Percolating liquids

Central Asia Metals' Kounrad SX-EW project in Kazakhstan delivers weak acid solution to the top of waste dumps and irrigating the surface of the dump, through a pump and pipeline system

Stacking rather than truck dumping, the importance of modelling, subsurface leaching: John Chadwick considers these and much more, including some innovative new ideas in leaching

Heap leaching may appear to be simple but it is in fact a very complex process. "A plethora of technologies such as material handling, environmental control, analytical techniques, solution chemistry, hydrology and many others contribute to the design and operation of a heap leach. Heap leaching requires an inter-disciplinary approach between geologists, mining engineers and metallurgists[2].

"Many operational factors affect heap leaching. The process must address climatic factors, flexible operation, quality control before and after leaching, physical characteristics of the ore, geology, mineralogy, reagent consumption, solution application rate and methods (wobblers or emitters), particle size, and favourable conditions for bacterial growth and survival.

"Predicting, troubleshooting, and optimisation of leach recovery is a significant challenge when considering the number of variables involved and their interactions."

The second survey of global copper leaching operations[1] shows:

- Primary copper mineralogy in leach ore has seen a significant shift to mixed ore types
- Ore preparation has seen a 17% increase in crushed leach operations
- Run of mine operations decreased by 34%. The predominate crush size ranges between P80s of 9.5 to 51 mm (3/8" to 2")
- Leach ore preparation has shown a dramatic shift toward agglomeration and acid curing
- Leach heap and stockpile construction indicates an increase of 30% in crush, convey and stacker operations with a corresponding decrease in truck dumping. Leach pad types remained approximately the same
- Solution application methodology has seen a dramatic increase of 30% toward drip emitter technology
- The average of total copper recovery has trended slightly lower. Probably due to the age of these mines and the trend to more mixed oxide and supergene ore types
- PLS copper grades are trending lower to a range of 0.2 to 2.3 g/litre
- PLS pH has trended lower (more acidic) with most SX plants now processing feed solutions in the pH range of 1.6 to 1.8
- Iron in PLS has seen a significant reduction where the majority is now in the range of less than 1.0 to 2.0 g/litre.

Today, "more operations are acid curing the leach ore and particle size distribution (P80) of the ore has decreased."

Alan Taylor, Metallurgical Consultant/ Managing Director, **ALTA Metallurgical Services**, notes "the ability to use heap leaching, together with SX/EW to go from ore to high grade metal at the mine-site, makes it particularly attractive to aspiring juniors." He cautions that test work and scale-up procedures are still in a state of flux, with no universally recognised standards. This is reflected in the number of heap leach modelling

He recommends laying "a sound foundation with well planned drilling and sampling":

- Metallurgical test work consumes a lot of diamond drill core, and the drilling program must be designed accordingly. Some drill chips can be used for the initial test work phase, but core is needed for most of the program
- Maximise diamond drill diameter. "Far better to pay the extra cost than to find out too late that you can't test a coarse enough crush size," says Taylor
- Assay for leachable copper as well as total copper. Leachable copper is the true head grade for heap leaching, and the orebody should be modelled accordingly
- Select the appropriate leachable copper assay procedure. Better to start correctly than be faced later with a major re-assaying effort
- For oxide ore, use a hot sulphuric acid soluble procedure. The cold acid soluble method has been proven to be unreliable, and often understates the leachable copper assay
- For secondary sulphide ore use a sequential procedure of hot acid soluble followed by cyanide soluble on the residue, especially in the early stages. The cyanide soluble assay alone does not always work (for example it does not pick up chrysocolla) and can be revisited later when more is known about the orebody
- It may be worth tracking other key elements – e.g. calcium for gangue acid consumption
- Metallurgists and geologists should put their heads together early to set the assay procedure for the drilling program to avoid later backtracking
- Use recent core wherever possible for metallurgical samples. Consider older core only when there is limited oxidation or degradation. Protect your investment by keeping sulphide core in a freezer
- Carry out thorough mineralogical work to identify potential metallurgical issues early
- Define potential metallurgical ore types for testing based on detailed chemical analyses, mineralogical information, physical characteristics and core logging data. Be inclusive; the number of ore types can be reduced as test work progresses.

"Systematic test work is essential. Being systematic is the name of the game. Avoid

taking apparent short-cuts; you will usually live to regret it." Taylor adds the following advice:

- Adopt a phased approach, with increasing levels of detail and increasingly large column tests (e.g. bottle rolls>mini columns>short columns>tall columns)
- Carry out parallel economic studies and risk analyses covering all aspects of the project
- Tap water is usually ok for initial work, but switch to site water as soon as possible. Water composition can affect leaching and plant materials (e.g. high chloride)
- Track quality of potential site water. Watch out as the supply and/or quality can be seasonable
- Test a range of crush sizes and select the optimum as early as possible
- Always use realistic commercial leach conditions for column tests, such as acid level and irrigation rate
- Test alternative acid addition strategies early, including strong acid cure. Be aware of the difference between gross and net acid consumption. The net figure takes account of acid regenerated downstream if SX/EW is used
- Ambient temperature, pressure and even humidity can affect leaching test work, especially with sulphides. Therefore pay attention to any difference in ambient conditions between the test work location and the proposed mine site. Sometimes it may be necessary do test work in an enclosure under controlled conditions or at the proposed mine site
- Consider using controlled aeration for sulphide leach column tests – it is increasingly used in commercial operations
- If fines and/or clays are present, carry out percolation tests before committing to column tests. You may need to adopt agglomeration with strong acid and/or polymer, blending or desliming. If agglomeration is adopted, stability of agglomerates during handling and leaching is an issue to watch
- Build-up of impurities during leaching is not easy to simulate. If this is an issue, you may have to do supplementary work or benchmark against similar operations. High impurity levels can cause viscosity problems in SX during very cold weather
- Final column tests must be at the full projected lift height. This can lead to long test duration, especially for sulphides. For example, a 6 m high secondary sulphide column test can take a year to complete. Primary sulphide leaching can be even slower
- Final test work should be based on composites representing the final mine plan
- The question of pilot scale tests is always a thorny issue. It may be determined by corporate policy or financial institution requirements. In reality, a well-designed tall column program with comprehensive orebody coverage may provide more security than larger scale pilot work, which is usually limited to only a portion of the orebody
- If pilot scale tests are necessary, consider large 'box' or large diameter pipe tests as an alternative to test heaps
- Give early consideration to whether ROM leaching is an option for part or all of the orebody. This requires a specially designed test program and obtaining suitable samples can be a big challenge
- If ore sorting is included, all leach test work must be carried out on upgraded material which poses additional challenges to sample procurement.

Taylor says to be conservative in scale-up:

- Must apply adequate safety factors to test figures especially for copper recovery and leach kinetics. Remember to allow for a realistic ramp-up time which can be lengthy, especially for sulphide ores
- The SX circuit has an overriding effect on the leach curve, and must be taken into account. Don't be too optimistic when projecting the copper level in the SX feed solution. Allow for dilution with rain or snow and decreasing ore grades when appropriate
- Include an allowance for 'catch-up' in the SX/EW design, especially for the EW rectiformer, which is the ultimate bottleneck.

Picture courtesy of Netafim

GoldSim™ software

Success can depend on commissioning and ramp-up. Taylor warns against changing "the mine-plan unless supported by test work. If you lower the ore grade, you can't expect to make the same SX feed copper level. Failure to carry out additional tests will seriously jeopardise plant production and project economics."

