Geo-Logic ASSOCIATES

Heap Leach Injection

The Basics

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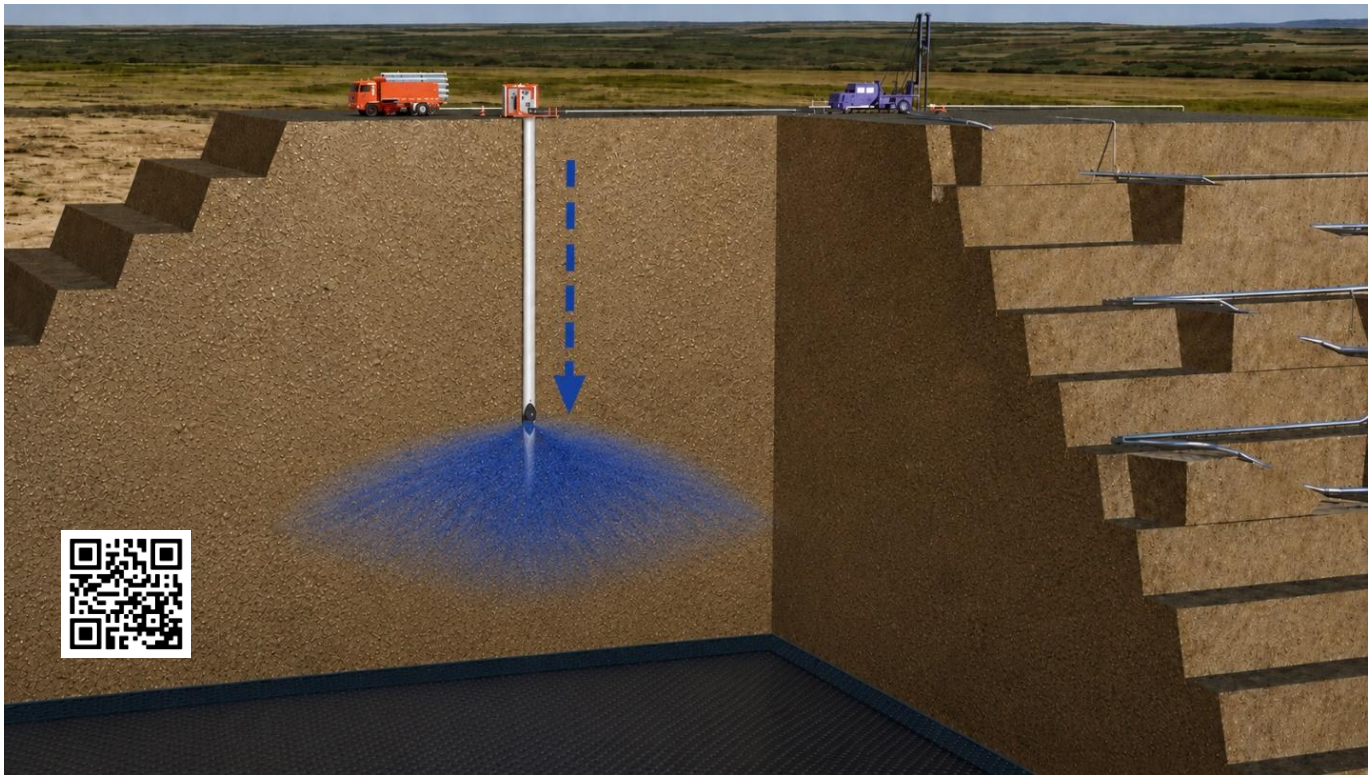

Figure 1. Heap leach injection video: **See How Heap Leach Injection Works**

> Heap leach injection recovers gold, silver and copper that surface application leaves behind — reaching dry zones, low permeability clay zones, and metal-bearing solution trapped at field capacity.

Background

Heap leach injection (Injection) or enhanced metal recovery (EMR) is a subsurface solution application technology that works to recover metals from primarily gold, silver and copper heap leach ore that would have otherwise been left behind during the leaching process.

Traditional surface application of solution often results in dry zones in the heap leach ore in both crushed and run-of-mine (ROM) heaps where solution did not efficiently contact the ore. Injections work to contact these dry or under-

leached zones to improve recovery. Leach pads with higher clay fractions can develop lower permeability zones. Injections work to "loosen" the lower permeability clay zones allowing solution to contact ore that may not have otherwise been contacted. Additionally, when surface application ceases, metal enriched solution will become trapped in the ore (soil) matrix as the moisture content approaches field capacity. Injections help to flush these previously dissolved metals.

