost, the HPGR-ball mill circuit was found to give significantly better financial returns in all cases investigated in the feasibility study. A comparison between the



Currently the largest Loesche mills have drive-power capabilities up to 10 MW. The mills have redundant systems to avoid machine failures and to ensure high levels of availability. They operate dry and require substantially less power than SAG Mills for comparable grinding capacities of up to 2,000 t/h

specific energy requirements of the HPGR, crush and SAG based circuits (SABC) from the feasibility work was conducted and the HPGR circuit was found to be considerably more energy efficient. A survey was conducted and the efficiency of the HPGR was similar to both the overall circuit design and the HPGR laboratory results, reflecting the accuracy that is possible for design and operation of HPGR circuits. Between 2015 and 2016, the Tropicana circuit has achieved a 20% increase in throughput from 780 to 930 t/h, and this increase was maintained in 2017. This improvement can largely be attributed to upgrades to material handling processes, increased HPGR speed and smaller HPGR screen apertures. The result of these changes has been to increase the ball mill capacity by increasing the breakage conducted by the HPGR.

Pumping gold slurries

It has been 80 years since Charles Warman invented the hard-wearing slurry pump which is synonymous with his name. Still the pump of choice for many gold mining companies operating around the town of Kalgoorlie in the Goldfields of Western Australia, where it all began, the iconic blue piece of equipment performs dutifully for years on end.

This, says Weir Minerals, “combined with its superior performance, high wear and the dedicated support of the Weir Minerals service team is why customers like Northern Star Resources count on Warman® pumps to get more out of their mine.”

At the company's Kanowna Belle gold mine in Kalgoorlie, the processing plant has a throughput capacity of 1.88 Mt/y. In order to operate at full capacity, high performing and reliable equipment is crucial.

Slurry pumps are the heart of the processing plant, without them everything stops. The customer was experiencing multiple pump rebuilds which was putting a great deal of strain on the process, so it approached Weir Minerals to provide a solution.

“We worked closely with the customer and suggested a trial of our Warman MCU 250 pump lined with Hyperchrome A61 material which is extremely abrasion resistant and ideal for high wear situations like this one. Based on more than 25 years of research, the MC pump

range is renowned for its ability to handle large particles in abrasive slurries and is designed for aggressive wear applications,” states Anthony Robertson, Weir Minerals' Area Sales Manager for Goldfields, Western Australia.



Kanowna Belle Warman pump - Weir Minerals has celebrated 80 years of innovation with the Warman slurry pump, which remains one of the most popular high wear slurry pumps on the market

Installed in May 2017, the MCU® 250FF pump had an estimated wear life goal of 3,000 hours, significantly more than the superseded model. Upon installation, the pump quickly demonstrated why this range is an exceptional

choice for mill circuit applications.

Processing 3,654,009 m³ of slurry during its initial run, the pump performed for an impressive 3,111 hours before its first routine overhaul. It exceeded the original wear life target by over 100 hours and improved on the wear life of the original pump by 246%.

The expertise and experience of the Weir Minerals team resulted in an invitation from the customer to investigate additional opportunities for improvement at Kanowna Belle mine. As a testament to the success of the trial, Northern Star Resources has distributed results internally to its other sites.

“The Warman pump is really well supported. It’s tried and trusted. We’ve been very well supported by the Weir Minerals team. This trial has allowed us to free up resources as there have been fewer rebuilds, making it a cost effective solution. We’ve gone from around 900 hours of operation time on our Weir consumables to about a little over 3,000 hours,” Greg Sheppard, Processing Manager Kalgoorlie Operations states.

Leaching

Veolia Water Technologies has been awarded the contract to design and supply a reverse osmosis plant to reduce the chloride levels in the produced water stream at the Fosterville gold mine. The water treatment plant solution will

allow Kirkland Lake Gold to continue meeting its operations license conditions in a sustainable way.

Fosterville gold mine plans to implement a water treatment plant to treat mine water for reuse within the process water circuit. Veolia Water Technologies’ reverse osmosis plant is to reduce the chloride levels <500 mg/l. The plant will consist of multimedia and carbon filtration followed by primary reverse osmosis and reject recovery reverse osmosis.