Do not skimp on pre-production mining. You may need additional ore in a hurry if problems occur during commissioning and early operation. He also stresses that people must be available "to monitor the leaching performance during commissioning, no matter what. Leaching is your future; so don't let initial downstream, equipment or infrastructure problems divert your attention. Hire extra people for commissioning if needed – it will be money well spent.

"Recalibrate the leaching model with actual data on an ongoing basis. Do regular supporting column tests to predict leaching behaviour in advance of mining.

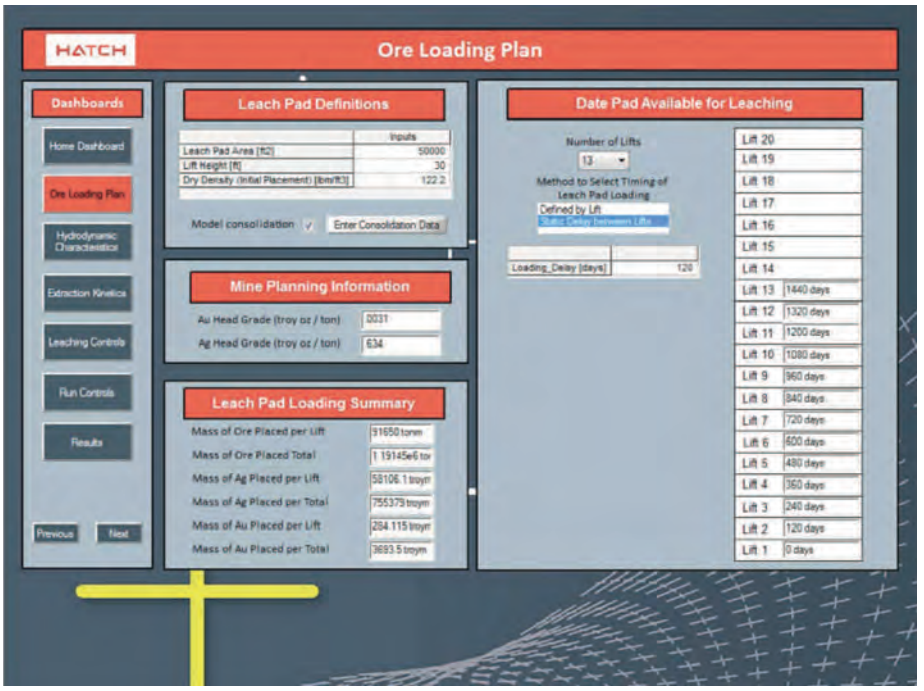
"If you use a contract crusher and heap builder, provide close supervision, especially in the early stages. Their priorities may be different from yours.

"Locate the heads of your geological, mining and metallurgical groups in adjoining offices, and insist they talk to each other daily. Successful heap leaching has to be a team effort. There is no room for a 'them and us' culture."

Barry Carlson, Regional Director of Mineral Processing, is one of **Hatch's** foremost engineering experts in heap-leach facility design, operation and closure. He is also a nominee to the *International Mining Technology Hall of Fame*. He is a leader in heap-leach monitoring systems—developing, championing, and pushing the boundaries of dynamic systems-modelling technology to new heights.

Dynamic modelling is helping heap-leach operators optimise performance dramatically. The system uses the first principles of hydrology and kinetic reactions to forecast gold recovery and solution inventory. Economic analysis is factored into the model directly, maximising value every step of the way.

When these modelling paradigms are applied early— during the design phase of a project—heap-leach performance can be optimised and its NPV maximised. Specific information about the mining company is combined with site metallurgical and hydrodynamic data, collected and entered into the modelling software. Scenarios are created and simulated to reflect the life-of-mine site. The result is a detailed understanding of ore recovery as a function of time, solution inventory, and drain-down analysis. This also assists in closure planning, providing alternative options to help evaluate financial feasibility and all associated costs. This modelling approach has increased gold recovery, increased project NPV and maximised solution tender.



As the heap height increases, the solution tenor is normally diluted. Under first leach, gold comes out of the ore very quickly, but then slows down near the end of the heap-leach cycle, diluted because of the lower concentrations of gold or tenor in the lower lifts and slower diffusion rates. But with the dynamic modelling tools Carlson is developing, lift heights and solution application rates can be optimised as the ore is stacked, maximising the recovery of lower-grade ore.

The models also lead to a better understanding of optimal leaching flow rates, allowing downstream components, such as the CIC sizing, to be modified for optimal returns. In one case, Carlson was able to show a client company that, based on the original design criteria, doing it the standard way was actually leaving gold behind. Using his methodology, the company's CIC capacity increased from 450 m^3/h to over 600 m^3/h, bringing ounces forward, producing gold sooner and increasing NPV.

An algorithm identifies where it is most optimal to leach, using metrics like solution-to-ore ratios to maximise recovery and minimise solution inventory. Operators can then make better-informed choices when considering future leaching operations and loading scenarios,

driving the overall performance of the mine with much greater success.

Looking at total gold recovery of the pad as a function of time, heap-leach modelling may impact the cutoff grades—either higher or lower—for mining. This information is critical for operators looking to optimise processes and maximise the recovery of metals. Instead of looking at the heap-leach pad operation in isolation, it becomes part of the entire operation of the gold mine that's being evaluated.

Stacking the pads

HUESKER says heap leach pads are considered the highest lined fills in the world. "The stability of the ore lifts is critical in order to avoid potential downhill heap failure. Stacking more ore faster enables faster returns, however, high loads and harsh chemical environments provide limited pad liner interface stabilisation options."

The stabilisation of the pad liner/overliner interface with chemically resistant geosynthetic reinforcement materials provides opportunities to stack ore lifts higher while maintaining the stability and integrity of critical interfaces. HUESKER offers engineered geogrid or geotextile reinforcement solutions which are proven to have high chemical resistance and long term stability. The advantages are:

- Increased liner interface stability
- Faster stacking of more ore leading to greater and quicker returns on investment
- Chemical resistant raw materials contributes to pad liner longevity
- Increased heap leach pad site safety.

HUESKER's geosynthetic engineering experience and capabilities enable the design of project specific solutions to enable the decoupling of loads from the heap leach pad barrier system. Geosynthetic reinforcement solutions which reduce or eliminate ore load transfer to the barrier system contribute to critical barrier system longevity and improved seismic interface stability. Advantages:

- Decoupling the barrier system from the ore loads
- Enabling steeper slope construction
- Increasing ore stacking volumes
- Contributing to interface stability of barrier systems.

In Arizona, North America's largest producer of copper, and the world's largest producer of copper cathode from the SX-EW, uses multiple leach pads.

In support of stacking operations on one of these leaching sites, between 2007 and 2014 **Terra Nova Technologies (TNT)** was responsible for the design, supply and construction of a total of five 72"x250' and three 54"x250' Super Portable® conveyors. Each of these mobile conveyors was supplied with an initial design capacity of 2,600 t/h.

For the development of a new heap leach pad as part of this mine's Southwest Mine-for-Leach project, TNT designed, supplied and erected 5 km of overland conveyors and a Super Portable stacking system (including an additional five 72"x250' Super Portable® conveyors, horizontal feed, horizontal and radial stacker) for the Southwest Pad. Equipment in this mobile stacking system has a capacity of 5,467 t/h.

