With the strength of the gold and copper markets maintained at historically high levels, the number of new operations targeting those commodities will undoubtedly increase and the pressure on technology to meet the challenges of an expanding industry will intensify as a result. Essentially, that means the process of heap leaching is likely to come under the microscope.

According to the authors of *State of the Practice Review of Heap Leach Pad Design Issues*, Richard Thiel and Mark Smith, the greatest challenges facing the heap leaching process in recent times – as far as pad design is concerned – are the increasing size of heaps; increasing loading of machines on the pads of up to 53 t per wheel; coarse rock overliner; concentrated acid exposure; increasing size of hydraulic heads; and liquefaction and water management in tropical climates.

"Modern heap leaching practices represent an expanding technology that is pushing the limits of known performance parameters and creating some the world’s largest man made structures," Thiel and Smith wrote.

The paper, published in 2003, examined advancements including heap leach depths that have passed 150 m; linear systems performance including developments in drainage pipe performance testing; and using concentrated sulphuric acid pre-curing for copper ores. He told *International Mining* recently that the physical technology examined in the study had not been surpassed since its publication.

By way of background, Thiel and Smith explained that from a geotechnical and containment perspective, the critical aspects of heap leach design are depth of ore, presence of water and local terrain.

"Heap leaching presents a combination of extreme base pressures and high moisture conditions not present in any other containment application. Often these sites, by virtue of being associated with mineralised ground, are in active geology."

When heap leaching first became a popular extraction technology for gold in the 1980s, the typical maximum ore depths were around 15 m. That limit was up to 50 m by 1990 and today there are some operations with ore depths of more than 200m.

The increase in heap sizes has not come about purely as a result of economic efficiency, but also largely as a function surface area availability.

"And the general trend, with drivers ranging from closure and reclamation costs to minimising diversion of agricultural land and encouraging sustainable development, is to reduce the amount of land impacted by mining. A higher heap means fewer hectares of disturbance," the study said.

Leach solution application rates are designed to optimise metal recovery and chemical consumption. This is more challenging in more tropical environments where annual rainfall can be more than 3,000 mm such as in Brazil, Central America and West Africa. This results in elevated phreatic levels over the base liner, usually of about 1 m for conventional pads, but in some rare cases up to 10 m, according to the study. Valley fill designs require very high solution levels during at least part of the operating year and in extreme cases this can reach about 60 m above the liner.

**Slope Stability**

Slope stability is possibly the hardest performance area to maintain. Stability of the system is affected by extreme heights and base pressures; sliding rock stability along the geomembrane interfaces; active leaching with elevated degrees of saturation; long-term chemical and biological degradation of ore; and first-lift stability affected by lift thickness and stacking direction.

Global slope stability evaluations of leach piles are performed using standard geotechnical engineering principals, Thiel and Smith wrote.
The four types of leach pads

Conventional or ‘flat’ pads – relatively flat, either graded smooth or terrain contouring on gentle alluvial fans in relatively thin lifts typically between 5 m and 15 m.

Dump leach pads – similar to flat pads or can include rolling terrain. The term ‘dump’ usually means that the lifts are much thicker at around 50 m.

Valley fills – as the name suggests, these systems incorporate leach pads designed in natural valleys using either a buttress dam at the bottom of the valley, or a levelling fill within the valley. A buttress dam 100 m high would typically crest out 300 m vertically from the toe of the dam to the crest of the heap, providing over 100 Mt of capacity.

On/off pads – also known as dynamic heaps, on/off pads are hybrid leach systems. A relatively flat pad is built using a robust liner and overliner system. Then a single lift of ore, from 4 m to 10 m thick, is loaded and leached. At the end of the leach cycle the spent ore, or ‘ripios’ in most mining literature, is removed for disposal and the pad recharged with fresh ore. Usually loading is automated, using conveyors and stackers. In some cases, bucket wheel excavators and conveyors are used in the unloading cycle, while in others, wheel loaders and trucks are used. For on/off pads, the critical design loads for the containment system come from the ore handling equipment, not the weight of the ore. Trucks and loaders can apply wheels loads of up to 53 t, with 24 t being common.

Source: State of the Practice Review of Heap Leach Pad Design Issues

Standard circular and block type failure analysis are typically completed with computer-based limit-equilibrium techniques, such as Spencer’s method. Since the piles may become locally saturated from leach solution irrigation, the potential for liquefaction also exists and is often considered. In addition, the largest heap leaching areas in the world – Chile and southern Peru – are also the most seismically active.

Larger leach piles in particular present an increasing number of challenges and make life difficult for the geotechnical engineer charged with assessing their stability. As the heaps reach heights never scaled before, those evaluating their steadiness do not have the luxury of a case study on which they can base their factor-of-safety margins and reliability estimates.

“Practitioners are finding themselves at the cutting edge of laboratory testing, field observation, and engineering judgement in providing recommendations to owners and operators,” Thiel and Smith wrote.

They identified the following specific issues:

- Deeper fills require expanded limits of shear strength testing. Typically, the shear strength envelope is curved over a broad range of normal stresses, and the secant friction angle decreases as the normal stress increases. For practical purposes, it is always non-conservative to extrapolate shear strength parameters, either higher or lower, from the normal load range under which they were determined. These principals apply to both the internal strength of the ore material and to the interface with the geomembrane liners.