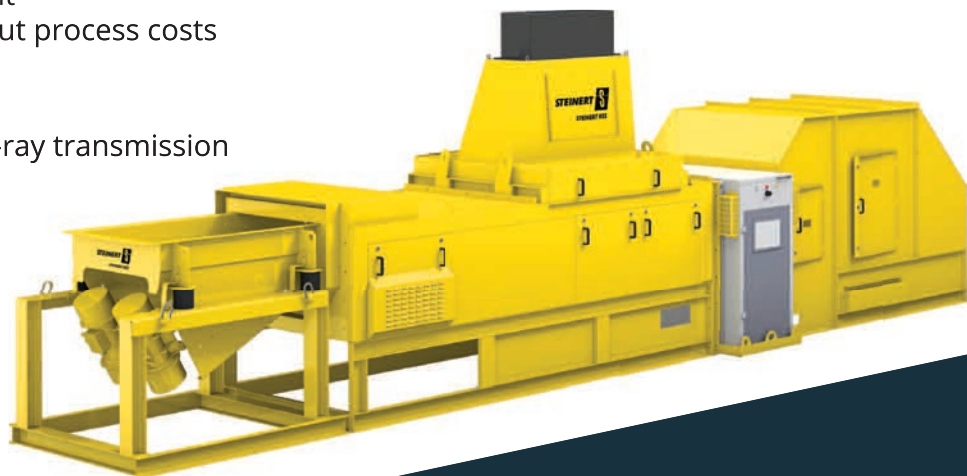
“Leveraging our extensive experience in reverse osmosis technology for treating mine water, we are very proud to deliver this water treatment system to enable Kirkland Lake Gold to further enhance its sustainability credentials by producing a high quality treated water for reuse within the mine,” said Leno Cavarra, Client Executive Manager – Projects, Veolia Water Technologies (Australia).

The water treatment plant has a daily capacity to treat 2 million litres and is planned to be operational in 2019.

EnviroLeach, a finalist in #DisruptMining 2018, has developed what is reported to be “the world’s only safe, stable, sustainable, eco-friendly and economic alternative to cyanide. A unique, cost-effective and environmentally friendly alternative to the current methods used in the hydrometallurgical extraction of precious metals, including the prolific use of cyanide,

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strong acids, mercury and smelting processes.”

The EnviroLeach process, a patented chemistry based on five FDA-approved ingredients, results in a product that is non-toxic, safe to use and provides similar or superior leach kinetics and recoveries to that of cyanide. “It’s the first economically and technically viable alternative to the use of cyanide since its introduction in the 1870s. Adoption and application of the EnviroLeach method is expected to help to reduce the environmental impact of mining, streamline permitting processes, improve occupational safety and enhance operational efficiencies.”

CIL and CIP technologies are widely used but breakage of carbon during processing sometimes results in significant gold loss. Carbon consumption at a gold plant can vary from 10 to 150 g/t of ore processed, with an industry average of 50 g/t. This fine carbon can contain from 50 up to 2,000 g of gold per tonne.

Duane Nelson, EnviroLeach CEO, states; “We consider our unique formulas and technologies to be among the most innovative and disruptive new technologies ever introduced to the mining and urban mining sectors and will continue to push the boundaries to create eco-friendly solutions for this sector.”

Recently, Mintek developed a Resin-in-Leach (RIL) process for the recovery of gold from carbon fines which was based on contact of carbon fines slurried up in a cyanide medium with gold-selective strong-base resin. Bench scale studies conducted on the synthetically pre-fouled carbon showed that it was possible to reduce Au concentration in the fines from 1,500 to below 10 g/t.

In order to verify the robustness of the technology, gold recovery from actual carbon fines and operation in continuous counter-current mode had to be confirmed. South African gold mines provided a number of samples containing between 50 and 200 g/t Au. It was demonstrated that in all cases at least 90% of Au can be transferred from carbon onto the resin phase.

Efficiency of gold transfer was tested during a counter-current mini pilot plant campaign where a composite sample was treated. In addition to evaluating Au behaviour, other elements such as Ag, Ni, Zn, Fe and Cu were monitored. It was possible to achieve ~10 g/t Au in the treated fines with more than 10 times Au upgrade onto the resin phase. High silver recoveries were observed which can be considered as an additional benefit of Mintek’s technology.

GeoProMining (GPM) is evaluating an expansion project comprising a second line of an Albion Process™ plant at its Ararat gold plant in Armenia. The first line successfully increased recovery from sulphide concentrates in its Ararat plant from 20% to over 95%, defying expectations and targets. The plant was

commissioned in June 2014 and achieved full capacity after three months. GPM owns and operates the Zod gold mine and Ararat processing plant in Armenia to produce gold and silver bullion.

The Albion Process was required to recover gold from a complex matrix in tails dam (80% recovery, up from 35%), and leave arsenic minerals inert.

In order to expand, GPM needed to treat the underlying sulphide material at the Zod mine which only resulted in around 20 to 30% gold recovery through the existing conventional CIL flowsheet.

In 2010, GPM approved a refurbishment project at the Zod mine and Ararat processing plant – an increased crushing capacity to deal with the harder ore and a refurbishment and re-commissioning of the existing flotation plant. Added to this was the installation of a new Albion Process plant for the oxidation of the sulphide concentrate prior to its treatment in the existing CIL plant. The new flowsheet would be configured such that the CIL would treat flotation tailings and oxidised residue from the Albion Process.