Superior Industries TeleStacker® Conveyor is a telescoping radial stacker conveyor that, Superior says, "achieves speedy payback, which is measured in more tonnes per move, larger leach pad footprints and increased profitability."

Engineered with an internal stinger conveyor that maintains constant motion along a cell, the TeleStacker Conveyor distributes material evenly to achieve flat top piles, while also piling more material per move. Its longer stinger conveyor allows for greater flexibility and the popular FD Series Axle assembly allows a quick transition from radial to linear modes.

Irrigating the heaps

Netafim, known worldwide for its driplines, filters, valves, air valves, sprinklers, flushing packages and flow meters, recently introduced a cost-saving way to increase leaching performance while helping mines reduce labour and downtime. This comes in the form of a radio or cell-based monitoring and control package designed to increase operational efficiency from a single location so mines have real-time information regarding flow, temperature and pressure. This complete package of software, hardware and support equipment remotely monitors any number of elements deemed important by the mine and provides real-time information on which to act. The scalable system can also manage automated flushing of piping networks which until now has been a time-consuming and labour-intensive manual operation that required personnel to walk from area to area to open and close ball valves. Whether used in a cloud-based application or managed locally at a site, the technology 'turns on the mine' in a way that lets operators know real-time what is occurring across the site and helps to remove the need for personnel to walk the site in search of problems that may not be there.

Mike Stoll, Netafim Industrial Division Director Of Sales & Marketing, explains that "in addition to the newest control package, Netafim has a 50+ year history of manufacturing low-volume drip and driplines for applications as varied as landscape irrigation, agriculture, greenhouse and nursery as well as wastewater treatment and mining.

"In mining Netafim offers the broadest range of flow rates that start at 1.0 litres/h and go up to 8 litres/h (0.26-2.0 g/h), and uses the latest evolution in emitter technology that does not rely on a long flow path to reduce the pressure and manage the flow rate. This is critical because the shorter the flow path in an emitter, the less likely it is to become clogged. Simply put, the faster you can reduce the pressure along the length of the dripper from the point of entry to the exit, the more suspended particles will be and as such, the less likely that clogging will occur. In addition, Netafim's ability to mount the dripper to the inside wall of the dripline allows the emitter to capture its flow from the centre of the tubing where the flow is fastest and cleanest. That means the emitter is not capturing its flow from the wall of the dripline where debris collects."

Ore-Max was a pioneer in the application of drip irrigation to gold and copper mines in the late 1980s. The company says that "previously mines had used sprinklers which had many environmental and production limitations which were solved by the application of mining solution using drip systems.

"Today the use of drip on mines is standard on 90% of the gold, copper and uranium mines and it is also used on nickel and extraction of lithium."

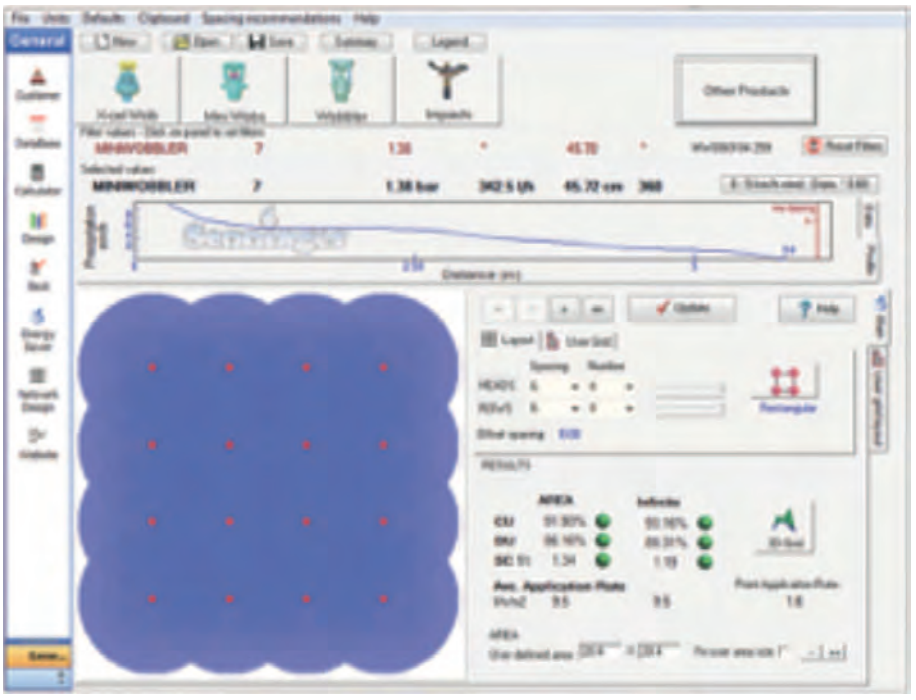
Ore-Max says its Max-Emitter™ is "designed to reduce plugging because mining solution always has contaminants in it. Hundreds of screens filter the solution so that it is almost impossible to plug the screens and the flow path is the largest available on the market. Further, two exit holes are standard but the emitter can be ordered with four holes to reduce plugging. All of this means that more emitters will be operating more of the time so you can achieve maximum ore extraction."

The Max-Emitter has a full 330° flow path - fully 90% of the emitter is flow path. This ensures that much lower flow rates can be used without plugging.

Senninger Irrigation's position is that low pressure, 1.03-1.38 bar spray nozzles like its "mini-Wobbler® evenly apply solution over large surface areas, much like a gentle rain," maximising solution/ore contact, while minimising the potential for channelling or clogging.

Senninger's WinSIPP2 custom mining software was developed to help leaching operations achieve required application rates and uniformity. It provides visual comparisons of various combinations of applicators, flows, pressures, and spacing options. "Analysing these combinations in advance helps assure optimal system design and operation," the company says.

WinSIPP2 software calculates the precipitation rate of irrigation systems. It aids in the selection of the best heap irrigation products by testing

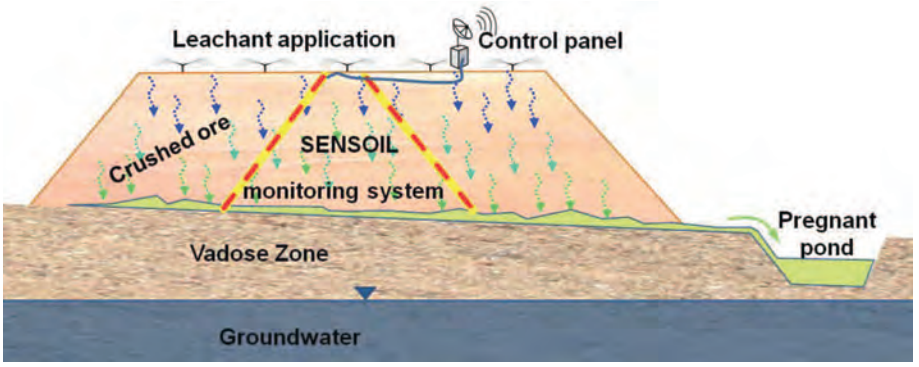


Senninger's WinSIPP2 software illustrates the uniformity, wetted diameter, and application pattern of a given profile through densograms. Then it displays the distribution uniformity of multiple overlapping devices to help determine what spacing would be optimum

the application uniformity of sprinkler layouts before a system is installed. The program compares different spacings, sprinkler models, nozzle sizes, and operating pressures to determine which would be best for any specific installation.