- The larger, deeper leach piles – especially for dump leach facilities that tend to process low-grade and ‘salvaged’ ore and use very thick lifts – typically have a greater variability in ore quality. This variability must be accounted for in the factor of safety or reliability estimates for slope stability. The thicker lifts can lead to more particle-sized segregation during dumping, with the larger rocks collecting at the outer face and toes of the lifts. This can result in heterogeneous shear strength and preferential path flows, or channelling, within the piles. This internal focusing of fluids could in turn lead to localised pore pressure build-ups or static liquefaction triggers.

- Ore degradation caused by mineral dissolution and bacterial action through the leaching process is always a concern with leach piles. To date, no reliable testing has been developed for long-term performance, and rules of thumb developed for 50 m deep oxide heaps are being adapted to 150 m deep sulphide heaps. The effects of ore degradation can include decrease in shear strength of the ore and along geosynthetic interfaces; lowering of ore permeability and increased degrees of saturation, and increased fines migration and the potential for filter incompatibility.

- Inter-lift liners are more common, principally as a tool to reduce the consumption of expensive sulphuric acid (for copper oxide ores). These can be spaced as close as each 2 m vertically, but 4 m to 8 m is more common. These create both weak shear plans and perched water within the heap.

Hydrology

According to Canadian mining feasibility experts O’Kane Consultants, one of the keys to heap leaching is favourable heap hydrology: “Heap leach piles are unsaturated systems and therefore must be addressed as such, by applying the knowledge and tools of unsaturated soil science to design and optimise operation,” a report from the consultant stated.

O’Kane completed a laboratory column study, which included the numerical modelling of column tests, with the aim of showing the application of unsaturated zone hydrology to aspects of heap

AmmLeach™

New innovative mineral processing technology

The AmmLeach™ process is a new technology for the extraction of base and precious metals, especially copper and zinc, from ore deposits. The process utilises ammonia-based chemistry to selectively extract metals from ores in a heap leach environment. AmmLeach™ is an alternative to acid leach processes and has significant advantages because of its selectivity. AmmLeach™ can treat complex oxide ores, high acid consuming ores and selected primary and secondary sulphide minerals.

The primary advantages are:

- Delivering significant economic benefits
- Considerable comparable environmental improvements
- Cost advantages over conventional acid heap leaching
- No gypsum, jarosite precipitation or silica gel formation
- Faster leaching kinetics
- Reagents recycle through the heap

For more information on our AmmLeach™ technology contact Matt Rutcliffe or Martin Ross at Alexander Mining plc. T: +44 (0)20 7292 1300, msutcliffe@alexandermining.com.
The study reported that layers of coarse and fine textured ore inevitably develop within the heap and dump leach piles as natural processes segregate coarse and fine material during material placement. Segregation of heap leach material will occur regardless of whether the material is agglomerated or not. “Clearly, segregation is significantly reduced for the agglomerated heap leach materials,” it reported. “However, due to the methodologies employed to place the material, segregation of agglomerated heap leach material will occur.”

O’Kane reported that ROM material, or dump leach piles, would definitely segregate. Under such conditions, leaching solution flows preferentially in the more conductive layer, potentially leaving areas within the heap unleached. The preferred flow path is not dependent only on the physical properties of each layers, but also on the stress state and resulting degree of saturation, and therefore the solution application rate, the consultant wrote. “For this reason, either the coarse or the finer material can be the preferred path flow.”

Research completed as part of the study looked at flow rates required to create both preferential flow conditions and the affect that extreme cases of preferential flow have on the leaching of adjacent layers, with the aim of showing that tools exist to help understand key processes and characteristics that control performance; and to improve design and operation.

“Column testing revealed that solution application rates greater than the saturated hydraulic conductivity of the finer material.” Research revealed that coarse and fine textured layers of material in the columns were also “spiked” with salt before placement in the column and subsequent leaching. Under preferential flow conditions, 30% of the salt within the less conductive material could be leached from that material by the horizontal movement of water into the more conductive material. That relied on the amount of infiltration into the less permeable layer and the top of the column. The research showed that an ineffectual volume flowed preferentially if little water originally entered the less conductive material.

“Noteworthy is that for the segregated components investigated, the preferred flow path was the finer textured material for application rates common to heap leaching. The implication is that a typical operational response to poor recovery is to increase the solution application rate. However, the effect of this response will potentially decrease recovery because it enhances the potential of the solution flow in the coarse textured material,” O’Kane revealed.

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tools proved to be valuable in predicting the performance of heap leach piles. “The study clearly demonstrated that unsaturated zone hydrology should be used as a basis for heap and dump leach performance.”

The numerical modelling as used in geotechnical engineering “was raised to a new standard” in May this year, when SoilVision publicly released the SVOffice software package, which was the result of more than three years of development. The software is designed to simplify model creation and provides a three-dimensional environment in which models are visualised as they are made, according to SoilVision. The company said numerical modelling of heap leach pads was valuable in improving the efficiency of operations; in estimating the drain-down times during heap leach pad closure; and in estimating the long-term performance of earth cover systems.