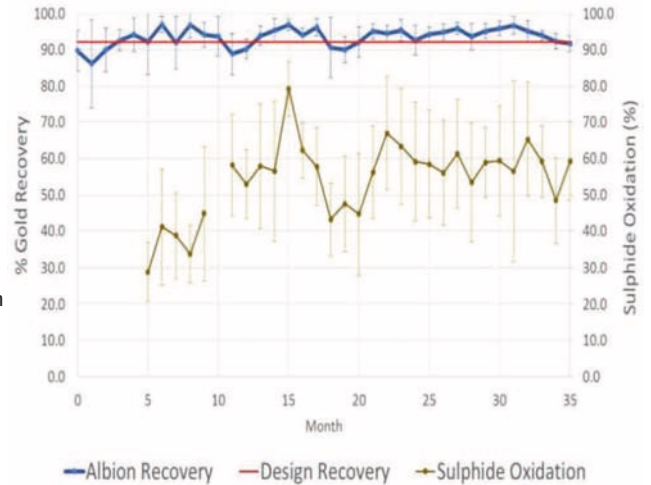
The Albion Process is an atmospheric leaching process developed and owned by Glencore Technology. It uses ultrafine grinding to reduce the activation energy needed in oxidation of the sulphides, so that it can occur under atmospheric conditions. The leaching occurs in an agitated tank that uses HyperSparg™ supersonic gas injectors to boost oxygen capture efficiency.

Glencore Technology was engaged to design, supply and commission the Albion Process and to provide installation supervision assistance.

The design basis for GPM’s Albion Process was oxidation of 100,000 t/y of concentrate to give an overall production of 100,000 oz/y of gold from concentrate and flotation tailings. The design recovery of gold from the Albion residue was 92% but the plant frequently achieves over 95% recovery with an overall plant-wide design recovery of 86% but commonly achieving 88%.

The refurbishment project was commissioned in June 2014, with ramp-up occurring for the remainder of 2014. The plant has achieved and exceeded nameplate production, treating in fact 120,000 t/y concentrate with an overall production of 120,000 oz/y.

The grade of concentrate has been more or less stable, and increased production might normally be expected to decrease as equipment is stretched. But in GPM’s case, it has



Three years of stable gold recoveries using the Albion Process at Zod

successfully kept recovery above design using the Albion Process.

Overcoming preg robbing

Nordgold’s Suzdal mine has realised the second successful commercial implementation of the HiTeCC technology to combat the preg-robbing of its double refractory ore. The mine is located 55 km southwest of the city of Semey in Kazakhstan and since 2005 has used the Outotec BIOX® technology to pre-treat its refractory sulphide orebody. The orebody is a well-known double refractory ore with both visible and invisible gold hosted in sulphide associations of pyrite and arsenopyrite and also carbonaceous black shale.

Following extensive laboratory and demonstration scale testing of the Outotec HiTeCC technology over the period 2012 to 2015, Suzdal commenced the construction of a 385 t/d HiTeCC facility. The plant was designed to recover gold from both the current and historic CIL tailings and, in 2016, the first Eurasian HiTeCC plant was successfully commissioned. Through the HiTeCC process, preg-robbled gold is



The BIOX process was developed for the pre-treatment of refractory concentrates ahead of conventional cyanide leaching for gold recovery

efficiently desorbed from the carbonaceous matter by manipulating the ionic strength and temperature of the Suzdal CIL product leading to enhanced metal recovery.

There are currently two important Outotec development initiatives, the development of the MesoTherm process to reduce cyanide consumption following bio-oxidation and the development of an OKTOP® BIOX reactor and agitator for improved mixing efficiency in the BIOX reactors.

The MesoTherm process uses a combination of the traditional BIOX mesophile process for the primary bio-oxidation stage, followed by a thermophile bio-oxidation stage to complete the oxidation. The higher oxidation rates and more complete oxidation at the higher temperature results in lower cyanide consumption during subsequent leaching of the bio-oxidation product. Development of the process included several stages of batch and continuous pilot plant testing. The final stage in the development is the successful operation of a 21 m³ demonstration tank, currently in operation at the Fairview BIOX plant in South Africa.

The BIOX agitator performance is critical for the overall performance and efficiency of the BIOX process. The Outotec OKTOP® 3105 dual impeller was developed to give superior gas handling and oxygen mass transfer rates under typical BIOX operating conditions. The Outotec

OKTOP® 3105 unit was tested in water and BIOX slurry using the test reactor at Fairview.

Cyanide replacement

Sazini Makamu of Mintek has conducted a literature review of cyanide alternatives, specifically focusing the attention on the application, efficiency, and quantity of reagent, reagent consumption, health, safety and environmental concerns of gold alternative lixivants. This was presented at *Alta 2018* in May. Many interesting presentations from that conference can be found at <https://www.altamet.com.au/conferences/alta-2018/program/>

Based on the review, six promising reagents were selected to conduct high level test work and a base case test with cyanide was conducted for comparison purposes. The lixivants tested included cyanide, glycine, thiocyanate, thiourea and thiosulphate. Lower gold leach efficiencies were achieved with the majority of alternative lixivants compared to cyanide. It was noticed that combinations of lixivants (thiosulphate and ammonia, thiourea and thiocyanate, glycine and cyanide) yielded improved gold leach efficiencies (similar to that achieved with cyanide).