Maximising recovery

In heap leaching, implementation of optimal leaching conditions in thick unsaturated heaps is often based on the assumption that percolation from land surface through the deep section of the unsaturated sediments would create the desired hydraulic and chemical conditions that promote leaching of the desired elements from the sediments. However, water application on land surface does not necessarily result in the desired chemical and hydraulic conditions in deep sections of the vadose zone. As such, in-situ monitoring of the actual conditions in the subsurface could contribute dramatically to optimisation of the leaching process. The ability to monitor deep sections of unsaturated sediments, such as prevails in ore heaps, was recently improved by the novel Sensoil Vadose zone Monitoring System (VMS) from **Tenova Bateman Technologies** (TBT). The VMS was specially developed to provide real time information on the hydrological and chemical properties of the percolating water across the unsaturated domain. It has been successfully tested in shallow alluvial aquifers with monitoring under ephemeral rivers in hyper-arid deserts in Namibia, South Africa, Israel and Spain.



Schematic illustration of heap instrumented with TBT's VMS. The VMS provides the heap manager with continuous information on the chemical composition of the pore solution as well as online information on the flow characteristics of the leachant through the heap

Data collected by the system allows direct measurements of the temporal variations in sediment water content with respect to the irrigation cycles implemented on land surface. As such the solution percolation velocity and fluxes in the unsaturated sediments may be measured on-line and provide direct feedback to the pad managers on the efficiency of the infiltration process. In addition, the monitoring system allows continuous sampling of the percolating solution across the entire ore heap. As such the chemical evolution of the percolating solution with respect to the chemical properties of the implemented leachant on land surface and the mineral dissolution in the heap ore may be monitored across the entire heap cross section. Accordingly, the leachant application cycles and applied concentration may be managed according to the actual chemical evolution of the percolating solution in the heap for optimal mineral extraction.

The VMS is a new addition to the family of advanced hydrometallurgical technologies and systems supplied by TBT, which include the Bateman Settler™, Bateman Pulsed Columns (BPC) and the Turbulent Technologies Mixing System.

The VMS enhances monitoring of the heap leach pad, and provides on-line temperature, moisture, pressure measurement and continuous solution sampling. It enables hydraulic and chemical profiles to be drawn through the heap, indicating the extent of percolation, leaching and extraction efficiency. Its analytical sample collection feature allows monitoring of the leach profile in almost real-time, in-situ, instead of waiting until the heap is dismantled.

Dale F. Rucker, Chief Technical Officer of **hydroGEOPHYSICS**, explains that "many studies have shown that surface leaching of low-grade rubblised ore is generally an effective means to extract nearly 70 to 90% of a heap's metal content. The last 10-30%, however, has significant economic impacts on the operation, profitability, and eventual closure of the mine. Therefore, any inexpensive means to extract the last bit of metal from the heap can be of great value.

"Lately, we have been conducting targeted subsurface leaching (SSL) on copper ore that has historically underperformed due to high fines and compaction. To this end, we recently hit a milestone in our experience: a billion gallons of barren solution injected through a number of wells that targets the underleached ore. Our experience in this endeavour has provided much insight into heap performance, effects of localised phenomena, and the importance of hydraulic and metallurgical monitoring to understand the economic impact of SSL."

The Carlota mine in central Arizona includes a fines-rich, 42 Mt run-of-mine heap that has undergone many changes during construction and operations (C&O)[3]. Most changes have been driven by the need to increase production, which is directly tied to the ability of the ore to drain and the fines content has limited the mobility of the leachate. Deviation from the original C&O plan has concentrated on better stacking practices and focused raffinate delivery. "Specifically, the mine has undergone three major C&O phases, listed in order from oldest to newest: advanced truck dumping, retreat conveyance stacking, and deep well rinsing (or SSL).

"Truck dumping was part of the original mine design, but it became apparent that the traffic on the heap's surface increased the ore compaction and density, which ultimately led to lower irrigation rates. Construction then switched to retreat stacking, which allowed for better irrigation rates and little surface ponding. The SSL program was initiated at the end of active mining and is being used to target older areas where copper is abundant and surface leaching is unable to reach.

"Throughout the life of the heap, geophysical mapping with electrical resistivity tomography and ore samples obtained from sonic drilling have been used to help spatially define hydraulically troubled areas along with specific hydraulic properties that give rise to the low drainage. These methods have also been used to guide C&O practices and provide a level of confidence in expected outcome."

At the start of the project, the heap was estimated to contain 50 Mlb of copper. The data and findings from seven years of geophysical investigation at Carlota generally show improved drainage conditions through newer stacked ore, but poor drainage persists in parts of the older truck dumped material. "SSL has been shown to push raffinate to areas that have been underleached and favourably change the hydraulic conditions to allow for additional drainage."

Electrical resistivity is a fairly common geophysical method to evaluate the internal structure of heaps and understand the hydraulic consequences of different C&O strategies. At Carlota, this method was applied over many years as C&O evolved.

"The resistivity acquired within the truck dump material revealed heterogeneous material as interpreted from the electrical data. A few areas would be extremely wet, while others appeared to remain dry. Significant ponding occurred in the material because localised low permeability zones prevented adequate drainage. When the mine switched to retreat stacking, the newer material atop the truck dumped ore was more uniform in electrical resistivity, indicating uniform wetting, but drainage was still an issue though older truck dumped ore. Interlift drain pipes were placed at the interface in anticipation of the problem, with the drains stubbing out at the toe of the heap. The drains were effective at removing a portion of the PLS as they were always full.

"At the last stage of C&O, SSL was initiated to help with inventory drawdown. The electrical resistivity data showed conclusively that the raffinate could cover broad swathes of ore uniformly and monitoring wells placed near the rinse wells extracted solution with significantly higher copper and lower free acid than the raffinate. Over the next three to four years, SSL and electrical resistivity monitoring will continue the inventory drawdown. It is hoped that at least 40 to 50% of the remaining inventory can be extracted prior to initiating closure."

A pilot-scale injection test, four rinse wells, was conducted in 2013. Work examined injection scenarios and engineering parameters were developed. The following year was the operational-scale test with 21 rinse wells. Monitoring continued. Full scale operation began in 2015, with 31 additional rinse wells. 2016 sees the drilling of 32 more rinse wells, with 28 more planned. The draindown will begin in 2020.

Initial strategy was to start simply by introducing raffinate to the rinse wells. The initial well design was by Haley and Aldrich, with

drilling by Yellow Jacket with a hollow stem auger. Fine grained material facilitated spreading in the heap.

- Rinse wells spaced about 90 ft (27 m)
- Phase I designed with four-spot pattern
- Phase II designed with wells in a line

Rinse well screens have started to plug. This typically happens after about three months of continual rinsing. Cameras indicate biological growth.

The SSL program has been operating for well over two years and has been shown to be successful at removing inventory. Expansion of this program will continue for a few more years, but "there is still much to learn," says Rucker.

The authors[2] expect that "geophysical data obtained in the future, well into closure and reclamation, will be used in helping determine draindown conditions, effective cover design, and stability of the heap."

Flexible wall unsaturated flow apparatus as recommended by GeoSystems Analysis

Ore permeability

Michael Milczarek and colleagues at **GeoSystems Analysis** (GSA) stress that "ore permeability has long been recognised as a critical factor in heap leaching performance. Poor ore permeability results in decreased metal recovery and increased leach recovery time."

