Current Developments in Heap Leach Closure

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Abstract

The typical conceptual approach to heap leach closure planning assumes heaps will be rinsed to achieve water quality goals, followed by physical reclamation of the heap to meet revegetation goals. While rinsing is initially effective in reducing concentrations of some constituents, primarily cyanide, experience has shown that it may be very difficult to reach drinking water standards for all constituents. Also, the addition of fresh water to the system in order to achieve water quality goals increases the volume of heap leach drain down that must be managed. Therefore, the use of rinsing must be closely evaluated considering the ultimate management of the solution during the "tail" of the drain down curve. Effective closure will depend upon the volume and quality of the heap solution inventory; geochemical behavior of the spent ore; climate and other site conditions such as depth to groundwater, revegetation goals, and post-closure land use. In effect, there is no single "one size fits all" closure approach for heap leach pads; each heap requires an approach that considers site-specific factors. Depending on those site factors, there are a variety of tools that can be used to achieve closure. Revegetation measures (through direct seeding of the heap or placement of a soil cover) should be considered in light of their implications for solution management; in some cases, low-permeability covers or engineered storage/evaporation covers may be warranted. Evaporation, land application, and treatment present a range of methods to deal with heap solution drain down and residual drainage.

This paper presents case studies of heap leach closure plan development and implementation using a range of approaches at various Kinross properties.

Site Specific Closure Approaches

Although most heaps share some common characteristics, there are several factors that vary widely from site to site, and as such may affect operation and ultimate closure of the pad. Examples include:

- Material properties and pad hydraulics
- Ore mineralogy and leaching characteristics
- Source water quality for process "fresh" water make-up
- Leaching and operation history
- Elevation and climate
- Presence / absence of nearby surface and ground water
- Availability of construction materials: clay, soil, gravel, sand
- Post-closure land use.

While this variety may preclude universal closure methods, it is possible to define overall goals for any closure:

- To protect the public safety;
- To protect sensitive environmental receptors;
- To reduce or eliminate long-term management burdens and liability; and
- To achieve closure in the most efficient manner possible.

Based upon these universal objectives, and a careful examination of site-specific factors, a closure approach can be developed that is well suited to the particular site, using a variety of "tools" that have been developed for heap leach closure.

Closure Tools

Rinsing

The primary challenge of heap leach closure is management of the process solution inventory. Managing the drain down that occurs after recirculation pumps are turned off presents particular challenges, in part due to residual process reagents and other constituents that may pose an environmental concern. Also, while most heaps initially will drain quickly (weeks), residual flows on the "tail" of the drain down will require management for long periods (years).

Traditionally, most conceptual heap leach closure plans have proposed rinsing to achieve specific water quality goals prior to allowing the heap to drain down.

While rinsing is initially effective in reducing concentrations of some constituents, primarily cyanide, experience has shown that it may be very difficult to reach drinking water standards for all constituents (1, 2).

In fact, rinsing in some cases may exacerbate water quality problems by modifying the equilibrium chemistry of the heap, mobilizing metals or other constituents that were not mobilized during operations. This is particularly true of heaps that contain sulfide-bearing ores. Also, adding fresh water to the system in order to achieve water quality goals for particular parameters increases the volume of heap leach drain down that must be managed.

Therefore, the use of rinsing to achieve closure must be closely evaluated considering the ultimate management of the solution during the "tail" of the drain down curve. In some cases, rinsing may not be warranted.

When rinsing is used, either an open circuit (fresh water application) or a closed circuit (application of recycled drainage from the heap) may be used. In either case, some form of treatment may be needed to allow release (open circuit) or recirculation (closed circuit). Common methods of treatment include addition of chemicals such as peroxide or hypochlorite to existing solution ponds. Other treatment options include the use of bacteria to metabolize residual cyanide in the heap.

The applicability of rinsing for a particular heap can be evaluated in column tests; generally, composite samples of material from the heap should be used. Sample collection for rinse testing can be coordinated with sample collection for other purposes, e.g. grade control and metallurgical balances. If the site layout allows, pilot-scale rinsing of an individual heap cell can be a more representative test of rinse effectiveness. Rinse tests should incorporate any treatment method under consideration in order to evaluate the potential to mobilize constituents of concern in the heap. Results should identify the chemistry of the rinse water and the pore water in the heap materials before, during, and after rinsing; chemical addition rates (in g reagent/g CN_{WAD} and/or g reagent / m^3 solution); and required rinse application rates (in $L/min/m^2$) and total volume (in t rinse applied / t heap material).