Last year this article reported on MPS and its GlyLeach process (*IM, August 2017*). In April this year MPS executed a partner agreement with Hazen Research, based in Golden, Colorado. The agreement licences Hazen to independently

undertake bench and pilot work using the GlyLeach and GlyCat Process for its clients and for any clients referred to them by MPS. This is the first agreement in MPS's Certified Laboratory Partner (CLP) program where laboratories globally are to be engaged to provide mining companies with an additional option to that provided by MPS at its Perth facilities.

Operations Director, Tim Newton, commented that "Hazen Research was an obvious first choice for us in implementing our CLP program. The Hazen team has a great reputation amongst mining companies who use them, and they have been in business for over 55 years providing chemical analyses, bench-scale work, and continuous pilot plant demonstrations. Their facilities are first class and their location in the US provides MPS with global reach that we would not otherwise be able to establish."

GlyLeach is an environmentally benign hydrometallurgical process that will leach base and precious metals from oxide, mixed oxide, supergene, and some primary sulphide ores. Glycine is the simplest amino acid and is available in bulk quantities. Its unique properties can offer substantial advantages over conventional lixivants:

- Environment/safety: Glycine is non-toxic to humans as well as wildlife
- Selectivity: Glycine will solubilise copper, nickel, cobalt and zinc, while iron, manganese,

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silicates and carbonates remain in the solid phase

- **Alkalinity:** Leach conditions are at high pH, allowing simple and inexpensive materials of construction
- **Mild conditions:** Leaching is typically at ambient temperature with no heating cost or pressure vessels
- **Low consumption:** Glycine is non-volatile (unlike cyanide, ammonia, hydrochloric acid) and stable under process conditions
- **Recycle:** Glycine is not chemically consumed in the overall process. It is easily recovered and recycled, and process losses can be minimised by good design.

Small amounts of cyanide used in conjunction with a glycine-dominant lixiviant have many beneficial properties, particularly for the leaching of precious metals with elevated copper content. This is a consequence of copper preferentially bonding to glycine rather than cyanide, thus freeing the cyanide to leach gold. Furthermore, the cupric glycinate is an effective oxidant for gold and replaces the need for free oxygen in the solution. Benefits of GlyCat include lower cost:

- A small addition of glycine can cause a marked reduction in cyanide consumption
- The main glycine reagent is recovered and recycled
- Free and WAD cyanide in the leach tails are below the limits for disposal prescribed by the International Cyanide Management Code, thus avoiding costly detoxification.

Other advantages are:

- **Catalysis:** Gold extraction can be significantly faster than with cyanide alone
- **Problematic ores:** GlyCat enables economical gold extraction from ores with elevated soluble copper.

A recent GlyCat study used a silver-gold ore that contained 3.13 g/t Au and 64 g/t Ag. The gold was predominantly present as native gold and the silver predominantly present as silver halides. The leaching conditions for the GlyCat system were glycine at 7.5 g/litre, ferricyanide at 1.5 g/litre, with the sodium cyanide (NaCN) concentration maintained at 200 ppm for the duration of the test. Cyanidation leaching was undertaken with NaCN maintained at concentrations of 1,000 ppm for the duration of the test. A level of 1,000 ppm cyanidation was adopted for this study as it represents a level that would typically be employed industrially for this type of ore.

The leaching rate in the GlyCat system was found to be some tenfold faster than the 1,000 ppm cyanidation system, with higher gold recovery after six hours at 98% for the GlyCat system. Gold and silver recovery from cyanidation leaching at 1,000 ppm after 48 hours were 97.1% and 80% respectively, compared to



GlyCat™ is the application of glycine with cyanide to mixed base metal and precious metal ores

96.7% and 75.6% respectively for the GlyCat system for the same time period. Gold and silver recovery from cyanidation leaching at 200 ppm after 48 hours was much lower at 85.5% and 52.0% respectively. In the GlyCat system, 0.81 kg/t of NaCN was consumed compared with 2 kg/t in the 1,000 ppm cyanidation system. Lime consumption was also lower for GlyCat, with 2.82 kg/t lime consumed compared to 4.3 kg/t lime for the cyanidation system. Lower mercury dissolution was observed in the GlyCat system, with 0.7% dissolved into solution, compared to 10% during the cyanidation at 1,000 ppm. The concentration of free cyanide present in the final leach solution for the GlyCat process was 175 mg/litre, which was approximately 20% of the free cyanide present in the final leach from the 1,000 ppm cyanidation process.

The results showed that the GlyCat leaching system achieved a similar level of gold and silver metal recovery to cyanidation at 1,000 ppm, but with reduced cyanide consumption, reduced lime consumption and reduced mercury dissolution compared to the cyanidation system. Cyanidation at 200 ppm achieved significantly lower gold and silver recoveries compared to the GlyCat leaching system.