Many factors influence leach ore permeability, including ore/rock behaviour under physical crushing, chemical decrepitation from acid agglomeration and raffinate contact (chemical crushing), the nominal crush size, heap height and lixiviant irrigation rate. During mine planning, ore permeability characterisation programs provide data to characterise the effect of these factors on permeability and allow for optimisation of operations methods. During operations, in-situ monitoring programs can provide real-time data to determine heap leaching efficiency.

Permeability characterisation programs should test the ore material at the designed crush size (or ROM), and under operating conditions such as heap height and irrigation rates. GSA recommends the use of "large diameter cores/flow cells which can directly measure solution and air permeability under nominal irrigation conditions, and the use of flexible wall (compression) methods which can mimic the effect of overburden pressure and variable bulk density which may occur within an operating lift and also allow unsaturated flow parameters to be measured. In addition, care should be taken to use the appropriate lixiviant and simulate the amount of ore decrepitation (chemical crushing) that may occur during leaching operations."

In one such example, a 500,000 t copper sulphide leach pad was instrumented and monitored to investigate large-scale heap leach fluid dynamics under varying irrigation and aeration schemes. The 18 m high heap had an approximately 90 m x 90 m leaching area. Prior to stacking, aeration lines were placed on the gravel drainage layer to provide oxygen to the leach core for enhancing bio-assisted leaching. Two aeration line grids were established that allowed for the air source to originate from east or west of the pad.

"The in-situ monitoring data indicated that the initial solution and air permeability of the heap was sufficient to develop high temperatures; however, gaseous oxygen contents were observed to be variable and rapidly declined. It is believed that a decrease in ore permeability (resulting from ore decrepitation after initial leaching) resulted in a decrease in aeration (low oxygen) efficiency. The doubling of aeration rates improved the oxygen flow into the heap temporarily until air entrapment created back pressure in the leach ore which further reduced permeability and resulted in further declines in aeration efficiency. Decreases in irrigation rates and alternating the aeration source then stabilised the heap. Results from the monitoring allowed for real-time adjustments of heap pad irrigation and aeration rates to increase heap leaching efficiency."

Better chemistry

"Physical impurity transfer in SX has a significant impact on operating costs, EW performance, and cathode quality. Some operations use a wash stage to limit impurity transfer by diluting the entrained PLS to prevent direct transfer to EW. Wash stage operating conditions vary, impacting impurity transfer. A number of factors impact dilution efficiency including mixer continuity, wash aqueous acidity, and organic quality." **Cytec** studied the impact of these variables on dilution efficiency and compared them to current industry practice[4].

Clariant Mining Solutions says its FLOTICOR® LA 7163 excels in improving dissolved oxygen in a gold mine leaching process because it:

- Provides better cost performance than competitive products, saving the mine money
- Offers a dosage rate one third that of other reagents
- Does not adsorb on activated carbon
- Delivers lower foam production
- Reduces air pumping rate by 10%, lowering energy costs

A gold mining operation in Brazil requested an additive to improve dissolved oxygen in gold leaching pulp. Clariant responded with two additives and a new chemistry to be tested against the mine's current reagent.

The pulp containing the leached gold is in contact with activated carbon, so this new gold leaching additive could not adsorb on the carbon.

Some critical ore concentrates form into a pulp, where it is difficult to increase the dissolved oxygen, so more cyanide is added to compensate for the lack of oxygen. However, there is a limit to the cyanide dosage amount, since residual cyanide must be removed before being discharged to the tailings dam. As a solution to this issue, the mine began using a polymeric dispersant to increase the dissolved oxygen.

Clariant's R&D team tested multiple products at the laboratory scale taking into account the ore's mineralogy. It discovered that a new type of chemistry, FLOTICOR LA 7163, exhibited clear advantages compared to the competitor's product: a much lower dosage and low foaming.

After laboratory approval, Clariant supplied 2 t of FLOTICOR LA 7163 and developed a product dosage system that was both simple and reliable. FLOTICOR LA 7163 went through more than six months of testing.

At the plant trial stage, FLOTICOR LA 7163 was initially dosed at 300 g/t. Upon reviewing the laboratory results, the product increased the dissolved oxygen in the pre-leaching tank from 2.5 to 3.5 mg/litre. The air pumping rate was also reduced by 10%, saving energy costs.

Lower dosages of the product were subsequently tested, all showing an increase in dissolved oxygen in the pre-leaching tank and in the following leaching tanks. The final dosage rate selected by the customer was approximately one-third that of the competitive product's dosage.

Given these benefits, the customer is now evaluating FLOTICOR LA 7163 as an additive to increase dispersed oxygen in non-critical ores, where the customer historically did not use an additive.

Huntsman's POLYSIL® coagulant range is useful for improving processing outcomes in hydrometallurgy plants where colloidal silica is present in leach liquors[5]. By coagulating colloidal

silica with POLYSIL, these particles can be grown in size to the point where they can be flocculated and removed from leach liquors. The removal of these fine colloidal particles can reduce flocculent demand, enhance settling rates and improve TSS and solution clarity of overflow liquors from CCD/clarifiers reporting to SX.

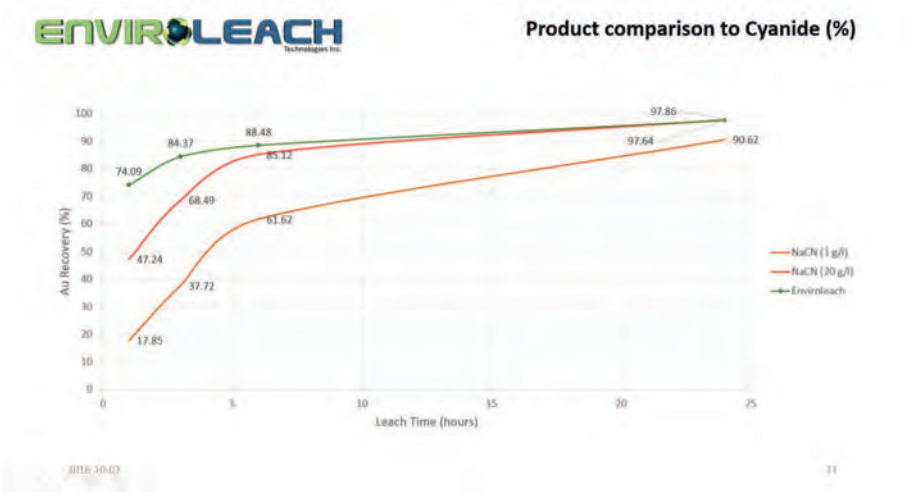
New leaching ideas

In July 2016 **Iberian Minerals** filed a patent in the US for its Enviroleach, a proprietary, environmentally-friendly, non-cyanide based leach formula for the extraction of precious metals from ores, concentrates and tailings. A new 100% owned subsidiary, **Enviroleach Technologies** has been created to pursue commercial opportunities for this product. The past 12 months have seen extensive testing of the unique Enviroleach formula on a number of different ores, concentrates and tailings. Iberian notes; "the sustainability of the gold industry is being challenged by reduced grades, more complex ores and increasingly stringent environmental conditions. Within industry both the use and disposal of cyanide present significant safety and environmental challenges".

Enviroleach Technologies is helping reduce the risks and environmental impact of current processing operations and developing alternative processes that use less-toxic alternatives to cyanide.The primary challenge in devising a suitable substitute for cyanide in gold processing lies in developing an equally effective, stable and degradable leach reagent, which is not a persistent environmental toxin. As gold cyanidation rates are relatively slow, the industry has been searching for faster gold leaching reactions capable of facilitating high metal recovery rates.