Evaporation Systems

For arid climates, one of the most widespread means of managing heap rinsate and drain down solutions is evaporation. The simplest systems use spray nozzles connected to the facility's existing solution application system on top of the heap. Kinross estimates evaporation losses from simple systems are usually 4 - 10% of the recirculation rate, although higher rates (up to 20%) may be possible depending on site conditions.

More sophisticated methods using physical atomizers and/or compressed air to create finer sprays and maximize the "flight time" of the individual drops are also available. While the efficiency of these systems is higher in terms of evaporation as a percentage of recirculation rate, these systems can be more costly than spray nozzles in terms of $\$/m^3$. To fully optimize an evaporation system, a combination of spray nozzles and more sophisticated evaporators may be appropriate, depending on space and timing considerations.

The arrangement of evaporation lines is important. Placing evaporation systems on top of the heap leach pad is generally easiest in terms of physical ease of installation, but evaporites will accumulate on top of the heap that may affect ultimate reclamation efforts. Placing spray lines in solution return ditches avoids salt accumulation on the heap itself, but may unduly affect water chemistry monitoring, since the quality of water exiting the launders would not necessarily represent the quality of water exiting the pad.

Kinross has also installed floating evaporation systems in solution ponds.

As heap discharge rates decline, low-volume methods such as gravity fed sprays or driplines installed around the perimeter of lined ponds can be implemented.

Use of evaporation for fluid management is limited in areas with abundant rainfall, and in periods of cold temperatures.

Land Application

Land Application Disposal (LAD) is a widespread practice at sewage treatment plants and other wastewater treatment plants, and since the late 1980s has found increasing application at mine sites. LAD treatment capitalizes on natural processes of adsorption on soil particles, bacterial metabolization, volitalization, plant uptake of nutrients, and storage of solution in vadose zone pore spaces.

Numerous studies have shown LAD treatment to be effective in attenuating metals and cyanide in mine solutions (3, 4, 5, 6, 7, 8, 9); however, varying or even contradictory results can be observed for certain parameters at various sites, and site-specific testwork is required to demonstrate the effectiveness of LAD treatment at a particular site.

Testwork must answer two questions:

- Will metals/cyanide move with water through the soil into ground water?
- Conversely, will metals/salts accumulate in the soil in levels that are toxic to plants?

Attenuation is quantified using column percolation tests, where solution is applied to columns containing samples of soil from the proposed LAD site. Results of tests include attenuation rates for each metal (in % removal and mg removed / kg of soil); and solution application rates (L/min/m^2). In-situ methods of determining attenuation are also available. Various models are available to evaluate migration through the vadose zone to ground water based upon the column percolation data (e.g., CXTFIT)(10).

Before-and-after testing of the soil material itself can be used to evaluate the second question, i.e., accumulation compared to plant toxicity tolerances. Several sets of benchmark standards are available (11, 12, 13, 14, 15); of these, criteria should be selected based upon an analysis of the site-specific risks and post-closure land use.

LAD treatment can be particularly effective in management of large volumes of initial drain down solutions.

Passive Treatment Systems

For most heaps, there will be low-flow residual discharge for an indefinite period of time due to continuing gravity drainage of the pores and infiltration of meteoric waters into the heap after closure. Increasingly, passive treatment systems are being developed to provide long-term management of this seepage.

One type of passive treatment system utilizes soil attenuation, as discussed above. Infiltration fields are constructed to achieve design application rates (L/min/m^2) based upon attenuation rates determined by column percolation tests. As with LAD, the design must consider potential migration to ground water, and potential uptake by plants.

Biological reactors are another type of passive treatment system. This may involve conversion of the facility's solution ponds into anaerobic or aerobic cells using gravel, limestone, manure, straw, wood chips, and drain pipe. This type of system is best designed using bench- and pilot-scale cells at the site. Applications include heaps with moderate acid generation potential ($pH > 3$).

Passive treatment systems are generally designed for several decades of useful life; after a certain time, replacement of the biological reactor medium, flushing of infiltration drainpipe, or other maintenance may be required.