Selinsing Gold Sulphide Project

Monument Mining is being innovative with the gold processing plant design and the Front End Engineering Design (FEED) for its Selinsing Gold Sulphide Project (SGSP) in Malaysia.

The basic gold processing plant design and FEED form a major part of the feasibility study. It is aimed to convert the existing oxide gold treatment processing plant to a sulphide treatment gold processing plant. As a result, it

would allow additional flotation process and BIOX® process to be added to the existing plant with certain alterations to the existing process. To date both design packages have been delivered for Monument's review, subject to further optimisation should it be required upon additional flotation test work.

The design of the new processing facilities featuring: flotation, BIOX oxidation, counter current decantation, neutralisation and conventional CIL processing has been completed by Orway Mineral Consultants. CIL tailings will undergo conventional cyanide detoxification prior to the Activated Sludge Tailings Effluent Remediation (ASTER™) process. A water recovery thickener will recover the bulk of process water from flotation tailings, neutralisation and ASTER discharge. The thickener underflow will be pumped to the existing tailings storage facility (TSF).

The BIOX process is a patented technology for pre-treatment of sulphide-based refractory ores and concentrates ahead of a conventional cyanide leach for gold recovery. Outotec, the owner of the patent has produced an ASTER process design package for the biological destruction of residual cyanide and thiocyanate. Operation of the ASTER process, as successfully practised at the Runruno BIOX plant in the Philippines, will provide clean water for milling and flotation and prevent the poisoning of the BIOX microbes by cyanide compounds.

SRK Consulting has provided a scoping level design confirming the feasibility to expand the existing TSF. Detailed design will be carried out following further geotechnical investigations and testing of suitable materials from borrow pits and open pit cutbacks.

Following the announcement of bioleaching test results in February 2018, additional bioleaching variability test work has been conducted by SGS Johannesburg under the supervision of Outotec to determine the metallurgical response of other ore sources to be processed in the first two years of production. The test results have shown excellent bioleaching kinetics with 98-99% sulphide sulphur oxidation achieved within 18 days. Cyanide leaching of the BIOX residues achieved gold dissolution of 94-99% in the standard 24-hour tests. It has confirmed the process being selected is most suitable for Selinsing and Buffalo Reef ore. No more test work is required.

Iron to arsenic solution grades indicated that the formation of a stable ferric arsenate compound would result and toxicity characteristic leaching procedure (TCLP) tests confirmed compliance with the US Environmental Protection Agency requirements.

The latest test work included the testing of Selinsing Pit 5 hanging wall limestone for its acid

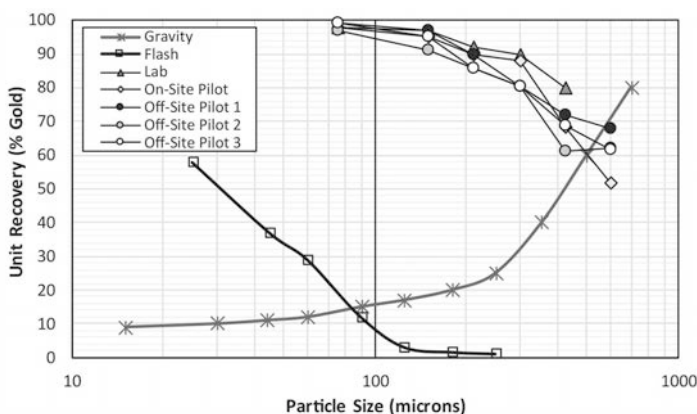
GOLD EXTRACTION

neutralisation capacity and potential use in the BIOX reactors and the neutralisation tanks. The limestone was found to have excellent neutralisation characteristics and could be used for pH control in the BIOX reactor tanks and for neutralisation of the effluent solution and BIOX residue.

Additional flotation test work, supervised by Orway, is underway, aiming to provide independent verification of the flotation conditions reported by the in house R&D team that achieved better recovery rate of gold to the flotation concentrate while maintaining the design sulphur grade and mass pull.

HydroFloat advances

In their paper *Improving coarse particle flotation using the HydroFloat™*, J.N. Kohmuench and fellow authors from Eriez (Minerals Engineering 121 (2018) 137–145) conclude that “current flotation practice can be improved by applying flotation fundamentals to fluidised-bed separation. This novel approach was utilised in the development of the HydroFloat air-assisted



Comparison of gold recovery by size for Flash flotation, gravity concentration and Eriez HydroFloat test results

teeter-bed separator which uses flotation within a fluidised-bed environment to improve the recovery of coarse particles. The quiescent nature of a teeter-bed separator increases the overall flotation rate and level of recovery by utilising efficient mixing conditions, increased retention time, reduced detachment (ie low turbulence), and improved collision rates when compared to conventional flotation cells.

Data generated from laboratory and pilot testing efforts have been used to model and simulate innovative flotation circuits which have been designed to take advantage of the benefits afforded by fluidised-bed flotation technology. Process economics can be vastly improved by capturing particles that would either require significantly more grinding or be lost when using traditional flotation methods. In fact, one study indicated that the capacity of a primary grinding circuit can be increased by 20–25% for a hypothetical concentrator treating a typical porphyry copper ore.