Alternative lixiviants or leaching agents should also be inexpensive, recyclable, selective, non-toxic and compatible with existing downstream recovery processes. There is an increasing interest in finding new alternatives or improving previously tried processes. Numerous other chemicals have been tested to leach gold, including; thiosulphate, thiocyanate, ammonia, bromine, chlorine, bisulphides, and thiourea but no-one has come up with a more cost effective and productive method than leaching with cyanide until now, reports Iberian.

The following table compares the applicability spectrum, costs, consumptions and sensitivities of the Enviroleach formula to cyanide and some of the more prominent alternatives to cyanide.



Gold and other precious metals are readily recovered from the Enviroleach solution through a number of well-known and proven extraction methods including; EW, carbon adsorption and precipitation.

Duane Nelson, CEO of Enviroleach Technologies, states: "we are very excited with the results of the Enviroleach formula. We have now completed over 2,000 tests and it has been proven by independent analysis to be safer, and it provides faster dissolution rates and much broader operational parameters than typical and high intensive cyanide solutions on a number of different ores, concentrates and tailings. Enviroleach can potentially offer an effective alternative to cyanide worldwide and help to reduce the risks and environmental impact of mineral processing. It may even open up opportunities in areas where the use of cyanide is banned including several European countries, South American countries and some American states. We will continue testing the formula on a broad selection of ores, concentrates and tailings and report the results over the next few months."

Recently, Iberian engaged the services of Met-Solve Laboratories to oversee the development and independent testing of the formula. Ish Grewal, President of Met-Solve Laboratories, states; "I have had the opportunity to test, review and analyse numerous lixiviants for gold. Having spent extensive time studying the results of the Enviroleach reagent, we are very impressed with this formula. We are delighted to be working with the Iberian team to advance this exciting non-toxic technology."

Last year, **Mining and Process Solutions** (MPS) was awarded an exclusive licence to the GlyLeach™ process. This is a novel leaching technology that was developed by Curtin University for leaching of base and precious metals. It is an alkaline based process that will leach copper from copper oxide, mixed oxide and supergene sulphide ores, and even primary copper sulphide ores. It will also leach gold when the temperature of the glycine is raised to 60°C.

In signing the agreement, the process inventor, Professor Jacques Eksteen, from Curtin University's Department of Mining Engineering and Metallurgical Engineering commented: "the process has a number of immediate applications including leaching of low grade ores, differentially leaching of copper and gold ores, upgrading concentrates, and tailings retreatment."

The major reagent in the process is glycine which is the simplest and cheapest of the amino acids, and is available in bulk ranging from food grade to technical grade. It has a number of attractive chemical and physical properties that gives it significant advantages over any other copper or gold lixiviant:

- It is an environmentally safe and stable reagent. It is biodegradable and is easily metabolised in most living organisms
- It is active as a selective leach agent only when used in an alkaline-based circuit between pH 8 and 12
- It provides a step change in copper leaching with enhanced solubility of copper ions in aqueous solutions and forms stable complexes with copper. It is a very effective leaching agent for almost all copper minerals apart from chrysocolla, a copper silicate mineral
- It is easily recovered and recycled. Apart from normal process losses (usually expected to be less than 5%), +99% of the glycine is recoverable

	Enviro Leach	Cyanide	Thiorea	Thiosulphate	Thiocyanate	Bisulphide	Ammonia	Chlorine
Applicability Spectrum	Broad	Broad	Limited	Limited	Limited	Limited	Limited	Limited
pH Sensitivity	Low	High	High	High	Low	High	High	High
Temp Sensitivity	Low	Low	High	Medium	High	Medium	High	Medium
Reagent Concentrate Sensitivity	Low	Low	High	High	High	High	High	High
Leach Kinetics	Fast	Medium	Fast	Fast	Medium	Slow	Fast	Fast
Toxicity	Low	High	High	Low	High	High	High	High
Highly Acidic Or Highly Caustic	No	Yes	Yes	No	Yes	Yes	Yes	Yes
WGK Value (H20 Hazard Classes)	1	3	2	1	1	2	2	2
Consumption Rate	Low	Low	High	High	High	Medium	Low	Medium
Reusabilty/Recyclability	High	Medium	Low	Medium	Medium	Medium	High	Medium
Detox Costs	N/A	High	High	Medium	High	High	High	Medium
Requires Off Gas Control	No	Yes	Yes	Yes	No	yes	yes	Yes
Requires Elevated Temperature	No	No	No	No	Yes	Yes	Yes	No
Costs compared to Cyanide	Higher	N/A	Higher	Higher	Higher	Lower	Higher	Similar
Capital Costs	Low	Medium	High	High	High	Medium	High	High

- Both glycine and sodium hydroxide (used to maintain alkaline conditions) are regenerative in the process so that reagent consumption is low.

MPS Technical Director, Frank Trask observed that it is a simple process that requires no new equipment to be designed, has low operating costs due to regeneration of the principal reagents, and is expected to provide high copper recoveries with almost all copper minerals even chalcopyrite; long considered the 'Holy Grail' of copper leaching. It will also offer the gold industry a non-toxic method of leaching gold, something that is becoming more important in many jurisdictions around the world.

MPS and Curtin have more recently developed a proprietary GlyCat™ leaching technology for gold-copper ores. In conventional gold heap leaching, quite low copper grades can dramatically increase cyanide consumption, often rendering the project uneconomic. Conversely, any gold present in copper ores is completely lost in acid heap leaching. GlyCat offers a way around these long standing problems by concurrently leaching both copper and gold in an alkaline glycine cyanide solution. The process economics get a triple boost; higher revenue from recovery of both metals, lower overall reagent cost, and potentially lower capex as a result of accelerated leach rates.

MetaLeach and DEMET

Alexander Mining PLC is pleased to report that it has received notification that its MetaLeach subsidiary has been granted a patent for a *Method for Leaching Zinc Silicate Ores* in Australia.

Martin Rosser, Chief Executive Officer: "The granting of our Zinc Silicate Leaching Patent in Australia is most significant. Zinc silicate mineralisation comprises a significant proportion of non-sulphide zinc ores targeted for use by our AmmLeach® process and this is the first patent to be granted for this particular leaching method patent family."

Also in Australia, MetaLeach has executed a licence agreement with Accudo Metals, a new Australian company which has been established to exploit Alexander's proprietary leaching technologies. It is funded by investors and clients of BlueMount Capital, a national mid-tier Australian investment bank. Pre-funding for test work and a full scoping study on the first targeted opportunity has been committed. Subject to the study being positive, Accudo foundation funders and BlueMount clients will fund a detailed feasibility study.

MetaLeach has granted Accudo an exclusive licence for up to five mining projects in Australia to use its leaching technologies.

Rosser said: "Accudo is well financed and intent upon rigorously evaluating the use of Alexander's leaching technologies in Australia. We have been in detailed discussion with them about a range of identified potential projects of interest and we look forward to developments with optimism."

Accudo director Saliba Sassine said: "Accudo is pleased to have entered into this ground-breaking agreement for both parties. The company is excited about the prospects and testing the technology on targeted ores."