Laboratory column testing of oxide ores may result in recoveries upward of 80% to 95% whereas actual recoveries during production can be approximately 65%-80% to 50%-70% for crushed and ROM oxide ore, respectively. Heap Leach Injection technology is a proven extraction technique that can be performed safely to increase metal recoveries and help enhance the bottom line!

FROM 1992 TO PRESENT

Heap leach injection was initially a Newmont-funded technology born from the oil fracking industry. The original intent was to install wells and inject process solution into lined mill tailings facilities. Newmont initiated a field program in 1992, with an oil fracking consultant, from which many of the concepts and methods used in heap leach injection, used today, were developed. This application was never pursued by Newmont. Newmont later considered injecting reagents into waste rock dumps for acid mine drainage mitigation, and again this application was not pursued**. Stay tuned for an exclusive interview with the original creator of injection leaching, coming soon!**

Newmont determined that utilizing the methods developed during the 1992 mill tailings in-situ leaching project for heap leach pads could be a viable use of the technology. In the early 2000's, the 1992 report was dusted off and additional input was received from the drilling, metallurgical and mining consulting industries, as well as Newmont personnel to initiate the first pilot program on a heap leach pad.

Since Newmont's initial successful trials, Geo-Logic Associates (GLA) has made significant contributions and improvements to the technology used today, developing proprietary injection tools and incorporating geotechnical monitoring and numerical modeling tools coupled with geochemical evaluations and more recently artificial intelligence (AI) to optimize project performance.

+20	11	+16
YEARS OF EXPERIENCE	MINING OPERATIONS	LEACH PADS INJECTED

GLA professionals have over 20 years of experience in subsurface application of process solution in heap leach pads. GLA has currently performed injections at 11 different mining operations on over 16 different leach pads of varying ore types (oxide and sulfide), size fractions (crushed and ROM) and varying percentages of clay (both higher and lower permeability ore) making GLA a world leader in heap leach injection technology!

General Methods

Heap leach injection requires the installation of perforated steel cased wells utilizing drilling methods suitable for water well installation, dual rotary (two independent hydraulic rotary drives, one for drill bit, one for casing) or similar with casing advance. It is critical to prevent solution from "piping" along the outside of the casing that can increase solution dilution down the well, solution expressing at the ore surface, and/or subsidence.

Figure 2. Typical completed injection well

Figure 3. Typical dual rotary drill rig

Figure 4. Example of perforated casing section with in-situ perforator

Figure 5. Example of laser cut pre-perforated casing

Typically, following the installation of the steel casing, a perforator tool creates the "injection zones" in-situ. The casing could also be perforated prior to installation at predetermined intervals. The length and design of the injection zones can vary based on project-specific parameters that include ore type and variable ore hydraulic conductivity. In our experience, in-situ perforations are the most effective and allow for field fitting the injection zone elevations if necessary. There are advantages and disadvantages to both in-situ and laser cut perforations. We would be happy to discuss in more detail for your next injection project.

Injections are generally carried out in two distinct methods; low pressure and high pressure.

Low Pressure Injections

Low pressure injections generally refers to solution applied either directly from the barren line or through the pump, with the pump engine off, at either the barren pipeline supplied pressure, without pump assistance, or with the solution being gravity fed down the well (like a constant head test) maintaining a flow rate and solution elevation in the well to where the solution does not overflow.

Prior to low pressure injection, the injection zone or zones are isolated to receive solution.

Low pressure injections are often utilized for “pre-wetting” the ore and/or for rinsing the ore following high pressure injections. Pre-wetting is injecting the low pressure solution prior to performing any higher pressure injections to essentially “wet up” the initial injection zone closer to the casing, much like pre-wetting a hole for a standard soil percolation test when designing a septic system. Following high pressure injections, rinsing can take place to periodically flush previously dissolved metals and encourage additional metals leaching.

> GLA’s select clients have continued rinsing their injection wells for many years, which resulted in generating tens of thousands of additional ounces to the bottom line.

High Pressure Injections

High pressure injections are performed utilizing pump assisted solution application down well to an isolated injection zone. In our experience, it is best to inject a single zone, one at a time, within each respective injection well. Both the flow rates and solution pressures applied to each respective zone is based on the ore characteristics (grain size distribution, density, porosity, hydraulic conductivity) and calculated average overburden pressures at the respective zones. The timing of applied solution will vary based on these parameters as well as balancing the solution chemistry. Heap leach injection must balance between injecting enough solution to efficiently leach the ore without over diluting the injection grades.