“As this technology progresses, it provides process engineers with another tool for circuit optimisation where the engineered solution includes less grinding, increased capacity, higher recovery and, most importantly, reduced costs. It is becoming increasingly more important to demonstrate payback as the traditional approach of simply adding additional capacity is not as clear cut when determining payback with respect to complete utilisation of the resource. As a result, it is becoming more important for mining companies to challenge traditional methods by evaluating innovative technology that can maximise the recovery of valuable minerals from ore reserves.”

Biological processing

Leading cyanide provider Cyplus GmbH and the bio economy company BRAIN AG have announced the development of an initial range of market-

COMPATIBILITY IE4 TOTAL COST OF PAYBACK CALCULATION OWNERSHIP ELECTRIC SMALL WORKS MOTORS MINI-ELECTRICAL SUBSTATIONS CONSTRUCTION SABS IP66 MOTOR TRAINING SABS DIESEL TRANSMISSION AND DISTRIBUTION GENERATORS ENERGY MOTOR CONTROL CENTRES TRANSFORMERS LEARNERSHIPS STARTER ENCLOSURES PANELS ZEST ISO 9001 SOFTWARE ENERGY SABS STARTERS MOTOR & DRIVE COMBINATIONS EXTENDED GUARANTEES GENERATOR BBBEE CABLE & LEVEL RACKING SETS COOLING TOWER IP55 MOTORS VSD & CONTROL INSTRUMENTATION TURNKEY ENGINEERING SOLUTIONS DISTRIBUTION 24 HR TECHNICAL SUPPORT SUBSTATIONS PAD MOUNT MOTOR FLAMEPROOF MOTORS MINING CUSTOM ENGINEERED SUBSTATION SOLUTIONS PERMANENT MAGNET ENERGY EFFICIENCY QUALITY AFRICA IE3 SERVICE DESIGN VARIABLE SPEED DRIVES COST SAVINGS www.zestweg.com

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relevant products. This work has been carried out as part of a multi-year collaboration between the companies in the area of biological ore processing to extract gold and silver. On the basis of successful laboratory research up to the 100-litre scale, the partners then succeeded in scaling up the process to the metric ton level last October, thus reaching an important milestone in the last stage towards market maturity. The bio-based process could produce the desired precious metals from ores in industrially relevant yields, even for throughputs on the metric ton scale. The method is now being further improved for industrial application and this process is sufficiently advanced for the partners to expect the market launch of the first range of products as early as 2019.

The extraction of precious metals from the ores is based on the use of naturally occurring and enhanced micro-organisms from the BRAIN BioArchives. During the ongoing collaboration, the partners very soon identified a variety of micro-organisms that, having highly specific adhesion effects, give the gold and silver-bearing minerals a new physical property. This effect can be exploited to separate gold or silver specifically from gangue and enrich it in an integrated process step.

“Our research aims at developing bio-based methods that could offer innovative and sustainable processes for green mining in global markets for ore processing,” says Stefan Welbers, Senior Vice President and General Manager of CyPlus. “For this reason we’ve continuously kept the technical requirements and structural conditions in mines in mind. In the foreseeable future, for example, we’ll be able to offer mine operators the possibility of integrating advanced biotechnological methods into their current processes without significant investment costs or delays in operation. In this way, we’re expanding our technology portfolio to include biological components for efficient and eco-friendly processing of precious metals.”

Dr Guido Meurer, member of the Management Board and Unit Head Producer Strain Development at BRAIN, says: “We’re delighted – and proud – that the BRAIN and CyPlus interdisciplinary team has succeeded in establishing a ground breaking biological process for a new processing technology and developing it to high product maturity in just a few years. With our processes for Green Mining it will be possible in the future to exploit ore deposits containing precious metals even in regions where the conventional processes are out of the question. Green Mining is an increasingly important issue and an attractive field of business also in view of the increasing scarcity of raw materials.”

The partners have already filed a patent for



Finely ground gold ore for biological processing with Green Mining technologies developed by BRAIN and CyPlus

the bio-based method, which describes the special microorganisms possessing selectively adhesive properties that can be used to enrich precious metals from ores.

Under the mining program, BRAIN is also researching into biological solutions for what is known as Urban Mining, where precious metals are obtained from side streams and waste streams such as slags, ashes, and electronic scrap. The BRAIN BioXtractor has been established as a demo system for this purpose.

Closed loop chlorination

As *IM* reported last year (August issue 2017) Dundee Sustainable Technologies (DST) has developed a closed loop chlorination process as an alternative to the conventional cyanidation process for the extraction of precious metals from minerals. The tailings from the process are inert from toxic substances such as cyanide and organic compounds, are sulphide depleted, which means they do not generate acid, and thus, meet and/or exceed environmental norms.