Soil Covers

Soil covers are used at sites where revegetation is required for post-closure use, and direct revegetation (see below) is not feasible. Soil covers also provide hydraulic benefits, and reduce the amount of long-term seepage by storing water in the pore spaces of the root zone, where it can be used by plants.

In some cases, a capillary break may be installed under the soil cover to enhance the hydraulic performance of the cover; this type of engineered cover is typically referred to as a storage-evaporation or ET cover (16, 17, 18).

Direct Revegetation

Where revegetation is required for post-closure land uses, some heaps will contain material that has physical and chemical characteristics that will support direct seeding and revegetation of the heap without placement of a soil cover. Test plots are usually a good indication of potential revegetation success. Results can be enhanced by rinsing with fresh water to wash surface salts down into the heap prior to application of seed. At one Kinross site, putting cattle on re-seeded sections has enhanced results.

Low Permeability Covers

For heaps with extreme acid generation potential, and in areas with high rainfall / high infiltration rates, low-permeability covers may be appropriate. Due to the cost of installation, low-permeability covers are usually justified only when there are significant water quality issues and close proximity of sensitive receiving waters.

Where natural materials are available, compacted clay covers may be used. This type of cover is generally considered inappropriate for arid areas due to dessication leading to cracking in the clay cover. Freeze/thaw protection must also be considered when using natural materials as hydraulic barriers.

For small heaps, synthetic covers may be used. Design considerations include slope stability at the liner/heap contact and at the liner/soil cover contact.

For low-permeability covers, consideration must be given to long-term maintenance (vegetation, erosion).

Case Studies

Wind Mountain

The Wind Mountain Mine is located in northwestern Nevada, and operated from 1989 to 1992 as a conventional loader and truck open pit facility. A total of 22 Mt of ore was placed in two pads covering 31.3 ha and 26.3 ha, respectively. Lift height was approximately 2.5 m, with maximum pad depths of 40 m.

Closure of the Wind Mountain heap leach pads followed the classic sequence of extended rinsing followed by recirculation to evaporate fluids (19). After mining ceased in 1992, cyanide application continued for two years. Testwork indicated that rinsate treatment with hydrogen peroxide would mobilize selenium from the heap; other treatment methods were not cost effective compared with fresh water rinsing (20). Rinsing and residual gold recovery continued for three years. During this period, pilot testing of biological treatment methods was conducted, with inconclusive results. Gold recovery continued until 1997; by then, cyanide concentrations in the drainage dropped to drinking water levels. Fluids were recycled to the top of the heap to enhance evaporation of the remaining solution inventory.

Although extended rinsing was effective in reducing cyanide levels and meeting pH targets, several other parameters, including metals and salts, were still present in levels of concern. In particular, selenium concentrations averaged about 5 mg/L. Kinross evaluated various methods to manage this effluent.

Site environmental conditions were carefully considered in selection of a closure alternative. The site is located in the arid San Emidio Desert, with 100 – 150 mm of precipitation annually, and evaporation well in excess of 1000 mm. In these arid conditions, infiltration into the pad after closure is minimal. Also, exploration drilling had failed to identify ground water aquifers within 185 m of the surface; the only ground water source in the vicinity was a geothermal aquifer with water that did not meet drinking water standards, which was used as the mine's source of process water (many of the salts in the heap effluent were introduced to the heap with the process water, and concentrated during the extended period of recirculation and evaporation). A range-line fault ran between the mine site and the basin aquifer, and appeared to form a hydraulic barrier. Based upon these conditions, a passive treatment system consisting of a low-flow infiltration field was identified as a viable closure approach.

Column percolation tests were used to determine soil and bedrock attenuation capacities; evaluation showed that drainage from the proposed infiltration fields would not impact ground water. The infiltration field was designed to spread the drainage over an adequate area based upon the attenuation testing. Monitoring wells were installed to ensure water was not moving across the fall-line fault zone.

This system was the first such system in Nevada to undergo public review and comments through the BLM's NEPA analysis (21), although at the time there were at least 14 similar systems operating in Nevada. This system has been operating for more than a year, with no detection of drainage in downstream monitoring wells and no operational difficulties.

Candelaria

Like Wind Mountain, the Candelaria Mine is also located in an arid region of Nevada. The mine is in a historic mining area (1860s); recent heap-leach processing was conducted between 1980 and 1998. There are two pads at the mine: Pad 1 contains 23 Mt of ore on 55 ha, and Pad 2 contains 13 Mt of ore on 28 ha.