Figure 6. Typical low pressure injection well head

Figure 7. Typical high pressure injection well head

Geotechnical Evaluation

Prior to performing a heap leach injection project, GLA performs a geotechnical evaluation of the proposed areas of the heap leach pads where both injections are to be performed and where solution will be collected by the liner system. We perform a review of previous geotechnical evaluations and determine, along with mine personnel, whether existing parameters can be used for the analyses or if it warrants additional fieldwork and laboratory testing.

GLA has been performing transient seepage analyses on heap leach injection projects since 2017. Results of these analyses serve as an input into limit equilibrium slope stability evaluations. Recently, stability evaluations have been expanded to account for static liquefaction (liquefaction induced by a single cycle of loading). This is achieved by means of advanced numerical modeling, as incorporated into the FLAC finite difference code.

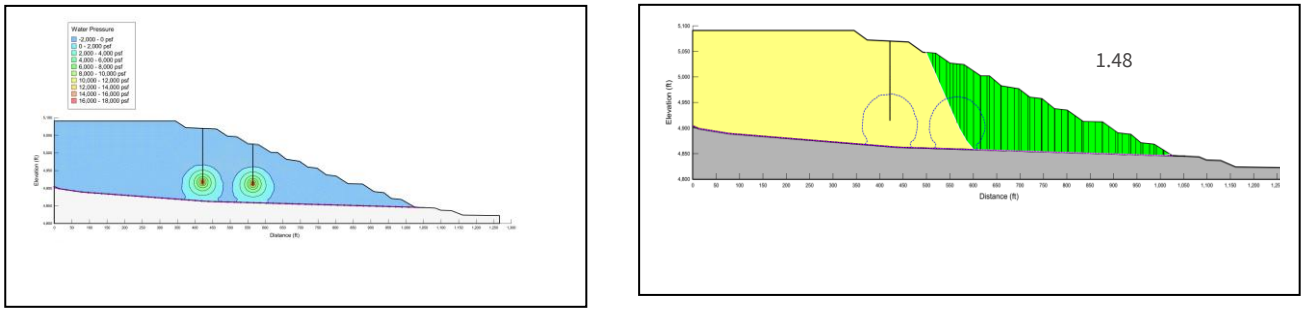

Figure 8. Example of transient seepage analysis and slope stability evaluation for injection wells

The above outlined evaluation and numerical modeling approaches can be utilized internally by facility owners to provide both clarity and assurance that the proposed injections will not negatively impact the stability of the leach

pad. The results of evaluations can also be utilized for permitting purposes. GLA has prepared these types of evaluations to satisfy regulatory requirements throughout the Americas including the U.S. State of Nevada, which has some of the most rigorous mine permitting requirements that are often used as a model for other states as well as in many other countries.

Subsequent technical bulletins will go into more detail regarding geotechnical evaluations of heap leach injection projects.

Monitoring

The size and the geometry of the injection zone can vary by ore type. GLA utilizes various techniques to monitor the movement of solution through a leach pad including geophysical sounding.