The process has demonstrated excellent gold recoveries within a fraction of the time needed for cyanidation to obtain similar results. Moreover, the closed loop process does not generate any liquid effluent and does not

consume much water: it only requires a water make-up to compensate for moisture leaving with the tailings and by-products, and seawater may be used. The improved environmental footprint of the DST process has been certified by the Environment Technology Validation program (ETV) which provides an independent evaluation of the performance claims of

innovative technologies.

About 18 months ago, DST announced successful extraction results on gold concentrates from Chile using its chlorination technology at its demonstration plant in Quebec. A gold extraction yield of 97.3% was achieved at the outlet of the chlorination reactor with full environmental controls over the sulphur and mercury content.

“These results are another important demonstration of the efficiency and effectiveness of the DST chlorination process and of its potential as a robust and environmentally friendly alternative to cyanide extraction in the gold mining industry,” said Brian Howlett, President and CEO of DST. “We are partnering with a number of mining companies in an effort to advance our technology and further explore the commercialisation of our patented process.”

In the Chilean example, excellent results at the pilot scale enabled DST to move on to the next stage, which involved the processing of the concentrate, which contained an estimated 110 g/t Au, Cu grades of 9.0% and Hg content in excess of 700 g/t at the demonstration plant.

DST processed 40 t of this complex material which is difficult to process using conventional processing methods without the associated environmental liabilities and metallurgical challenges. In particular, the 700 g/t of mercury was effectively removed during processing to a level of 99%.



DST is now considering where to locate its first commercial closed loop chlorination process plant

DST's chlorination process (see schematic) uses sodium hypochlorite with a catalytic amount of sodium hypobromite in acidic conditions to put gold into solution. Contact time is short, and all chemicals are recycled within the circuit, and sea water is also suitable where available.

Pre-treatment may be required prior to the gold extraction step by chlorination. When dealing with sulphide bearing ores or concentrates, controlled oxidation is required as a pre-treatment prior to chlorination. Controlled oxidation is performed by introducing materials into a fluidised bed, with a controlled air supply, to volatilise certain components such as sulphur, while retaining the porous character of the solid fraction. The gases that are produced by this operation are first passed through a dust collector where the particles are recovered and recycled into the fluidised bed. The gases are then routed to a wet scrubber circuit, where the sulphur compounds are transformed into a sulphuric acid by-product.

If the oxidised mineral contains base metals that need to be recovered a water or acid leach is carried out prior to the gold extraction step. In fact, if the operation conditions of the controlled oxidation predominately lead to the formation of copper sulphates, a water leach, instead of an acid leach with sulphuric acid, can be performed. Following the filtration of the water or acid leached slurry, a copper sulphate solution can be fed to a SX-EW plant to recover the copper.

The water or acid leached cake is then fed into a reactor where it is contacted with sodium hypochlorite, with a catalytic amount of sodium bromide, in acidic conditions to solubilise gold. The contact time is short, one to two hours versus two days for cyanidation. Once the reaction is complete, the slurry is filtered, leaving an inert, stable and sulphide depleted solid residue.

The gold containing brine is sent to an agitated vessel where the oxidation-reduction potential (ORP) of the solution is reduced, which leads to the gold deposition onto silica. The solution is filtered, and the gold loaded silica, which may contain up to 30% of its weight in gold, is then fused to isolate and collect the precious metal. The silica slag is ground and re-used in the circuit. The process operates in a closed loop, with the gold depleted brine undergoing different polishing steps prior to being sent to membrane-less electrolysis cells, to regenerate sodium hypochlorite for reuse in the process.

Digital processing

The highlight of this year's FLSmidth's Electra Mining Africa exhibition stand will be a 1:20 scale model of its REFLUX™ Classifier (RC) modular plant, representing, the company says – “in more

ways than one – the future of processing.” According to FLSmidth Commercial Manager Terence Osborn, the RC plant is a good example of an integrated solution designed to meet a customer's tailings-related risks and requirements.

“The plant demonstrates how our insights and expertise make us more than an equipment supplier,” says Osborn. “Our focus is to bring the value of our technical knowledge base – along with our range of advanced product offerings – directly to bear on improving customers' sustainability and profitability.”

The RC plant embodies FLSmidth's leading technologies as well as its innovative business approach. Equipped with advanced automation facilities, a full-size version of this plant is in

operation for a mining customer on an outcomes-based toll treatment model. It treats waste product, or tailings, and recovers valuable minerals as a saleable product for the customer, without adding extra workload or risk to the operation.

FLSmidth's technical advances in automation and digitalisation is vital in making these solutions more valuable; both FLSmidth and the customer can observe and assess the key operational parameters of the plant in real-time in their respective head offices anywhere in the world. Osborn emphasised how much of a priority this direction was for the business.

“Our appointment in May this year of a Chief Digital Officer at global group executive level reflects our focus on digital efforts to leverage solutions,” he says. “This is key to our corporate



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strategy going forward and customers will see increasing levels of bottom line benefit arising from this direction.