Pursuing a philosophy of treatment without chemicals, **Blue Planet Strategies** (BPS) continues to advance its innovative and versatile proprietary DEMET™ (Dynamic Electrolytic Metals Effluent Treatment) platform technology and process suite. "Electricity; rather than chemicals, is used to adjust target stream parameters in a variety of desirable ways to offer an unprecedented range of treatment options that can be tailored to site-specific needs," explains Patrick James, BPS President/CEO. DEMET treatment serves to recover valuable products, clean the target stream, or control target stream chemistry to improve overall process efficiency/stability or extract value from bleeds or waste water prior to final treatment for discharge or reuse and potentially extend production to the use of marginal/waste grade ores. "Treatment is cleaner, often cheaper, and can recycle key consumables and/or provide new revenues via recovery of components now lost," says James.

Originally developed to either directly electrowin or concentrate metals from weak PLS to enable production from waste-grade ore, difficult to leach ore, or tailings, DEMET continues to rapidly demonstrate new functionality.

DEMET treatment can target a variety of mining influenced waters (MIW), including both hydrometallurgical sources like weak leach streams, raffinates, bleed streams, or drain down waters and pyrometallurgical sources like smelter/refinery blow down waters, electrorefining bleeds, and forming/descaling/casting operations dragout and spent solution treatment.

In PLS and raffinate treatment, DEMET can target residual metals and/or acid recovery or concentration, control of pH or interfering iron concentrations, sulphate removal and selective recovery of valuable leached components. The latter can include the target ore metal and other common major PLS/MIW contaminants as enhanced value products.

"DEMET implementation capitalises on advanced design features that provide low energy consumption, high operation rates for compact footprints, and resist fouling and dendritic shorting which often challenge conventional electrolytic cells," James says.

A recent application focused on tailoring the chemistry of a leach raffinate stream for a top tier copper producer using heap leach processing. Cost-effective raffinate treatment of a high TDS raffinate bleed stream to adjust solution chemistry without creating solids was targeted to enhance production. The primary treatment goal was stream pH and targeted iron level adjustment to customer specifications with acid recovery as a secondary goal. Scoping work indicated DEMET treatment feedstock costs of ~60% that of conventional lime treatment (electricity for DEMET versus lime-CaO for conventional neutralisation) for target neutralisation and that product acid solutions up to 6% sulphuric acid could be directly generated using DEMET.

A low capacity (~1/2,000th flow)

validation prototype using full-sized components in a shortened stack configuration (*shown in the picture*) was and continues to be tested. Activities include third party validation at an established mining equipment/process validation facility near Tucson, Arizona. The basic unit serves to cost-effectively demonstrate both dimensional and stacking scaling while also enabling site-specific tailoring of salient key operational and design parameters. This facilitates refining site-specific application and provides a data driven basis for modular scale-up to target system capacities through additive summation of repeat units. The unit was shown to successfully adjust treated stream pH and eliminate target iron to low levels without generating solids and while concurrently creating ≥1.0% sulphuric acid product as desired. Additional operational refinement is currently underway to drive cost/benefit analyses to underpin specification development and design refinement for a targeted follow-on ~1/10th capacity pilot.

Application of DEMET treatment for the adjustment of the salient chemistry of leach streams generated by pressure oxidation treatment and residual metal recovery from process stream water was also recently considered in a presentation and an associated proceedings paper for the SME Annual Conference in February in Phoenix. Briefly, James explains, "application of DEMET to a proposed gold processing facility was considered in light of the public information provided in the prefeasibility of the project. Considerable cost savings (~50%: again on a feedstock basis versus using lime) were noted for the project and indicated a medium estimated IRR on DEMET implementation of +22% over the planned Life of Mine (LOM) when feedstock and sludge handling savings plus defrayed acid purchase costs were considered. Additional potential tertiary revenue recovery opportunities to further improve LOM economics by net ~$100 million of revenue were noted but not included in the IRR analysis at this point."

The DEMET technology and treatment platform continues to rapidly evolve and find new applications treating MIW such as leach solutions to achieve cleaner and often more cost-effective solutions improving lifecycle costs. DEMET treatment may lower treatment costs, reduce sludge generation and handling costs, and provide new opportunities for revenue generation and/or cost defraying through selective saleable product generation during treatment.

SX/EW

Innovation Metals Corp (IMC) has developed the RapidSX™ process, which it says is a dramatically improved SX process for the separation and purification of rare-earth elements (REEs), nickel and cobalt, and other important metals including copper. The patent-pending process significantly reduces the number of process steps required for SX as well as the physical footprint of operations. The time to reach process equilibrium is also significantly reduced, from weeks in conventional SX systems, to a few days using the RapidSX approach. The process also reduces the quantities of organic reagents required and the power requirements for equipment operation, as well as the amount of inventory required to be loaded into the system at any one time.

The process was recently applied to the separation of nickel, cobalt and other valuable metals, from a PLS produced from a bulk sample provided by a major miner of nickel-laterite ores. Commercial-grade (99.6%+) purities were obtained.

"In addition to utilising IMC's RapidSX process for the separation and purification of these valuable metals once in solution," said Patrick Wong, CEO of IMC, "we have combined a unique, proprietary chloride-based leaching process for producing the PLS, with a cost-saving acid-regeneration step. This allows us to extract and to monetise over 80% of the metals present in these ores (compared to the typical 2-3% seen with current laterite-ore processes), while reducing acid consumption and cost. We are now looking for strategic and financial partners who can see the benefit of such an approach to lateritic-ore processing."

"Existing nickel-sulphide deposits are being depleted through mining," commented Gareth Hatch, President of IMC, "with few high-quality exploration targets on the horizon. Nickel-laterite deposits are therefore set to become the most important source of nickel in the future. In addition, future demand for cobalt in Li-ion batteries is projected to grow dramatically, as electric vehicles take increasing market share in the automotive sector."

In August, IMC announced the successful completion of a demonstration program to produce commercial-grade Pr-Nd oxide, using feedstock from the Mineração Serra Verde (MSV) deposit in Goias State, Brazil using RapidSX. Pr-Nd oxide is in increasing demand for the production of high-performance permanent magnets, used in a wide variety of industrial, automotive, defence and clean-tech applications.

Hatch explained: "Combining the time-proven chemistry of SX with IMC's proprietary column-based approach, avoids the risks associated with novelty separation approaches that require expensive resins and other complex methods, not yet demonstrated at scale."

The demonstration project was conducted at IMC's pilot-plant facility in Mississauga, Canada, capable of producing 2 t/month of REEs. The high-value Pr-Nd oxide was separated to 99.5% total REE purity using RapidSX; La oxide was also produced as a byproduct of the demonstration program, with 99.97% total REE purity.

Although the process needs to be further demonstrated at a larger scale, these initial results indicate average separation costs of below $2.00/kg for a suite of high-value separated REEs, with capital costs for a 2,500 t/y REE RapidSX-based facility in the region of $10-15 million or less.

Resource Recovery Technologies (RRT) offers MSX, its centrifugal solvent extraction plant which it says "reduces organic use by more than 95%." To prove the point, RRT offers an MSX 300D (300 gallon/min or 19 litres/s PLS) demonstration plant for copper SX. "MSX 300D pays for itself in 24 months or less by producing rich electrolyte for 1-2 Mlb/y of copper cathode," says Randy Finfrock, RRT Founder & President, "...depending on the feed grade. We also offer membrane demonstration plants to reclaim organic from raffinate or rich electrolyte.

"Our product and byproduct recovery systems apply centrifugal and/or membrane science to the separation of solutes from process solutions."