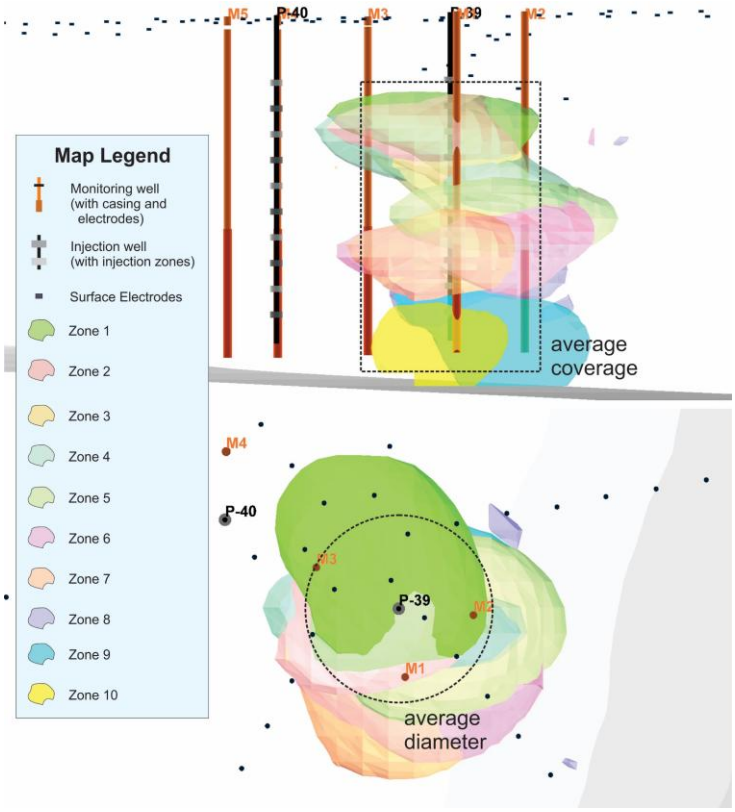

Figure 9. Composite of geophysical measurements for an injection well

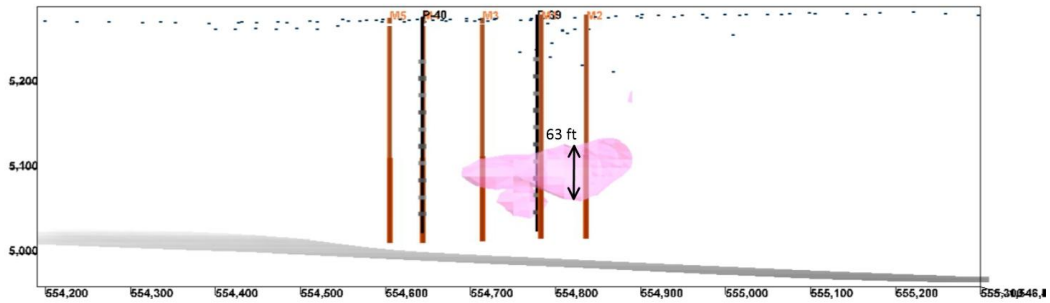

Figure 10. Profile view of geophysical measurement

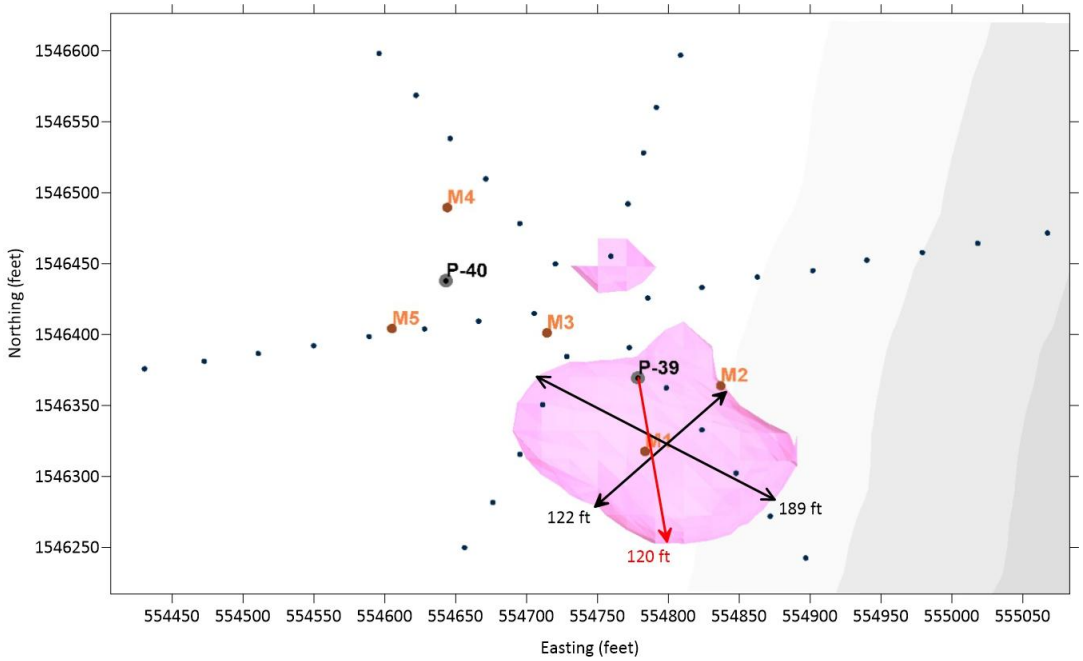

Figure 11. Plan view of geophysical measurement

Other monitoring techniques include installing piezometers to measure pore water pressures within the leach pad, installing pressure transducers in wells to monitor solution plume movement through the heap leach ore, and geotechnical monitoring. Geotechnical monitoring includes installation and monitoring of inclinometers (shape arrays), monitoring prisms and surface monuments, application of remote (slope) sensing, including radar, satellite based InSAR, and drone surveillance, all for large area inspections. Often the most effective monitoring tool is simple visual observation and reporting.