“Our role is increasingly to provide total solutions that package our expertise and equipment for the customer’s benefit – and to make it possible for them to run efficient plants with high recoveries. This includes our ability to effectively integrate equipment and solutions into existing infrastructure.”

Polyus has made significant improvement to its gold flotation analysis and automation systems. It has introduced a range of technologies from Outotec including the PSI 300i on-line analyser for mineral slurries; which automatically takes samples from one to three process streams and measures P₄₀ to P₉₀ particle size in the range 25-1,000 µm. Preliminary testing using PSI 300i analysis has shown optimised recovery and improvement by 0.28%. The Outotec PSI 300i sensor head directly measures the size of a representative sample of particles. The measurement data is then converted to size fraction readings for each measured stream. Each of these corresponds to a user-definable particle size screen fraction, such as percentage passing at 74 microns. This information is displayed on the analyser’s touchscreen and can be sent to plant process control system using several communications protocols.

Polyus has also installed Outotec’s FrothSense camera imaging of froth and bubble size analysis, which measures froth speed, direction, bubble size and froth stability; providing statistical data related to these variables. LevelSense is another tool that measures the slurry froth and froth air interfaces in a flotation cell. Froth bed thickness can be reliably measured with froth and slurry interfaces provided. Lastly Outotec Advanced Control Tools (ACT) represent a platform that includes interfaces for both engineering and operating customised control applications such as EXACT froth level control and automated control over the froth yield speed.

At Blagodatnoye, Polyus has installed a flash flotation operation designed to remove fine valuable mineral particles otherwise returned to a new processing cycle. The technology, first trialled by Polyus in its R&D centre, minimises overgrinding and improves overall mill throughput and recovery while optimising water cycles. It improves flotation output with more stable feed in the further flotation circuit, increasing metallurgical quality of the concentrate. Flash flotation units can halve the gold content in recirculating flows, increasing direct gold recovery. It is reported that one Outotec SkimAir flash flotation unit has the same efficiency as six gravitation concentrators but



requires much less space and is more economical. At Blagodatnoye, the gold content in the flotation tails in g/t stood at 0.19 before flash flotation was introduced and 0.17 after, a fall of 11%. One SkimAir flash flotation unit has been installed in Blagodatnoye Mill 4, with an additional unit being installed in 2018-2019; and another four ordered as part of the Mills 1, 2 and 3 expansion project, while the technology is also being tested at another mine.

A future game changer

FL Smidth’s Rapid Oxidative Leach (ROL), a mechano-chemical pretreatment process for refractory gold ores, was covered in detail in last year’s article (*IM, August 2017, pp 36-38*). In that article, Mike Woloschuk, FLSmidth’s global Industry Director for gold stated that with this technology proven, “miners will be looking at a completely different life of mine plan; by lowering the cutoff grade, more ore will be converted into reserves.”

Peter Flanagan, FLSmidth SVP Executive Accounts stresses that “lower processing costs reduce the cutoff grade, allowing more ounces to be processed economically. The only difference between a resource and a proven and probable reserve is that the former is uneconomic and no amount of additional drilling will ever make it economic.

“There are a lot of undeveloped refractory gold deposits that have less than 3 g/t gold head grade, and some are coupled with small resources, which translates into short mine lives. Currently, those assets have little to no value as greenfield deposits and need a step change in technology to unlock value,” says Flanagan.

FLSmidth believes the ROL pre-treatment process technology can be a breakthrough for the gold industry, displacing current refractory processing methods and prolonging mine lives.

The FLSmidth Modular REFLUX™ Classifier control room with operator controlling the whole plant with the FLSmidth’s Expert System automation software

Flanagan explains some limitations of current technology:

- Pressure oxidation, roasting and bioleaching all have high processing costs. This is due to extreme operating temperatures and pressures, exotic construction materials and ancillary equipment required to provide reagents and environmental controls
- Recent industry information indicates pressure oxidation (POX) ranges between \$50-65/t, with roasting at \$25-35/t, meaning that at a gold price of \$1,250/oz., these methods need 0.6-1.6 g/t Au just to cover processing costs
- Bioleaching operates at low slurry density and has a comparatively longer residence time, which inflates the leaching circuit size. Bio-oxidation is very sensitive to cyanide and thiocyanate, as they are toxic to bacteria; hence pre-treatment and cyanidation systems must be separated.

But, the ROL pre-treatment process could be the needed game-changer for gold:

- A typical refractory ore contains tiny inclusions, or submicroscopic gold, within a sulphide mineral matrix, requiring physical and chemical altering of the mineral matrix to liberate the gold for subsequent leaching. FLSmidth sees a great potential to unlock value in applying ROL to treat undeveloped gold deposits as it could make it feasible to extract gold from refractory low-grade ores
- The ROL pre-treatment process has already generated interesting results in the copper industry. From concentrates as low as 5%, the mechano-chemical process can leach 97-99% copper directly on site. **IM**