RRT's suite of services includes:

- Solution analytics and characterisation
- Bench scale and prototype evaluation
- Design, engineering and optimisation
- Operational support and training
- Centrifugal solvent extraction
- Byproduct membrane extraction
- Organic-aqueous membrane separation
- Nanofiltration for desalinisation.

RRT's gravity-enhanced MSX plants use an integrated centrifugal extractor (CSX) for mixing and separating immiscible process solutions in a single annular chamber. CSX is optimised for high throughputs to achieve desired extraction efficiency, maximum loading, and net transfer. Modular CSX trains, one for extracting and one for stripping, are scaled for feeds of 315 to 1,580 litres/s (5,000 to 25,000 g/min) simply by adding additional centrifuges. "MSX plants are fully enclosed with low holdup volumes, so the initial organic inventory to load the plant and makeup to replace organic lost to entrainment and evaporation are reduced by more than 95%," Finfrock notes.

The annular CSX was originally developed by the US Department of Energy (DOE) to process uranium. DOE designed the elegantly simple centrifuge to both mix and separate process solutions in the same housing. One of DOE's national security labs, now a strategic technology partner of RRT, is working with RRT to optimise CSX for copper SX and scale it to a 63-litre/s (1,000 g/min) production model for rugged mining applications. RRT initially ran feasibility tests of MSX at an Arizona copper mine. An off-the-shelf DOE centrifuge was installed and the MSX skid was automated to perform extracting

and stripping. Field data showed 89% extraction efficiency using 42% less organic and minimal organic entrainment – "all in less than 15 seconds for extracting and 30 seconds for stripping," reports Finfrock. "We also found that optimising O/A and V/O ratios will further enhance extraction efficiency and max loading, and redesigning minor internal parts of the centrifuge will improve net transfer and phase separation. That's when we engaged the DOE lab to customise a proprietary CSX centrifuge for copper SX – the first of its kind on the market.

"In another study, we compared holdup volumes of an MSX plant to a conventional SX plant of equal capacity, and found that the MSX plant requires over 95% less initial organic inventory to load the plant. Since MSX is a fully-enclosed loop system, it also requires over 95% less makeup organic to replace losses due to evaporation and entrainment."

RRT's BFX ceramic membrane solution is ideal for reclaiming entrained organic. BFX (byproduct filtration extraction) plants recover organic entrained in raffinate or rich electrolyte for reuse. RRT uses ceramic membranes since they are resistant to concentrated caustic, acidic, and organic solvents. Ceramic material enables high mechanical strength, chemical compatibility, thermal stability, and flux for a longer operational life.

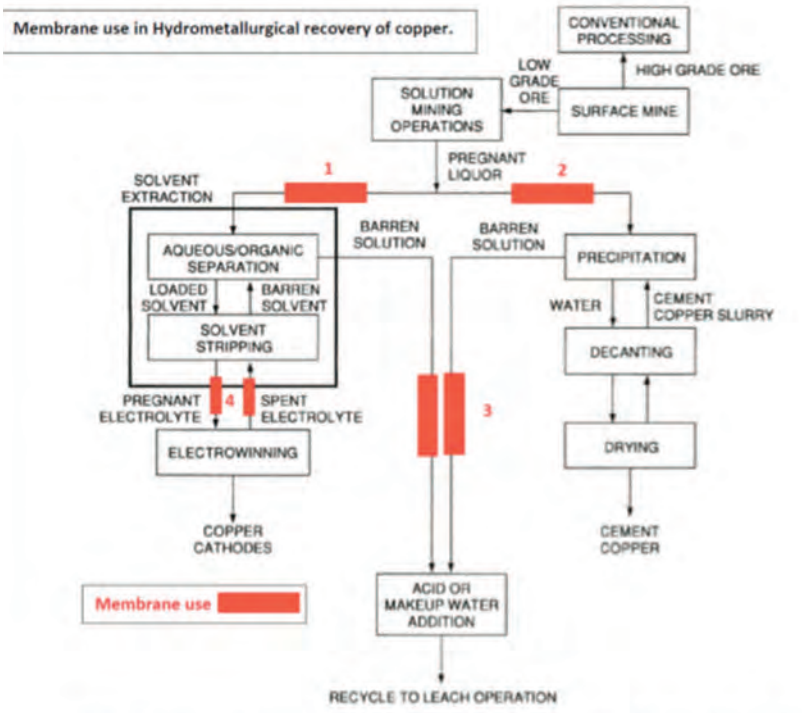
RRT is also developing a nanofiltration solution with a copper producer for treating pregnant leach solution prior to entering the SX plant to improve the quality of the PLS and reduce the size of the stream.

Phil Morton, Mining Business Development Manager at **Genesys International**, a leading provider of chemicals for reverse osmosis, nanofiltration and ultrafiltration systems, notes that one of the earliest large-scale examples of reverse osmosis membranes being used to both clean up wastewater and recover metals was at Mexicana de Cananea mine in northern Mexico. The mine was facing closure due to an ironic combination of insufficient water and the threat of the operational parts of the mine becoming flooded. 17 million m³ of wastewater had accumulated in the pit, which had been used as a pregnant leach reservoir since the 1980s. Following successful pilot plant tests the management team decided to install a full-scale reverse osmosis membrane plant in 1997, working with Harrison Western.

The plant was used to:

- Remove water from the pit
- Increase the copper concentration in the acid leach water fed to the copper extraction plant
- Remove excess water from the leach circuits
- Recover water from the tailings thickener
- Produce clean water for ongoing production.

It was designed to treat a feed water flow of 900 m^3/h (4,000 US gal/min) operating at 50% recovery and producing a 450 m^3/h concentrate stream at 1.6 g/litre of copper and 450 m^3/h of clean permeate water for reuse.



Adapted from Source: Technical Resource Department: Extraction and Beneficiation of Ores and Minerals, Volume 4 Copper, August 1994 U.S. EPA.

The key objective was to increase the copper concentration in the feed to the SX/EW plant.

Copper deposited on the cathodes increased by more than 14%, creating savings of $212,000 in process water cost and $27,000 in sulphuric acid costs. The level of water in the pit also dropped and was predicted to continue dropping by about 3.5 m/y, equating to around a billion gallons.

According to Harrison Western, the typical capital cost for the membrane plant was $1.5-$2.5/US gal/d. The typical operating costs were $1-$2/1,000 US gal of water recovered, giving a payback period of one to three years.

The operating costs included:

- Power consumption
- Prefiltration and pretreatment
- Antiscalant and cleaning chemicals
- Membrane cleaning and replacement.

The combined capital and operating costs of an alternative solution, a lime precipitation system to account for the loss of copper, would have been around $5/1,000 US gal of water recovered.

"Despite the success of this first example, adoption of the technology in the mining industry was slow to take off. This may have been due to the operational and capital costs involved as well as a shroud of secrecy, which resulted in a lack of published reference material," Morton says.

"Most of the operational membrane plants in the industry have been commissioned in the last five years, thanks to a drop in the price of membrane elements and more reliable plant designs. Mining companies Barrick and Newmont in particular have established several successful plants around the world during this time.

"At Genesys International we have identified just 70 operational membrane plants in the mining sector globally. Of these, 51 of these were commissioned within the last decade, 69% are located at gold and copper mines and nearly a quarter are registered for use to recover metal. This is because, in precious metal mines, membrane plants can be used to concentrate waste water, making it possible to recover additional metal from 'barren' liquor."

The Genesys International team can advise on the most appropriate cleaning regime to maximise the efficiency of membrane plants for metal recovery. ***IM***

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