The Latest Technology
Alexander Mining, a copper, gold and silver mining company with projects in Argentina and Peru, has developed a new ammonia heap leaching process for copper oxide deposits at its Leon copper project in Salta Province, northwest Argentina. Not only does it have specific benefits for treating the Leon copper oxide deposit but it also has potentially significant advantages for treating other copper oxide and base metals deposits, especially those deposits where existing mineral processing methods do not work or are uneconomic.

The process uses ammonia-based chemistry to selectively extract metals from ores. The target ores will typically be high acid consuming, although AmmLeach is also an alternative to acid leach processes as it is far more selective and offers a number of benefits, the company reports. The technology consists of the same three major stages as acid processes – leaching, SX and EW. The leaching occurs in two steps, an ore-specific pre-treatment, which converts the metals into a soluble form and the main leaching step that uses recycled raffinate from the SX stage. SX is used to separate and concentrate the metals whilst also changing from ammoniacal media to acid sulphate media from which metals can be directly electrowon using industry standard unit operations. One of the key benefits of the AmmLeach process is that unlike some new technologies it requires no special purpose built equipment.

AmmLeach technology is suitable for both low-grade heap leaching and higher grade tank leaching; the choice is dictated by the grade and deposit economics. Polymetallic deposits can be readily handled using standard SX and solution

Dr Matt Sutcliffe, Chairman and CEO, said the AmmLeach process had serious commercial potential. “Approximately 40% of the world’s copper is produced using the acid heap leaching method and the price of acid is at record highs. The AmmLeach process can significantly reduce the operating cost of the heap leaching process. In addition, it has the potential for a major breakthrough in the processing of previously untreatable zinc oxide deposits, with the development of the first heap leach zinc mines. Alexander is moving rapidly to maximise the commercial value of this exciting new process,” he said.

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There is an economic precious metal content after removal of high cyanide, allowing immediate application of cyanide leaching of gold and silver in ores where revegetation with the residual ammonia acting as a fertiliser. The alkaline residue from final leaching the heap is simply washed to recover ammonia and then left to decompose. The process is necessary and the potential for acid mine drainage is virtually eliminated. After decomposition, ammonia can be recovered, however in practice small losses do occur. Small losses do have also been shown to leach after appropriate pre-treatment. Polymetallic ores can also be processed by AmmLeach with separation achieved using SX to separate metals and produce multiple revenue streams. The minimisation of ammonia transfer allows these metals to be recovered directly from their strip solution by precipitation, crystallisation or electrowinning.

The use of ammonium carbonate will allow the simultaneous recovery of uranium and base metals from roll-front deposits, with the carbonate extracting the uranium and the ammonia the base metals. Current technology does not allow recovery of both.

**Leaching for nickel**

Heap leaching is not reserved purely for copper and gold ores. As discussed briefly in July, nickel laterite ores are being treated with the process as a cheaper alternative to high pressure acid leach plants.

European Nickel has become somewhat of a pioneer in this field through its Çaldag operation in Turkey where it plans to produce 21,400 t/y of nickel and 1,000 t of cobalt in a mixed hydroxide product to be sold to refineries. ENickel has successfully tested a simple acid heap leach process on three trial heaps of differing sizes. Following the successful completion of the prefeasibility in late 2005, the company has been working on a bankable feasibility study in order to bring the project into production in the coming years.

The geological formation that led to the Çaldag nickel deposit lends itself to heap leaching because of the low clay content of the ore, according to ENickel. The nickel is present in the goethitic phase and is soluble in dilute sulphuric acid. The lack of clays in the laterite profile assists the percolation of the solutions through the heaps throughout the heap leach cycle, which in Çaldag's case is over a year.

“We have demonstrated the percolation and extraction of nickel on a large scale on three full height heaps, irrigated with dilute sulphuric acid over a 15 month period. The nickel in the Çaldag deposit is predominantly in the goethitic mineral and explains the longer leach cycles required to extract the metal compared to other laterites that have been tested. The leach rates have been consistent with three phases of leaching being identified, a neutralizing leach, primary leach and secondary leach,” the company said.

“Such leaching mechanisms vary between the different laterites with the length of leaching under one particular mode varying depending on the mineralogical characteristics of the laterite under test. The mineral extraction of the first trial heap has reached 78% nickel and 82% cobalt after some 15 months of irrigation, 72% for both metals has been used in the bankable feasibility study.

“The pregnant solution from the leach is collected in ponds and recirculated through the heaps to maximise the metal content before being pumped to the precipitation plant where first the iron content is precipitated by raising the pH level, thickened and filtered and disposed of as the waste product from the process. The liquor from the iron thickener is then further treated by raising the pH further with soda ash to produce a nickel-cobalt hydroxide with a nickel content of above 30% that is filtered and packaged for shipment to refineries in Europe, China and Australia.”

ENickel has also bought into Rusina Mining, which owns the Asco nickel-cobalt project in Philippines, where ENickel's expertise will be used to apply a similar heap leach process to develop that project.