Heap Leaching

Heap Leaching is being done these days on relatively low-grade ores for gold, copper and uranium recovery. Typical operations take place for about one to three months per heap and the recovery achieved is at least 60% and may be as high as 85% in some cases. Both oxide copper and sulfide copper ores are amenable to leaching with the rate of recovery being higher for oxide copper. Sulfide copper ores have slower kinetics but with good insulation, the internal temperature can be held about 10 °C warmer than ambient increasing dissolution rates. Biological leaching is practiced using appropriate bacteria.

The lixiviant with copper ores is typically sulfuric acid while sodium cyanide is used with gold ores. The solutions are sprayed or dripped on the top surface of the heap and permitted to drain down through the ore flowing to a channel around the perimeter where the pregnant solution can be recovered for metal recovery. With copper, the usual recovery system is SX-EW (solvent extraction/electrowinning) while with gold ores ion exchange using carbon columns can be used to produce a purified solution for gold electrowinning.

Agnico-Eagle's Pinos Altos Heap Leach in Mexico

Heap leaching operations present lower operating costs compared to typical gold ore milling. So, cut-off grade for heap leaching is typically much lower than that of a milled ore. There certain economic considerations in the design of a heap leach operation in order to obtain optimum conditions. Costs must be maintained at a low level throughout the project so the operation remains attractive during the life of mine. Metallurgical performance is key. Design should evaluate the best leach pad options. A typical leach pad covers a large areas ranging from a low of 40,000 m² (~200 m square) to a high of 1,500,000 m² (1.2 km square).
Important factors include:
1. topography,
2. earthworks upon which to build the leach pad,
3. liners and/or geomembranes,
4. construction process, and
5. drainage system.

Preparing the leach pad base.

A critical aspect is the slope of the pad which must consider the flow rate through a porous heap material under constant irrigation. The design must focus on the steady state of the system, which is influenced by the fines content of the ore and the irrigation rate. Solution flow should be laminar under ideal conditions. Darcy’s Law is a useful tool in the design. Darcy’s law is an equation that describes fluid flow through a porous medium. The law was formulated based on observations of water flow through a bed of sand. It forms the scientific basis of fluid permeability in the earth sciences, particularly hydrogeology.

\[ Q = \frac{-kA}{\mu} \left( \frac{P_b - P_a}{L} \right) \]

The hydraulic head of the system will impact solution distribution and percolation through to the leach pad. In several gold heap leach operations the hydraulic head is influenced by solution irrigation rate, height of phreatic surface at the drainage pipe and around the pad, location of the drainage outlets, slope of the pad and material permeability. Different hydraulic heads may be created if the ore is heterogeneous or segregated. As such, variability in irrigation and recovery may occur. Hydraulic head is also affected by the slope of the leach pad, cyanide irrigation rate, length of drainage system and the permeability of the material near the phreatic area. A leach pad with a slope of 12° to 14° will generally yield a permeability between $10^{-9}$ to $10^{-12}$ cm/sec. If the fines content is high, the material may be impermeable requiring agglomeration of the ore.
If the site has an appropriate natural slope, earthworks costs may be reduced and the level of investment reduced. The drainage system layout becomes a central aspect of leach pad construction. The foundation is a key aspect - preparation comprises grading of the leach pad area and compacting to a smooth surface to obtain a stable foundation for the heap. Small variations in slope are acceptable, but narrow channels should be avoided to ensure even distribution of the solution.

**Schematic of a Heap Leach System – note the number of lifts established in the dump.**

Heaps are often staged in lifts much like the construction of a tailings dam. When placing a new lift on top of an existing one, compaction of the underlying lift is necessary.
The leach pad should include installation of one or more impermeable liners to avoid environmental problems and leakage (loss) of pregnant solution. Selection of a liner includes aspects such chemical resistance to the solution and hydraulic pressure. A pad liner is subjected to a general stress created by the heap and local stress produced by equipment used during heap construction. The pond liner is also subjected to stress developed by the storage of pregnant or barren solutions. Liners may be installed using clay soils or synthetic membranes. The decision is influenced by site-related economic conditions and environmental regulations. Since the economical aspects are considered since the first stages of the project, environment regulations have a special impact on the economy and performance of the operation. A deficiency in silt or clay particles may be solved by adding small quantities of bentonite or high quality clay.
An effective soil liner must be conditioned to moisture conditions, layer thickness control and good compaction. The design must consider possible desiccation (drying), frost conditions and erosion to insure failures do not occur. For geomembranes the design must take into account material type, bedding and cover materials, and procedures to place the material. In the case of soil and soil liners, it is important to evaluate soil availability, soil composition, construction procedures, and environmental regulations. In some cases a double liner system is necessary for environmental reasons. The upper liner is usually a synthetic material with the lower liner being soil material.