Leach pads are a dynamic unsaturated soil/rock fill that will often reveal issues. Apply too much solution to the surface and it will pond and potentially generate runoff, erode, and potentially slough. Apply too much solution into the ore and it can pond on the surface and/or express itself on the side slopes as seepage, inundate the solution collection overliner layer, and can develop head on the liner that will often express as wetting at the toe of the pad. Although the latter is quite rare, it can occur if injection volumes and timing go unchecked. It is critical for a heap leach injection contractor to have extensive leach pad geohydrological and geotechnical expertise. This is a major advantage of working with a multidisciplined company that has seen it all, like GLA.

Subsequent technical bulletins will go into more detail regarding monitoring.

Data Evaluation

GLA works to create a teaming relationship with our clients on our heap leach injection projects where we can share data and results and work to improve project efficiencies as a team. GLA also applies artificial intelligence-based data evaluation techniques that can assist with improving efficiencies and overall results. Results include performing a project safely by prioritizing the health and safety of all personnel working on the project, optimizing the design of the wells and the parameters associated with the injected solution to perform geotechnically safe injections and ultimately lowering project costs while increasing recovered metals to maximize project profitability.

Along with evaluating the data is making “improvements” on mineral recoveries. This generally involves ensuring that the solution is the optimal chemistry for the metals being extracted and the various reagents that can be added to improve recoveries. One example is increasing dissolved oxygen (DO) in sodium cyanide solution for gold and silver projects to improve the gold cyanide reaction. Various techniques have been attempted to improve DO like utilizing spargers or dive compressors. These methods both increase the DO, but the DO very quickly dissipates from the solution. A similar result is achieved from simply running the solution through the pump whereas the DO increases and then very quickly decreases. There are other technologies like nano-bubble technology that can improve the DO and make it available in the solution for much longer time periods, which will consequently improve metal recoveries.

Subsequent technical bulletins will go into more detail regarding data evaluation, enhancements that improve overall recoveries and operational improvements that can provide for a safer work environment.

Pilot Program

Some mines jump right into a full production heap leach injection program with 40 to 60 wells to start while others will start with less than 20 wells and progress from there. This often depends on whether the mine has good records of what grade ore was placed and what they estimate to be the remaining and recoverable grades in those areas. GLA always recommends going after “low hanging fruit.” That is, if you know of some higher grade areas, then inject there first and generate revenue to pay for the project quickly and fund exploration of other potential areas of consideration. We have worked with mines that selected very low grade areas first reasoning that “if it works here, it

will work anywhere". This approach will very likely produce very low grades. Heap leach injections are very effective at extracting remaining recoverable metals but it's not alchemy; if the target metals are there and recoverable, we will recover a significant percentage!

Economies of scale will always improve with more installed wells. A preferred pilot program size is between 15 to 20 wells to adequately evaluate the viability of a full production injection program. This will often be an efficient use of the drilling contractor, considering mobilization/demobilization, etc., and will allow the mine to adequately distribute wells on the leach pad to evaluate various potential injection areas.

CASE IN POINT — PERU

One of our projects in Peru started with 1 pump and less than 10 wells. Within 18 months, it expanded to 4 pumps and several hundred wells. Several years later, the project includes several thousand wells installed with over 10 pumps operating on various leach pads within the mine site. This is a great example of a heap leach injection project that started as a pilot program and evolved to a full production operation and into "standard operating procedure" for the mine.

"All great things have small beginnings." (Sir Francis Drake)

At the end of the day, heap leach pad operators are looking for proven, cost-effective methods that can safely recover additional ounces. Depending on the size of the mine and available recoverable metal, these additional recoveries could mean the capital to fund the next leach pad or the next plan of operations to expand the mining operation and extend the overall mine life. If the mine is closer to closure, injections are a great way to offset closure costs. Whatever the needs of the mine, heap leach injections can accelerate recoveries and recover additional metals that may have otherwise been left behind and simply *enhance the bottom line!*

GET IN TOUCH

Discuss a heap leach injection program

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