Site environmental factors are similar to those described for Wind Mountain: low precipitation, abundant evaporation, and lack of nearby ground water or surface water resources. The closure plan for this site includes the following steps:

- Limited fresh water rinsing to drive surface salts into the heap to facilitate direct revegetation;
- Disposal of the initial drain down and rinsate in an infiltration field similar to a Land Application system;
- Management of the residual drainage in infiltration fields.

The success of direct revegetation of the heaps is dependent on physical factors (such as compaction), soil chemistry (soil salinity, sodium content, and organic content), and climate factors (for example, the amount of rainfall in the season following seeding). Sampling indicates the fresh water rinse was successful at reducing salinity and SAR values in the upper root zone of the Candelaria heaps. However, soil salinity may be in a state of flux, as pockets of white surface crusts sometimes appear after one precipitation event and disappear by the next. Seed mixes geared toward native salt-tolerant vegetation are called for in these circumstances.

The area with the best success is where cattle were pastured after the area was seeded; this technique was also used on some waste dumps. Kinross continues to monitor reclamation success on the dumps.

The initial drain down was discharged under a land application permit, and is similar to other LAD sites except that the upper 4 feet of soil were removed prior to, and replaced after, the application of heap solutions. To support this option, drilling was conducted in the proposed infiltration area, and showed no groundwater for at least 225 m, with a clay layer located at 87 m below ground surface. Analysis showed that the initial drain down would be stored in the pore spaces of the upper 87 m, and would not migrate below the 225 m level to any ground water that might be present there.

Batch treatment prior to discharge to the initial infiltration field was required by regulators to reduce cyanide levels to 2 mg/L (compared with drinking water standards of 0.2 mg/L), although test work showed that cyanide levels as high as 20 mg/L did not result in unsafe levels in the soil.

Residual drainage from the heaps will be discharged to infiltration fields similar to those at Wind Mountain.

An Environmental Assessment (22) was prepared to evaluate the potential impacts from metal and salt accumulation in the infiltration fields, and a Finding of No Significant Impact was issued by the BLM.

Haile

Unlike the two case studies previously discussed, which are in arid climate with no surface or ground water resources present, the Haile Mine is located in an area with abundant rainfall well in excess of evaporation. In addition, the two heaps at Haile contain sulfide ores, and are acid generating.

The two pads at the site were operated between 1984 and 1992. Since that time, all drainage has been treated using alkaline chlorination followed by lime precipitation with a belt press. The pads are adjacent to a reservoir and surface stream, which is the receiving water for the site.

Given the high precipitation at the site, the acid generation in the pads, and the proximity of surface and ground water, soil covers and infiltration fields were not viable options for this site. One pad was closed using locally available clay materials to form a low-permeability cover. The second pad cover consisted of a 40 mil HDPE liner (Agru/America Microspike on slopes, smooth liner on top) covered by 45 cm of soil (23). Runoff structures were designed considering the annual hurricanes that affect the site, and consisted of collection areas on top with large-diameter pipes to convey runoff to sediment ponds at the toe of the heaps. This protects the covers by minimizing erosion. The surfaces of the heaps were then re-vegetated.

The site has conducted pilot testing of a passive treatment system for acid runoff at the site. The pilot cell is a converted solution pond filled with drain rock and a mixture of manure, wood chips, and limestone. The manure/limestone medium creates conditions for anaerobic reduction of sulfate to sulfides; the resulting hydrogen sulfide combines with metals to form sulfide precipitates, alkalinity is generated and the pH of the system is elevated. The site is evaluating the applicability of this method for post-closure heap effluent; given the low pH, high dissolved solids, and high acidity, these effluents may need to be combined with other site flows to allow treatment in a passive cell.

Summary

There are several tools that have been proven effective for closure of heap leach pads. There is no single “one size fits all” approach to heap leach closure; at each site, a combination of methods will be used depending on the specific environmental factors at the site, the characteristics of the heap, and the post-closure use for the site. During leaching operations, information should be gathered to facilitate closure planning. Careful planning, technically sound analysis, and a consideration of alternatives will result in a closure plan that is efficient and meets the requirements of industry and government.

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