The seepage collection system is covered with gravel or a special geomembrane in which permeability does not change under loading of the gold ore. In some conditions, the soil liner may interact with chemical reagents and absorb some of the leaching compound. To optimize metal recovery and minimize potential losses, the system must have a low permeability layer to reduce and minimize seepage losses. The leach pad must be totally void of "preg-robbing" materials such as carbon that may remove gold and silver from the pregnant solution.

Other factors that may affect costs are the duration and time of year when construction begins. The worst pollution site in the U.S is the old Galactic Resources site near Denver in which the heap was constructed during the winter leaving snow inside the heap which melted in the spring causing long-term issues with cyanide release. A geomembrane installed in summer can undergo contraction during the colder seasons unless proper insulation is maintained. Another important consideration is the physical properties of the materials above and below the liner due to large highly angular particles that can damage the liner. It is important to protect against puncture (e.g. increase liner thickness).

The following table shows some reference costs for different liner installations:

<table>
<thead>
<tr>
<th>Liner Type</th>
<th>Material</th>
<th>Area (ha)</th>
<th>Thickness (mm)</th>
<th>Cost (US $/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthetic</td>
<td>60 mil PVC</td>
<td>8</td>
<td>1.5</td>
<td>6.12</td>
</tr>
<tr>
<td>Synthetic</td>
<td>40 mil HDPE</td>
<td>10</td>
<td>1.0</td>
<td>6.72</td>
</tr>
<tr>
<td>Synthetic</td>
<td>40 mil PVC</td>
<td>12</td>
<td>1.0</td>
<td>6.82</td>
</tr>
<tr>
<td>Soil</td>
<td>Weathered overburden</td>
<td>18</td>
<td>300</td>
<td>2.45</td>
</tr>
<tr>
<td>Soil</td>
<td>Weathered overburden</td>
<td>20</td>
<td>600</td>
<td>2.52</td>
</tr>
<tr>
<td>Soil</td>
<td>Weathered overburden/Clay</td>
<td>35</td>
<td>450</td>
<td>2.86</td>
</tr>
<tr>
<td>Soil</td>
<td>Weathered overburden/Clay</td>
<td>40</td>
<td>500</td>
<td>8.40</td>
</tr>
</tbody>
</table>

Soil liners have a typical permeability of $10^{-7}$ cm/sec while synthetic liners give about $10^{-11}$ cm/sec.

The value of the drainage system is enhanced when the cost of the drainage system is similar to the value of gold and silver saved. The drainage system is not cost effective if the cost of the system is greater than the potential savings. Thus it is important to perform accurate tests on the materials used to construct the pad and compact it during operation. Metallurgical performance and the economy of the project are improved. The material installed on the heap base above the liner must have free drainage. The design includes installation of perforated drainage pipes at predetermined points over the pad base, or by installing a bed of gravel for drainage. If the drainage system is properly designed, the pregnant solution flow can be more efficiently transferred with minimal interruptions and disturbances to the Merrill-Crowe plant or the Carbon-Column recovery circuit.
The pregnant solution collection system comprises the drainage area above the liner and may consist of rock with an appropriate permeability, gravel content, and collection pipes. It is possible to use ore or gravel to protect the liner. If the permeability of the ore is adequate, it may be possible to avoid a complete piping system on the leach pad and reduce costs. But, if the material has a low permeability in relation to the irrigation rate, then gravel or perforated pipe (Big-O) is necessary. The pipe must be able to withstand compressive due to the weight of the heap above, otherwise it is distorted to a point that prevents collection and proper flow. The drainage system should maintain a saturated zone above the liner at levels that do not affect the stability of the heap and pad.
Copper leach solution collection ditch for transfer to SX/EW.
Use of agglomeration to increase permeability.